MPRSA SECTION 103
SEDIMENT EVALUATION
SHIPYARD CREEK
CHARLESTON, SOUTH CAROLINA

Submitted to:

U.S. Army Corps of Engineers
Charleston District
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On Behalf of:

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ACRONYMS, INITIALISMS, and ABBREVIATIONS

ADDAMS	Automated Dredging and Disposal Alternatives Modeling System
AR	ammonia-reduced
BCF	bioconcentration factor
BSAF	biota sediment accumulation factor
CFR	Code of Federal Regulations
CMC	criteria maximum concentration
cy	cubic yards
DU	dredging unit
EC_{50}	effective concentration affecting 50% of a population
EPA, USEPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
HMW	high molecular weight
K_{OC}	soil organic carbon-water partitioning coefficient
K_{OW}	octanol-water partition coefficient
LC_{50}	lethal concentration affecting 50% of a population
LMW	low molecular weight
LOAEL	lowest observed adverse effects level
LPC	limiting permissible concentration
MDL	method detection limit
MLLW	mean lower low water
MPRSA	Marine Protection, Research, and Sanctuaries Act of 1972
MRL	method reporting limit
NOAEL	no observed adverse effects level
NOEC	no observed effects concentration
ODMDS	ocean dredged material disposal site
PAH	polynuclear aromatic hydrocarbon
QAPP	Quality Assurance Project Plan
SERIM	Southeast Regional Implementation Manual
SJST	South Jetty Sediment Trap
SMMP	Site Management and Monitoring Plan
SOP	standard operating procedure
STFATE	short-term fate
uM	micromole
USACE	U.S. Army Corps of Engineers
USCS	Unified Soil Classification System
SYC	Shipyard Creek
SCDHEC	South Carolina Department of Health and Environmental Control
cy	cubic yard
RCRA	Resource Conservation and Recovery Act (RCRA)
TEQ	toxicity equivalence
TOC	total organic carbon
TEF	toxicity equivalence factor
PCDD	polychlorinated dibenzo-p-dioxins
PCDF	polychlorinated dibenzofurans
TCDD	tetrachloro dibenzo-p-dioxins
pg/g	picograms per gram
ng/L	nanograms per liter
TBT	tributyltin
PCB	polychlorinated biphenyl

1 INTRODUCTION

This is an independent Marine Protection Research and Sanctuaries Act of 1972 (MPRSA) Section 103 Sediment Evaluation for the potential new work dredge material from expansion of the Shipyard Creek (SYC) in Charleston, South Carolina. The dredge material is proposed for disposal at the Charleston Harbor Ocean Dredged Material Disposal Site (ODMDS). The data for this evaluation are taken from the ANAMAR (2014) MPRSA sediment testing report for Shipyard Creek. The sampling took place in June 2014 and was the first time material from Shipyard Creek was tested for offshore disposal. All prior testing had been done for upland disposal only. Additional information used in the evaluation include the following documents:

- *U.S. Environmental Protection Agency (EPA) First Five-Year Review Report* on Macalloy Superfund Site with details outlined in Section 3.1 below.
- Analytical testing report by GEL Laboratories completed in 2013 for potential upland disposal. The findings from this report are addressed in Section 3.5. Based on the results, the material would have qualified for upland disposal, but the capacity in the upland disposal facility was not sufficient to handle the volume estimated as part of this project.
- A letter of support from the South Carolina Ports Authority regarding the additional capacity to be provided by the development of the Shipyard Creek is addressed in Section 1.1 below.
- As addressed in Section 3, the U. S. Army Corps of Engineers (USACE) provided a response to the permit application in December 2013. While the overall response was generally favorable to the development, it indicated on pages 2 and 3 that, due to capacity needs expected with the Post 45 harbor expansion, the USACE disposal area could not be used for the dredged material and that the client should consider offshore disposal as an option. Based on this recommendation, Shipyard Creek, LLC initiated a Section 103 evaluation to test the material for offshore disposal.
- Permit Application Supporting Documentation prepared by Moffatt & Nichol in support of the overall development of the Shipyard Creek property.

1.1 Project Area Description

Shipyard Creek is a small channel off the west bank of the Cooper River, which is part of the Charleston Harbor Federal Navigation Channel. The entrance to SYC is approximately 8 miles inland from the South Carolina coastline, and the channel is less than 1 mile in total length. The northernmost portion of the channel includes a turning basin. A map of the overall project are is shown in Figure 1, and sample locations and project bathymetry are included as part of the sediment testing results in Attachment 1 (ANAMAR 2014).

The Charleston Harbor Federal Navigation Channel is in Charleston Harbor, which is about midway along the South Carolina coastline. The harbor covers approximately 14 square miles and is formed by the confluence of the Ashley, Cooper, and Wando rivers. The majority of upland areas around Charleston Harbor are composed of residential, commercial, and industrial development. Harbor docking and maintenance facilities are concentrated along the west shore of the Cooper River extending from Battery Point of the peninsular city to the mouth of Goose Creek.

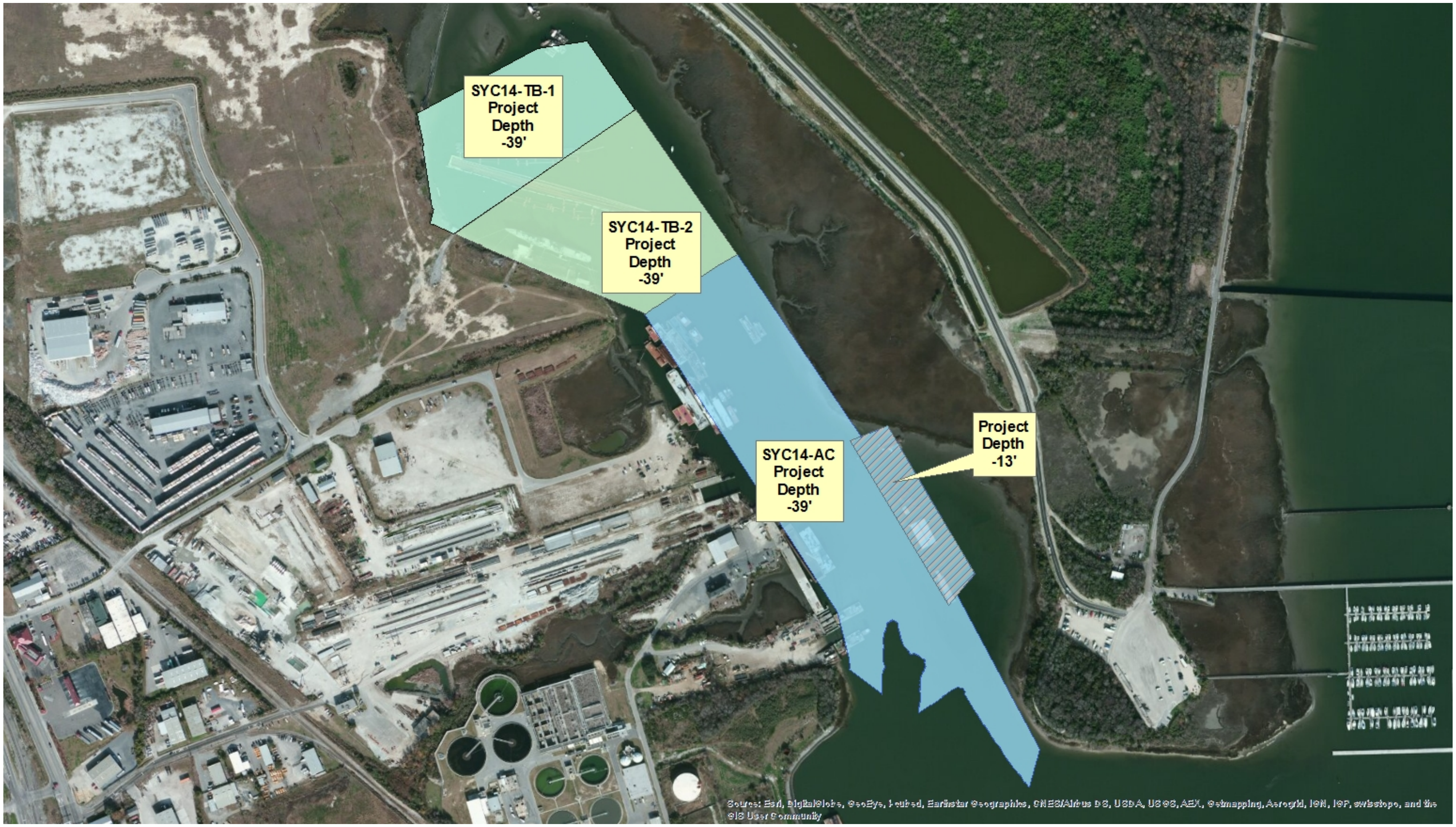
The existing channel is approximately 0.8 miles in length, and widths vary from 0.1 to 0.2 miles. Bathymetry shows current elevations above -30 feet mean lower low water (MLLW) throughout the turning basin and decreasing elevations through the channel. The elevation approaches -50 feet MLLW near the mouth of the channel where it intersects with the Cooper River. The proposed project elevation for this area is -38 feet MLLW with 1 foot of allowable overdepth, for a total of -39 feet MLLW. The dredge material will include maintenance and new work sediment.

Because of access to rail and other local resources, Shipyard Creek, LLC is planning to develop the property to provide berthing for bulk, break-bulk, and Ro-Ro vessels and storage and transportation of their respective cargos by land to or from the southeastern United States. Based on the additional capacity to be provided by the Shipyard Creek development, the South Carolina Ports Authority provided a brief letter (Attachment 2) offering its support.

1.2 Project Design

Upon initiation of this project, ANAMAR prepared a Quality Assurance Project Plan (QAPP) with all elements indicated in the Southeast Regional Implementation Manual (SERIM) (USEPA and USACE 2008). The development of the QAPP included meetings with USACE and EPA to ensure that all required sampling and testing would be performed in accordance with state and federal regulations. A summary of the initial meeting with EPA and a copy of the SERIM signature page are included in Attachment 3.

In addition, following completion of the sediment testing report, ANAMAR met with USACE and EPA to discuss the findings in the report. A summary of the meeting is included as part of Attachment 3 and discusses several areas to be addressed in the evaluation report.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 1. Shipyard Creek Dredging Units

1.3 Grain Sizes of the Dredged Material and Reference Sediment

Tables 3 and 4 of the ANAMAR (2014) report provide complete physical results for subsamples and composite samples, respectively. Exhibit 1 shows the description of the composite sediment samples, and Exhibit 2 shows the grain size and U.S. Soil Classification System (USCS) classification for each composite and subsample. Individual subsamples do not typically have hydrometer analyses performed, and the results show only a combined value for silt and clay percent concentrations. This is performed to demonstrate that the grain size concentrations in the composite approximately match the grain size of its individual subsample constituents. As a consequence, the USCS classifications for the composite samples are different from those of the subsamples presented in Exhibit 2.

Exhibit 1. Material Descriptions per Composite Sample and Subsample

Sample ID:	Sediment Description
SYC14-REF	SAND, silty, mostly fine-grained sand-sized quartz, little silt, (SM) greenish gray
SYC14-AC	CLAY, inorganic-H, little fine-grained sand-sized quartz, (CH) dark greenish gray
SYC14-TB1	CLAY, inorganic-H, trace silt, (CH) dark greenish gray
SYC14-TB2	CLAY, inorganic-H, trace quartz, (CH) dark greenish gray

Source: Table 4 of ANAMAR (2014)

Exhibit 2. Grain Size Distribution per Composite Sample and Subsample

Sample ID	% Gravel[1]	% Sand [1]	% Silt[1]	% Clay[1]	USCS Classification[2]
SYC14-AC	0.0	24.2	32.2	43.6	CH
SYC14-AC-A	0.3	28.2	71.5[3]		MH
SYC14-AC-B	0.0	0.4	99.6[3]		MH
SYC14-AC-C	0.0	24.9	75.1[3]		MH
SYC14-AC-D	1.8	10.7	87.5[3]		MH
SYC14-AC-E	0.0	2.0	98.0[3]		MH
SYC14-AC-F	0.1	60.2	39.7[3]		SM
SYC14-TB1	0.0	1.0	37.2	61.8	CH
SYC14-TB-A	0.0	0.7	99.3[3]		MH
SYC14-TB-B	0.0	1.0	99.0[3]		MH
SYC14-TB-C	0.0	1.1	98.9[3]		MH
SYC14-TB2	0.0	1.0	37.3	61.7	CH
SYC14-TB-D	0.0	0.8	99.2[3]		MH
SYC14-TB-E	0.0	0.9	99.1[3]		MH
SYC14-TB-F	0.0	0.6	99.4[3]		MH
SYC14-REF	0.0	79.8	17.2	3.0	SM

[1] Particle sizes: gravel ≥4.750 mm, sand = 0.075–4.749 mm, silt & clay <0.075 mm

[2] Unified Soil Classification System (USCS) classes defined: CH = clay of high plasticity, elastic silt; MH = silt of high plasticity, elastic silt; SM = silty sand

[3] The analysis of physicals in the subsamples did not include separate values for percent silt and percent clay. The result presented for the subsamples is the percentage for percent silt and percent clay combined.

Source: Tables 3 and 4 of ANAMAR (2014)

1.4 New Work and Maintenance Dredging

The SYC expansion project is a mixture of new work and maintenance materials. Dredging will be performed using a combination of mechanical and cutter/hopper methods. The exact methods and dredges to be used will be determined prior to actual dredging. Exhibit 3 shows the dredging units (DUs) for this project, required analyses, and estimated volumes of dredge material within SYC.

Exhibit 3. Description of Dredging Units, Required Analytical Protocols, and Estimated Volume of Maintenance Material

Sample ID	Subsample IDs	Description	Required Analysis	Estimated Volume, cy
SYC14-TB1	A through C	Northern portion of turning basin (-38 + 1 [paid overdepth] ft MLLW)	Tiers II & III	253,000
SYC14-TB2	D through F	Southern portion of turning basin (-38 + 1 [paid overdepth] ft MLLW)	Tiers II & III	249,400
SYC14-AC	A through F	Main access channel (-38 + 1 [paid overdepth] ft MLLW except for portions along the eastern edge that are at -12 + 1 [paid overdepth] ft MLLW)	Tiers II & III	442,200
			Total:	944,600

Sources: Table 10-1 of QAPP and Moffatt & Nichol (2013-2014) for dredge volumes

2 EXCLUSIONARY CRITERIA 40 CFR §227.13(B)

2.1 Exclusionary Material

The evaluation of the material for exclusionary criteria is done by comparing the analytical results of the sediment to three criteria, which are outlined in Section 3.1.1 of the SERIM and presented below.

> *(1) The dredged material is composed predominately of sand, gravel, rock, or any other naturally occurring bottom material with particle sizes larger than silt, and the material is found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels; or*
>
> *(2) The dredged material is for beach nourishment or restoration and is composed predominately of sand, gravel, or shell with particle sizes compatible with material on the receiving beach; or*
>
> *(3) When: a.) The material proposed for disposal is substantially the same as the substrate at the proposed dump site, and b.) The site from which the material proposed for disposal is to be taken is far removed from known sources of pollution so as to provide a reasonable assurance that such material has not been contaminated by such pollution.*

The material from SYC does not qualify for omission from further testing under any of the criteria in 40 CFR §227.13(b) and summarized in Appendix C of the SERIM (USEPA and USACE 2008). Therefore, all of the samples representing the three DUs underwent full chemical and bioassay analysis.

3 NEED FOR TESTING (TIER I)

The material to be evaluated will be from the sediment-water interface to the project depths shown in Figure 1 and Exhibit 3. An application response letter (Attachment 4) was provided by USACE to GEL on behalf of Shipyard Creek Associates, LLC addressing specific items in the application. While generally favorable to the development, USACE indicated that USACE's disposal area was unable to receive the material, and stated that alternatives for the dredge material should be investigated, including the evaluation of the material for offshore disposal. Due to the large volume of material to be dredged from the SYC DUs, ocean disposal is the only option for all sediment because the volume exceeds the available capacity in the upland disposal facilities.

Following consideration of all available information, it was determined that further evaluation of the material proposed for dredging was required. The material was analyzed under Tier II and Tier III protocols, and the results are included in this sediment evaluation. A history of the site, including potential contaminants in the area, is provided below.

3.1 Superfund Site

From 1941 until 1998, a ferrochromium-alloy smelting plant was operated within the SYC site. Following closure of the plant, the area was placed on EPA's Superfund National Priorities List in 2000 for contamination in groundwater, soil, and sediment. A plan of action for cleanup was prepared by EPA, South Carolina Department of Health and Environmental Control (SCDHEC), and Macalloy Potentially Responsible Party Group to clean up the site. The steps taken at the site include:

- Treating soil to prevent the spread of contamination from soil to groundwater.
- Treating contaminated groundwater by adding chemicals to the aquifer that create conditions necessary to remove contaminants from groundwater.
- Excavating and disposing of approximately 1,000 cubic yards (cy) of contaminated sediment from the tidal creek.
- Covering the excavated area with a cap to contain potentially hazardous contaminants.
- Implementing a stormwater management plan to reduce contamination from discharges to SYC.

The site achieved a "construction complete" designation in September 2006.

The 5-year plan produced by EPA in June 2010 (First Five-Year Review Report, Attachment 5) shows that the cleanup was largely effective, functioning as expected. A summary of the results from the previous 5 years of monitoring is shown in the list below. All section numbers listed below are referenced from the First Five-Year Review Report.

- Chromium contamination in the groundwater was below target levels in 19 of the 23 monitoring wells tested from 2006 through 2009 (Sections 6.4.1, and 7.1.2 through 7.1.4).
- Arsenic was identified as a potential contaminant for groundwater monitoring, but was not retained because levels found in the groundwater were below the maximum contaminant level of 50 µg/L (Section 7.2.1).

- Barium, cadmium, lead, mercury, selenium, and silver were below the laboratory reporting limit in groundwater samples and were removed from the analytical list for long-term monitoring (Section 6.4.1).
- Toxicity testing on the sediment from the tidal creek just north of SYC showed no adverse effects to benthic organisms and no statistically significant differences in embryo development between the Tidal Creek sediment and control material (Sections 6.4.4 and 7.1.3).
- Sediment concentrations of total chromium, nickel, and zinc were below the protective ranges established by the Final Removal Action Report for all sediment samples tested except one site from September 2008 (Table 6-3)
- Additional soil monitoring will be evaluated through groundwater monitoring (Section 7.1.5).
- The cap thickness has been monitored regularly since it was put in place. Measurements on the cap showed several instances where the thickness was less than 18 inches. Repairs to the cap have been performed, and monitoring is expected to continue as recommended in the report to ensure that the cap continues to function as specified (Section 7.1.2).

A complete discussion of the site, along with remedial actions and links to supporting documents, may be found at http://www.epa.gov/region4/superfund/sites/npl/southcarolina/macalsc.html.

3.2 1995 Hopper Barge Spill

In November 1995, the *Patricia Sheridan*, a 350- x 66- x 31.5-foot hopper barge, was grounded and flooded near the entrance to Charleston Harbor under adverse environmental conditions. The grounding caused a release of material from the barge containing approximately 12,500 tons of New York Harbor dredge spoils tainted with dioxin.

3.3 Current Land Usage

Figure 2 shows the current usage at the SYC site and surrounding areas. Surrounding land use reflects the urban/industrialized nature of the area. A number of industrial businesses currently occupy the southern portion of the SYC property. These businesses include the North Charleston Sewer District treatment facility; Kinder Morgan; Marinex Construction, Inc.; and a number of truck stops and towing services. An inter-modal rail shipping facility is planned north of the site, and a container storage facility is already in operation there. The Navy base terminal and the proposed Charleston port expansion dominate the area east of SYC. West of the property is the CSX Cooper Yard and a Santee Cooper facility.

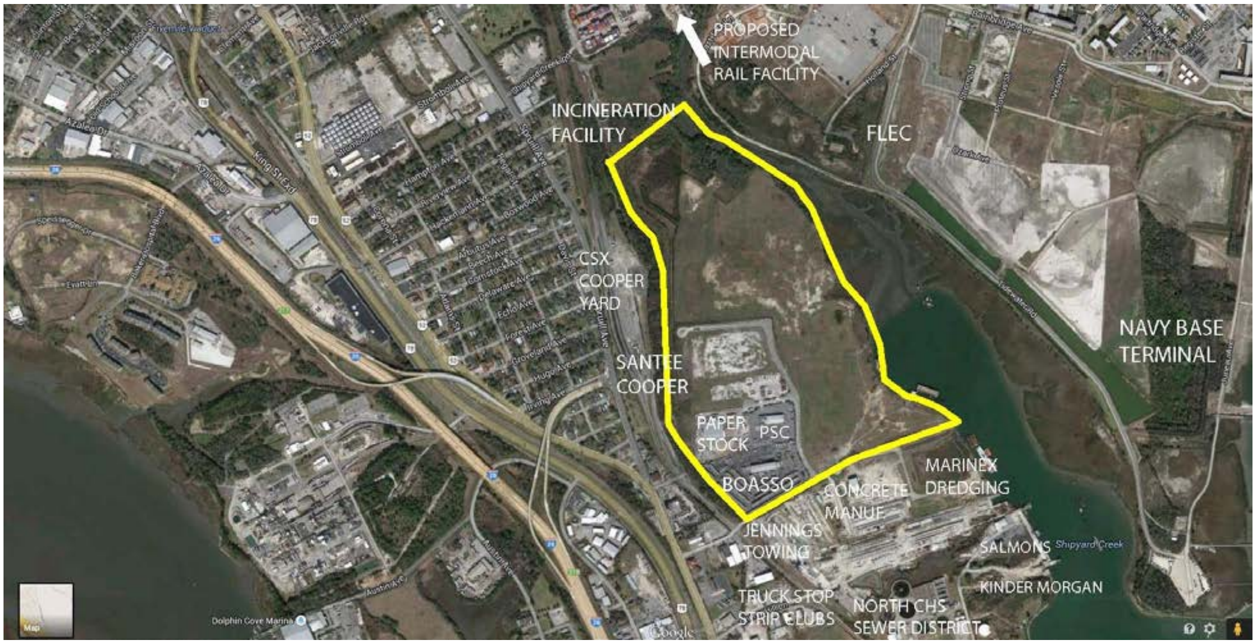


Figure 2. **Shipyard Creek Current Usage**

3.4 Dredging History

The deepening of Shipyard Creek to 38 feet MLLW was extensively studied by USACE and reported to Congress during the 1970s and 1980s. As a result, when Congress passed the Water Resources Development Act of 1986, it authorized deepening SYC to and maintaining it at 38 feet, widening each of the turning basins to 1,000 feet and widening the connector channel to 250 feet. Further, according to historical USACE surveys, the upper basin of Shipyard River was in fact dredged to and continuously maintained at depths between 36 and 40 feet from 1969 through 1993. It is likely that the dredging of the upper basin and connector channel was discontinued due to the Macalloy facility ceasing operations in the 1990s and the lack of interest of the adjoining property owners in maintaining dredging. The current project seeks to return SYC to a condition nearly identical to that which existed continuously between the late 1960s and early 1990s and which has been previously studied and authorized. A summary of project depths in SYC from 1920 through 2013 is included in Attachment 6. The depths indicate that maintenance dredging occurred at least five times in 1974, 1976, 1981, 1984, and 1990, with depths maintained as stated previously.

In 1992 SCDHEC Bureau of Water Pollution Control issued Administrative Order 92-64-W requiring the Macalloy Corporation to remediate hexavalent-chromium-contaminated groundwater on the property. Pursuant to this order, a pump-and-treat groundwater remediation system was installed in 1994 and 1995. In 1996, Macalloy began the Resource Conservation and Recovery Act (RCRA) corrective action process. In January 1997, pursuant to the terms of a consent order with SCDHEC (No. 96-38-HW), Macalloy initiated offsite disposal of treated electrostatic precipitator dust from the USI. Based on the cleanup order from SCDHEC, contamination into the water stream in and around SYC was limited, and past dredging projects through 1993 have removed nearly all of the contaminated sediment that could have been potentially contaminated.

While the area has not been dredged since 1993, extensive remediation of the previously contaminated grounds has been ongoing since its closure. As indicated in the EPA First Five-Year Review Report, contaminated soil was either excavated or capped. As stated in Section 3.1, long-term monitoring of the area showed low levels of contamination, and the conclusions indicate that the remediation was successful.

3.5 Analytical History

In addition to the extensive testing discussed in the EPA First Five-Year Review Report referenced in Section 3.1, analytical testing was conducted in 2013 by GEL Environmental Laboratories to determine the suitability of the dredge material for upland disposal. An upland disposal permit application was submitted to USACE in February 2013, with supporting analytical results submitted following the completion of sampling and testing by GEL. GEL's report included all analyses required by SCDHEC. An electronic version of this report is in Attachment 7. Because the 2013 testing was designed for an upland disposal permit only, it did not include all the required testing as referenced in the SERIM, which provides guidance for offshore disposal. It included sediment chemistry, elutriate chemistry following the modified elutriate preparation, and physical parameters. Toxicology and tissue chemistry tests were not performed. Analytical results showed detectable concentrations of metals, polynuclear aromatic hydrocarbons (PAHs), and dioxins in the sediment, while all pesticides and PCBs were below the laboratory reporting limit for all samples. Based on the results provided in the GEL report, PCBs were completely removed from the analytical requirements for a Section 103 evaluation. Although the elutriate testing was performed using a different methodology than the elutriation procedure used for Section 103 evaluations, a comparison of the elutriate results to applicable screening criteria indicated that the samples were not at concentrations that would prevent offshore disposal and would have been approved for upland disposal. Sampling locations are shown on page 60 in the GEL report in Attachment 7.

4 WATER COLUMN DETERMINATIONS FOR SEDIMENT TESTING

4.1 Evaluation of the Liquid Phase – Water Quality Criteria

Besides the EPA five year monitoring plan testing, the liquid phase of the dredge material was evaluated for compliance with 40 CFR §227.6(c)(1) and §227.27(a) and analyzed for the contaminants of concern in marine waters. Concentrations of contaminants of concern were compared to the water quality criteria maximum concentration (CMC [synonymous with 'acute']) published in USEPA (2006) and summarized in Buchman (2008). In order to meet offshore disposal criteria, the CMC values must not be exceeded following initial mixing.

Results of elutriate and site water metals and organotin analyses, along with applicable CMC values, can be found in Tables 9 and 10 of the ANAMAR (2014) report. A summary of elutriate chemistry results is in Section 3.4 of that report. Elutriate results represent 100% concentration (undiluted), which is required for comparison to CMC values.

4.1.1 Ammonia

Ammonia concentrations are shown in Exhibit 4.

Exhibit 4. Summary of Elutriate and Site Water Ammonia Results

Analyte	Concentration (mg/L)						
	SYC14-AC	SYC14-TB1	SYC14-TB2	SYC14-SW	SYC14-ODMDS-SW	Concentration Range (Dredge Area Samples Only)	CMC
Total Ammonia	**28.6**	**44.8**	**43.1**	0.114	ND	28.6 - 44.8	11.6

Bolded values indicate that the result is greater than the CMC.
ND indicates that the analyte was not detected at or above the method detection limit (MDL).

The CMC is calculated using pH, temperature, and salinity values from Table 2 of *Ambient Water Quality Criteria for Ammonia (Saltwater)-1989* (USEPA 1989) found at http://water.epa.gov/scitech/swguidance/standards/upload/2001_10_12_criteria_ambientwqc_ammoniasalt1989.pdf. Interpolation was used across all readings to determine the CMC. Because all ammonia results were greater than the determined CMC, STFATE modeling was performed on the result requiring the greatest dilution to meet the limiting permissible criteria.

4.1.2 Metals

No metals concentrations for elutriate or site water samples were greater than the CMC. Beryllium, cadmium, mercury, selenium, silver, and thallium were not detected in concentrations greater than the method reporting limit (MRL) in any sample. All other metals analyzed were detected in concentrations greater than the MRL in at least one of the elutriate samples or in the site water sample. All metals met the target detection limits specified in the SERIM. No concentration for any metal exceeded its corresponding CMC, where applicable, and STFATE modeling was not required for metals. Table 9 of the sediment testing report (ANAMAR 2014) contains complete analytical results for trace metals.

4.1.3 Pesticides

No pesticide concentration for elutriate or site water samples was greater than the CMC, and STFATE modeling was not required for pesticides. No pesticide concentration was greater than the MRL in any sample. With the exception of technical chlordane and toxaphene, all laboratory reporting limits met the target detection limits specified in the SERIM. For technical chlordane and toxaphene, the MDL was used for comparison to the CMC stated in Table 13-3 of the QAPP. Table 10 of the sediment testing report (ANAMAR 2014) contains complete results for trace metals analyses.

4.1.4 STFATE Modeling

Using the inputs from the SERIM and Exhibit 4, the STFATE model was run for Tier II analysis for ammonia. The results of the model run are presented in Exhibit 4 and show that the sediment meets the offshore disposal criteria up to a disposal volume of at least 9,000 cy without restriction in the ODMDS. Exhibit 5 shows the results of the model, including concentration above background, dilution on grid, location of maximum concentration, and the maximum concentration of ammonia outside the disposal area during the 4-hour modeling.

Exhibit 5. Four-Hour Criteria and Disposal Boundary Criteria after Initial Mixing for Ammonia

		Four-Hour Criteria after Initial Mixing			Disposal Site Boundary Criteria		
Depth, feet	**% Max Conc above Background on Grid**	**Dilution on Grid ($D_{a\text{-}wq}$)**	**X Location**	**Z Location**	**Time, hours**	**Max Conc Outside Disposal Area**	**Dilution on Grid ($D_{a\text{-}wq}$)**
Sample	SYC14-TB1 (Mechanical Dredging @ 9,000 cy) [Dilution Required = 2.89]						
0	2.58E-07	>100,000	8,400	11,900	4	0	N/A
18	3.59E-02	1247	8,400	11,900	4	0	N/A
26	1.36E-01	328	8,400	11,900	4	0	N/A
36	1.85E-02	2421	8,400	11,900	4	0	N/A
Sample	SYC14-TB1 (Hopper/Cutter Dredging @ 9,000 cy) [Dilution Required = 2.89]						
0	1.87E-06	>100,000	8,400	11,900	4	0	N/A
18	6.46E-02	692	8,400	11,900	4	0	N/A
26	1.91E-01	234	8,400	11,900	4	0	N/A
36	2.58E-02	1735	8,400	11,900	4	0	N/A

N/A = not applicable

4.2 Evaluation of the Suspended Particulate Phase Bioassays

The suspended particulate phase of the material was evaluated for compliance with 40 CFR §227.6(c)(2) and §227.27(b) to demonstrate that the material to be dredged would not exceed the limiting permissible criteria for disposal and thus would not result in significant mortality. Due to high concentrations of ammonia in all samples across all three test species, ammonia reduction was performed prior to testing. Ammonia-reduced and unreduced samples were tested side by side. Since the 100% concentration in each ammonia-reduced sample across all three species was not significantly different from the control sample, an application factor of 0.05 was applied to the results from the unreduced testing only to ensure there would be no significant adverse sub-lethal effects. Bioassays were conducted using three species: the mysid crustacean *Americamysis bahia* (opossum shrimp), the atherinoid fish *Menidia beryllina* (inland silverside), and larvae of the bivalve mollusk *Mytilus edulis* (blue mussel).

Results of the suspended phase assays can be found in Exhibits 6 through 8 below and in Tables 11 through 16 of the ANAMAR (2014) report. Ammonia-reduction procedures were used in bioassays for all three species and follow guidance in Appendix F of the SERIM as well as methods suggested by Ferretti et al. (2002).

4.2.1 Americamysis bahia

Mean percentage survival in the 100% elutriate preparations was significantly different from the control, and the estimated LC_{50} value ranged from 41.4% to 62.4% in the unreduced samples. Exhibit 6 presents a summary of the LC_{50} results and statistical evaluation of the 100% concentration for *A. bahia*.

Exhibit 6. Summary of Initial Survival Data for *Americamysis bahia*

Sample ID	Concentration (%)	Statistically Less Than Control (yes/no)	LC_{50} (%)
SYC14-SW		No	
SYC14-AC	100	Yes	62.4
SYC14-TB1	100	Yes	52.0
SYC14-TB2	100	Yes	41.4
SYC14-AC-AR	100	No	>100
SYC14-TB1-AR	100	No	>100
SYC14-TB2-AR	100	No	>100

AR = ammonia-reduced

Source: Tables 11 and 12 of ANAMAR (2014)

4.2.2 Menidia beryllina

Mean percentage survival in the 100% elutriate preparations was significantly different from that of the control, and the estimated LC_{50} value ranged from 21.1% to 28.2% in the unreduced samples. Exhibit 7 presents a summary of the LC_{50} results and statistical evaluation of the 100% concentration for *M. beryllina*.

Exhibit 7. Summary of Survival Data for *Menidia beryllina*

Sample ID	Concentration (%)	Statistically Less Than Control (yes/no)	LC_{50} (%)
SYC14-SW		No	
SYC14-AC	100	Yes	28.2
SYC14-TB1	100	Yes	22.4
SYC14-TB2	100	Yes	21.1
SYC14-AC-AR	100	No	>100
SYC14-TB1-AR	100	No	>100
SYC14-TB2-AR	100	No	>100

AR = ammonia-reduced

Source: Tables 13 and 14 of ANAMAR (2014)

4.2.3 Mytilus edulis

All samples expressed a significantly different mean survivorship than that of the control in the 100% elutriate concentrations. The estimated EC_{50} values for these samples ranged from 14.0% to 15.5% in the unreduced samples. Normal development and survivorship were increased in the ammonia-reduced treatments. Mean survivorship in the 100% concentrations of the ammonia-reduced elutriate samples was not significantly different from that of the control. The reduction in mean survivorship observed in the 100% elutriates was ameliorated by the ammonia-reduction procedure. Exhibit 8 presents a summary of the EC_{50} results and statistical evaluation of the 100% concentration for *M. edulis*.

Exhibit 8. Summary of Survival Data for *Mytilus edulis*

Sample ID	Concentration (%)	Statistically Less Than Control (yes/no)	EC_{50} (%)
SYC14-SW		No	
SYC14-AC	100	Yes	15.5
SYC14-TB1	100	Yes	14.8
SYC14-TB2	100	Yes	14.0
SYC14-AC-AR	100	No	>100
SYC14-TB1-AR	100	No	>100
SYC14-TB2-AR	100	No	>100

AR = ammonia-reduced.
Source: Tables 15 and 16 of ANAMAR (2014)

4.2.4 Suspended Particulate Phase Bioassays Determination and ADDAMS Modeling

Suspended phase bioassays showed survival and development as statistically less than control assays, and simulations of the STFATE module of the ADDAMS model were conducted with the results presented below in Exhibit 9.

Endpoint results of the water column bioassays showed that all samples exhibited statistically greater mortality or abnormal development than the control in all test species. Based on the LC_{50} and EC_{50} results of the toxicology elutriate test, six applications (model runs) were conducted for the project samples, one each for hopper/cutter and mechanical dredging operations. The results of the model runs are presented in Section 5 of ANAMAR (2014) as part of the MPRSA Section 103 Regulatory Analysis for Ocean Water, Tier III, Short-Term Fate of Dredged Material from Split Hull Barge or Scow Toxicity Run. All model input parameters and outputs are given in Section 5 and Appendix H of ANAMAR (2014). Results are summarized below.

The limiting permissible concentrations (LPC) in Exhibit 9 are based on the LC_{50} and EC_{50} results for each test presented in Exhibits 6 through 8 above. The lowest EC_{50}/LC_{50} value of the three water column tests was selected for each sample for use in the STFATE module. Exhibit 9 includes EC_{50} and LC_{50} values along with the application factors used in the STFATE module.

Exhibit 9. EC_{50} and LC_{50} Values and Application Factors Used in the STFATE Module

Result	SYC14-TB1	SYC14-TB2	SYC14-AC
Americamysis bahia			
LC_{50} (%) (Standard/Reduced)	52.0/>100	41.4/>100	62.4/>100
Application Factor	0.05	0.05	0.05
Calculated LPC*	>1.00	>1.00	>1.00
Menidia beryllina			
LC_{50} (%) (Standard/Reduced)	22.4/>100	21.1/>100	28.2/>100
Application Factor	0.05	0.05	0.05
Calculated LPC*	>1.00	>1.00	>1.00
Mytilus edulis			
EC_{50} (%)(Standard/Reduced)	14.8/>100	14.0/>100	15.5/>100
Application Factor	0.05	0.05	0.05
Calculated LPC*	0.74	0.70	0.78
Dilution Required to Meet Disposal Criteria			
Dilution	134	142	128
STFATE Model Input			
Final value used in STFATE model	0.74	0.70	0.78

* Values with greater-than symbols ('>') represent the values used in the STFATE module in place of the actual LC_{50}/EC_{50} values.

Source: Section 5 of ANAMAR (2014)

A summary of the results from the modeling, including the dilution actually achieved during the modeling, is shown in Exhibit 10.

Exhibit 10. Four-Hour Criteria and Disposal Boundary Criteria after Initial Mixing for Toxicology

	Four-Hour Criteria after Initial Mixing				Disposal Site Boundary Criteria		
Depth, feet	**% Max Conc above Background on Grid**	**Dilution on Grid ($D_{a\text{-}tox}$)**	**X Location**	**Z Location**	**Time, hours**	**Max Conc Outside Disposal Area**	**Dilution ($D_{a\text{-}tox}$)**
Sample	SYC14-AC (Mechanical Dredging @ 9,000 cy) [Required Dilution = 128]						
0	7.97E-08	>100,000	8,400	11,900	4	0	N/A
18	6.67E-02	1498	8,400	11,900	4	0	N/A
27	3.55E-01	281	8,400	11,900	4	0	N/A
36	4.80E-02	2082	8,400	11,900	4	0	N/A
Sample	SYC14-TB1 (Mechanical Dredging @ 9,000 cy) [Required Dilution = 134]						
0	5.77E-07	>100,000	8,400	11,900	4	0	N/A
18	8.02E-02	1246	8,400	11,900	4	0	N/A
26	3.04E-01	328	8,400	11,900	4	0	N/A
36	4.12E-02	2426	8,400	11,900	4	0	N/A
Sample	SYC14-TB2 (Mechanical Dredging @ 9,000 cy) [Required Dilution = 142]						
0	5.77E-07	>100,000	8,400	11,900	4	0	N/A
18	8.02E-02	1246	8,400	11,900	4	0	N/A
26	3.04E-01	328	8,400	11,900	4	0	N/A
36	4.12E-02	2426	8,400	11,900	4	0	N/A
Sample	SYC14-AC (Hopper/Cutter Dredging @ 9,000 cy) [Required Dilution = 128]						
0	9.73E-08	>100,000	8,400	11,900	4	0	N/A
18	8.35E-02	1197	8,400	11,900	4	0	N/A
27	4.47E-01	223	8,400	11,900	4	0	N/A
36	6.04E-02	1655	8,400	11,900	4	0	N/A
Sample	SYC14-TB1 (Hopper/Cutter Dredging @ 9,000 cy) [Required Dilution = 134]						
0	4.17E-06	>100,000	8,400	11,900	4	0	N/A
18	1.44E-01	693	8,400	11,900	4	0	N/A
26	4.26E-01	234	8,400	11,900	4	0	N/A
36	5.77E-02	1732	8,400	11,900	4	0	N/A
Sample	SYC14-TB2 (Hopper/Cutter Dredging @ 9,000 cy) [Required Dilution = 142]						
0	4.17E-06	>100,000	8,400	11,900	4	0	N/A
18	1.44E-01	693	8,400	11,900	4	0	N/A
26	4.26E-01	234	8,400	11,900	4	0	N/A
36	5.77E-02	1732	8,400	11,900	4	0	N/A

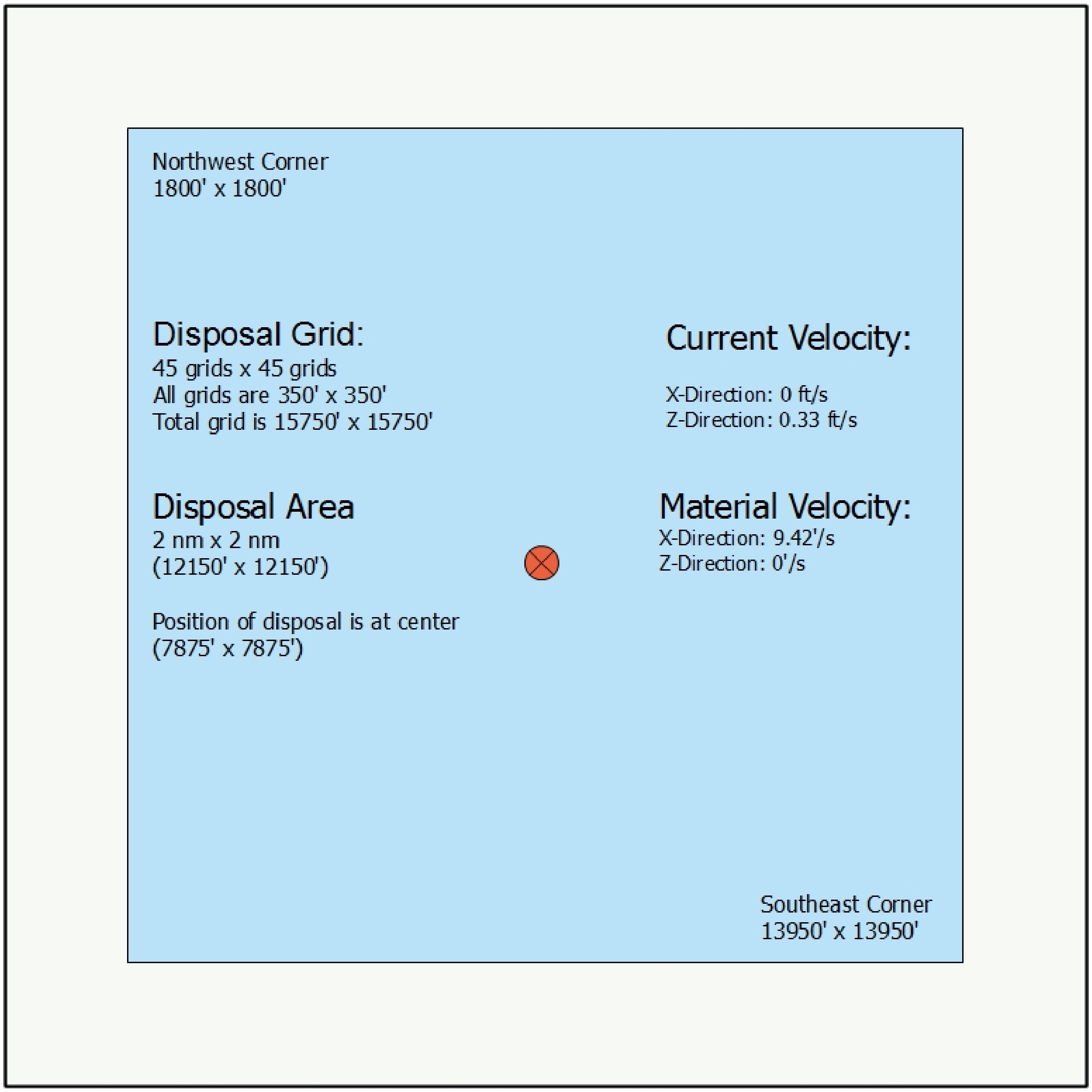
4.2.5 Disposal of Sediment with Unrestricted Release Area and 9,000-Cubic-Yard Volume for Disposal of Dredged Material

All modeling was performed using a disposal location of 7,875 feet by 7,875 feet, as indicated in the Site Management and Monitoring Plan (SMMP) (USEPA and USACE 2012).

Barge capacity was based on an approximately 9,000-cy -capacity vessel owned and operated by Great Lakes Dredge & Dock Co. Exact dimensions from Great Lakes Dredge & Dock Co. were not available at the time of writing. For this reason, dimensions were estimated based on the 9,000-cubic-yard capacity. These estimates obtained on April 9, 2013, from a representative at Weeks Marine, Inc. (http://www.weeksmarine.com/) of Cranford, New Jersey, compare well with dimensions of a smaller-capacity barge.

Material to be dredged from all SYC DUs can be disposed of in the Charleston Harbor ODMDS without restrictions on location using any dredge with a maximum disposal volume of 9,000 cy. All models met the disposal criteria using these volumes. Although a barge with a capacity as modeled may be too large to be logistically feasible with this project, the volume of this largest-known-capacity barge was used in the module to ensure that all smaller-volume-capacity equipment could be used as well. A map of the Charleston ODMDS with disposal inputs is shown below.

Charleston ODMDS Disposal Map



All samples may be disposed without restriction on location in the ODMDS with a maximum load of 9,000 cubic yards for each disposal.

4.2.6 ADDAMS Model Determination

Results show that following 4 hours of initial mixing (as determined under 40 CFR §227.29(a)(2)), the liquid phase of the material from all SYC sediment was in compliance with 40 CFR §227.6(c)(2) and §227.27(b). In order to maintain compliance with the required dilutions, any and all applicable restrictions related to these disposal scenarios will be included in the specifications of the dredging contract.

5 BENTHIC SCREEN

Benthic screening for theoretical bioaccumulation potential was not needed for this evaluation.

6 BENTHIC DETERMINATIONS

The solid phase of the material was evaluated for compliance with 40 CFR §227.6(c)(3) and §227.27(b). This evaluation was made using the results of two types of assays on the solid phase of the material—one focusing on the acute (10-day) toxicity of the material and the other focusing on the potential for the material to cause significant adverse effects due to bioaccumulation. Both types of tests used appropriate sensitive benthic marine organisms according to procedures approved by EPA and USACE.

6.1 Solid Phase Toxicity Evaluation

Ten-day toxicity tests were conducted on project materials using the polychaete worm *Neanthes arenaceodentata* and the amphipod crustaceans *Leptocheirus plumulosus* and *Ampelisca abdita*. These test species are appropriate sensitive benthic marine organisms and, as such, are good predictors of adverse effects to benthic marine communities. Test results for *L. plumulosus*, *A. abdita, and N. arenaceodentata* are shown in Exhibit 10 below and in Tables 17 through 22 of ANAMAR (2014).

6.1.1 Leptocheirus plumulosus

The amphipod benthic test was initially conducted using *L. plumulosus*. Mean survival was statistically significantly different from the reference in all three project samples, ranging from 52% to 70%, with survival of 97% in the reference. Mortality in the project samples was also more than 20% greater than that in the control. After a review of the available data, including physical and chemical results, the toxicology laboratory recommended re-analysis using the second approved species for EPA Region 4, *A. abdita*, based on the high levels of silt and clay found in the samples. Results are summarized in Exhibit 11, and complete results are provided in Tables 17 and 18.

Exhibit 11. Summary of Survival Data for *L. plumulosus*

Sample ID	Mean Survival (%)	Statistically Less than Reference?
Control	91	
SYC14-REF	97	
SYC14-AC	61	Yes
SYC14-TB1	70	Yes
SYC14-TB2	52	Yes

6.1.2 Ampelisca abdita

Based on the laboratory recommendation, a second analysis was performed in the SYC samples using the amphipod species *A. abdita*. Mean survival within the *A. abdita* benthic test ranged from 96% to 98%. Survival within all samples was not statistically different from that of the reference SYC14-REF. Mean percent survival in all treatments was within 20% of the reference (97%), indicating that the test treatments met the LPC for disposal. Results are summarized in Exhibit 12, and complete results are provided in Tables 19 and 20.

Exhibit 12. Summary of Survival Data for *Ampelisca abdita*

Sample ID	Mean Survival (%)	Standard Deviation	Statistically Less than Reference?
Control	98	4.5	
SYC14-REF	97	2.7	
SYC14-AC	96	2.2	No
SYC14-TB1	97	2.7	No
SYC14-TB2	98	2.7	No

6.1.3 Discussion of Low Survival Rate in the Amphipod *L. plumulosus*

Following the analysis of the amphipod *L. plumulosus*, an investigation into the low survival rate was undertaken to determine the most likely cause and whether further analysis, using either *L. plumulosus* or the second available species, *A. abdita* would yield acceptable results. Several factors were addressed in the review, including ammonia content, performance of other organisms during toxicological testing, and physical grain size of the sediment samples.

6.1.3.1 Ammonia

Ammonia levels in the bulk sediment porewaters were measured prior to the initiation of testing, and the levels are presented in Exhibit 13. The values that are bolded exceeded the screening levels shown in Exhibit 14, and were subject to ammonia reduction in accordance with the procedures presented in Appendix N of the SERIM.

Exhibit 13. Summary of Ammonia Concentrations in Project Samples

Sample ID	Total Ammonia (mg/L)	Un-ionized Ammonia (mg/L)
SYC14-REF	7.62	0.098
SYC14-AC	**94.8**	**0.876**
SYC14-TB	**139**	**1.528**
SYC14-TB1	**134**	**0.939**
SYC14-TB2	**140**	**1.298**

Exhibit 14. Summary of Ammonia Screening Levels

Parameter	*Leptocheirus plumulosus*	*Ampelisca abdita*
Total Ammonia (EPA 1994)	<60 mg/L (pH 7.7)	<30 mg/L (pH 7.7)
Un-ionized Ammonia (EPA 1994)	<0.8 mg/L (pH 7.7)	<0.4 mg/L (pH 7.7)
Total Ammonia (Internal lab - NOEC)	65.97 mg/L (running mean)	30.9 mg/L (running mean)
Un-ionized Ammonia (Internal lab - NOEC)	1.03 mg/L (running mean)	0.334 mg/L (running mean)

Following the ammonia-reduction procedures, the sediment had concentrations of ammonia as shown in Exhibit 15 for both species used. All other constituents and properties of the sediment, including grain size, were the same across both tests.

Exhibit 15. Summary of Ammonia Concentrations in Project Samples Following Ammonia-Reduction Procedures

Sample	*Leptocheirus plumulosus,* Initial Porewater Ammonia (total mg/L)	*Ampelisca abdita,* Initial Porewater Ammonia (total mg/L)
SYC14-REF	Not measured	2.63
SYC14-TB1	0.17	9.49
SYC14-TB2	8.43	8.50
SYC14-AC	0.51	4.87

Based on the concentrations presented, *A. abdita* was exposed to higher levels of ammonia for testing but survival was higher and not significantly different from the reference, indicating that ammonia was not likely to have been the cause of lower survival.

6.1.3.2 Performance of Other Organisms During Toxicological Testing

A review of the organisms across all other toxicological tests showed acceptable levels of survival and development. Notably, the results in the other benthic tests (*N. arenaceodentata*, discussed in Section 6.1.4, and *A. abdita*) were found to have no significant differences between the reference and any of the project samples. While the water column tests showed higher levels of mortality and abnormal development with the unadjusted samples, there were no statistical differences between the project samples and the control water once the ammonia had been ameliorated. This indicates that the low survival was limited in its scope to *L. plumulosus*.

6.1.3.3 Performance of *L. plumulosus* Affected by Grain Size

Grain size analysis was performed concurrently with the toxicological analysis and showed very high levels of fines across all project sediment samples. Sediment grain size is an important factor in evaluating benthic test performance for amphipods. The amount of fine-grained sediment (percentage of silts and clays) has been used as an indicator of grain size for selecting test species (PSEP 1995). Sediments dominated by a high percentage of fines have been correlated with poor survival in free-burrowing amphipod species. The percentage of fines in the SYC test sediments ranged from 75.8% to 99% fines (silt and clay), whereas the percentage of fines in the reference sediment was 20.2%, as shown in Exhibit 3. The reference sample resulted in 97% mean survival, while the project samples resulted in mean survivals of 52% to 70%. Barring the presence of significant contaminants of concern in the project composite samples, these results suggest that the grain size may have been a significant contributor to the observed toxicity.

In addition to the broad category of percent fines, another useful tool is understanding what proportion of the fines are comprised of the smallest fraction of clays (passing through a 0.0013-mm sieve). These small particles have been shown to elicit physical stress to certain species of amphipods by preventing proper tube construction, interfering with movement, or binding to and clogging respiratory surfaces of the animals. The turnin basin samples contained 42.5% to 45.6% of the finest fraction of clays (<0.0001 mm), while the access channel sample had 32.9%. The finest fraction of the percent fine material represents almost half of the total percent fines content. The presence of these very-fine-grained sediments may have been a contributing factor to the observed mortalities.

6.1.3.4 Literature Review

Following the investigation into the possible causes of the low survival in the *L. plumulosus* test, a literature review was conducted to determine the extent to which high levels of fines in sediment samples can affect survival rates in amphipods. The report provided by ENVIRON in Attachment 8 summarizes the generally accepted ranges of grain sizes for the *L. plumulosus* test. While earlier sources indicated that *L. plumulosus* would perform across all ranges of grain sizes, more recent work shows that this species will have lower survival rates at high levels of fines, especially those that pass through a 0.0013-mm sieve. These fines can elicit a physical response in the test organisms by preventing proper tube construction. The ENVIRON report contains a complete discussion of the grain size effects on *L. plumulosus* and includes references to the studies shown below:

Emery, V.L., Jr., D.W. Moore, B.R. Gray, B.M. Duke, A.B. Gibson, R.B. Wright, and J.D. Farrar. 1997. Development of a chronic sublethal sediment bioassay using the estuarine amphipod *Leptocheirus plumulosus* (Shoemaker). *Environ. Toxic. Chem.* 16:1912-1920.

Kennedy, A.J., J.A. Steevens, G.R. Lotufo, J.D. Farrar, M.R. Reiss, R.K. Kropp, J. Doi, T.S. Bridges. 2009. *A Comparison of Acute and Chronic Toxicity Methods for Marine Sediments, Marine Environmental Research* (2009), doi: 10.1016/ j.marenvres.2009.04.010

Postma, J.F., S. de Valk, M. Dubbeldam, J.L. Maas, M. Tonkes, C.A. Schipper, B.J. Kater. 2002. Confounding factors in bioassays with freshwater and marine organisms. *Ecotoxicol Environ Safety* 53, 226-237.

PSEP. 1995. *Recommended guidelines for conducting laboratory bioassays on puget sound sediment. In: Puget Sound Protocols and Guidelines, Puget Sound Estuary Program. Final Report* by PTI Environmental Services for U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Schlekat, C.E., B.L. McGee, and E. Reinharz. 1992. *T*esting sediment toxicity in chesapeake bay with the amphipod *Leptocheirus plumulosus*: An evaluation. *Environ. Toxicol, Chem*. 11:225-236.

USEPA and USACE. 2001. *Methods for Assessing the Chronic Toxicity of Marine and Estuarine Sediment-Associated Contaminants with the Amphipod Leptocheirus plumulosus*. U.S. Environmental Protection Agency, Washington, D.C . EPA/600/R-01/020

USEPA and USACE. 1994. *Methods for Assessing the Toxicity of Sediment-Associated Contaminants with Estuarine and Marine Amphipods*. EPA/600/R-94/025, Office of Research and Development, U.S. Environmental Protection Agency, Narragansett, Rhode Island.

Vorhees, D.J., S.B. Kane Driscoll, K. von Stackelberg, J.J. Cura, T.S. Bridges. 2002. An evaluation of sources of uncertainty in a dredged material assessment. *Human and Ecological Risk Assessment* 8, 369-389.

6.1.4 Neanthes arenaceodentata

Mean survival within the *N. arenaceodentata* benthic test ranged from 94% to 100%. Survival within all samples was not found to be statistically different from that of the reference sample SYC14-REF. Mean percent survival in all treatments was within 10% of the reference (98%), indicating that the test treatments met the LPC for disposal. Results are summarized in Exhibit 16, and complete results are provided in Tables 21 and 22.

Exhibit 16. Summary of Survival Data for *Neanthes arenaceodentata*

Sample ID	Mean Survival (%)	Standard Deviation	Statistically Less than Reference?
Control	100	0.0	
SYC14-REF	98	4.5	
SYC14-AC	96	8.9	No
SYC14-TB1	94	8.9	No
SYC14-TB2	100	0.0	No

6.1.5 Solid Phase Toxicity Summary

For the amphipod benthic analysis, the test was performed a second time using *Ampelisca abdita*, which is an EPA Region 4 approved species, and found to be within acceptable criteria. There have been at least two instances in recent projects where a change in species or test procedure was approved by EPA after documentation showed that, as in this case, the survival rate was being affected by other confounding factors.

- In 2008, a project to expand the turning basin in the Cape Fear River in Wilmington, North Carolina, had responses in the *L. plumulosus* that were below acceptable criteria in the control and project samples. Based on the type of material collected, it was suspected that the material had low-quality total organic carbon (TOC), which resulted in low survival due to starvation rather than contaminated sediment. The test was rerun twice, first with *L. plumulosus* and then using *Eohaustorius estuarius* in addition to the *L. plumulosus*. Unlike *Ampelisca abdita*, *Eohaustorius estuarius* is not approved for analysis by EPA Region 4, although it is approved for use by other EPA regions.
- In 2010, samples collected from Charleston Harbor for maintenance dredging showed poor *L. plumulosus* survival. A retest was performed using the same species, but allowing for the organisms to be fed during the course of the test due to suspected poor quality food. The retest had acceptable results.

In both cases, the dredge material received concurrence from EPA for offshore disposal.

Based on past events involving *L. plumulosus,* EPA accepted the amphipod results where a change in test procedure allowed the test to be more appropriately evaluated. Given the positive results for the other 7 species tested where survivability was not affected, the lower survivability for the L. plumulosus is most likely due to grain size. For this reason, sediment samples were found to meet the solid phase toxicity criteria of 40 CFR §227.6 and §227.27 as justified by the discussion found in this section.

6.2 Solid Phase Bioaccumulation Evaluation

The Green Book (USEPA and USACE 1991) describes a process for evaluating bioaccumulation potential using comparative analysis of test sediment bioaccumulation to U.S. Food and Drug Administration (FDA) action levels, reference sediment bioaccumulation, and eight additional factors for assessing the significance of bioaccumulation. This analysis was used to evaluate bioaccumulation potential in the SYC samples.

Bioaccumulation potential of contaminants in the SYC sediment samples was evaluated through a 28-day solid phase test using the representative species *Macoma nasuta* (bent-nose clam) and *Neanthes virens* (sand worm). These two species meet the requirements of 40 CFR §227.27(d), which recommends the use of filter-feeding, deposit-feeding, and burrowing species.

Samples tested for the bioaccumulation study in the ANAMAR (2014) report include SYC14-AC, SYC14-TB, and the SYC14-REF.

6.2.1 Metals

A report provided by GEL was used to determine levels of contaminants in the sediment from a recent project in SYC. The report indicated detectable levels of metals throughout SYC. Since sediment chemistry is not a requirement for analysis per the SERIM, and based on the GEL report, ANAMAR proposed to analyze all tissue samples for metals rather than re-analyze the sediment for metals.

6.2.2 Organotins

The analysis of organotins in sediment was performed for three congeners: n-butyltin, di-n-butyltin, and tri-n-butyltin. No concentration of any butyltin congener in sample SYC14-AC was found at or above the laboratory reporting limit. The concentration of each congener was greater than the laboratory reporting limit in sample SYC14-TB. As specified in the SERIM, the corresponding tissue samples produced from bioaccumulation tests with sediment sample SYC14-TB were recommended for analysis for organotins.

6.2.3 PAHs

Eighteen PAHs were tested as specified in Section 5 of the SERIM. Of these 18 PAHs, 16 were detected above the MRL in sample SYC14-AC, and 13 were detected above the MRL in sample SYC14-TB. All PAHs met the target detection limit specified in the SERIM. As specified in the SERIM, the corresponding tissue samples produced from bioaccumulation tests with both sediment samples were recommended for PAH analysis.

6.2.4 Dioxins and Furans

Dioxin and furan analyses were performed for the 17 congeners specified in Appendix M of the SERIM. The concentration for each congener was then normalized to *2,3,7,8*-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) using the toxicity equivalency factors from the World Health Organization (2005). The sum of each normalized value was calculated to yield a single toxicity equivalence (TEQ) for each sample. The laboratory MDL met the target detection limit for all congeners specified in the SERIM, while the laboratory reporting limit slightly exceeded the target detection limit for all congeners. Individual congeners do not have any corresponding screening criteria. The total TEQ exceeded both corresponding screening criteria, and, as specified in the SERIM, the corresponding tissue samples produced from bioaccumulation tests with both sediment samples were recommended for dioxin and furan analysis.

Other analyses performed included polybrominated diphenyl ethers, ammonia, and TOC; however, these are not part of the typical analytical regimen and they were not recommended for tissue chemistry analysis. Although pesticides and PCBs in sediments are typically analyzed as part of a Section 103 evaluation, the GEL report indicated that all results were below the reporting limit and were not required for this project. The elimination of these analytes from testing is addressed in the QAPP.

A recommendation for tissue chemistry analysis was prepared and submitted to USACE and EPA for approval based on the preceding criteria. The recommendation is provided in Attachment 9.

Exhibit 17 summarizes major analyte groups tested in tissues from project samples.

Exhibit 17. Tissue Analysis Scheme

Analyte	Project Sample ID
Metals	SYC14-AC, SYC14-TB, SYC14-REF
Organotins	SYC14-TB, SYC14-REF
PAHs	SYC14-AC, SYC14-TB, SYC14-REF
Dioxins and Furans	SYC14-AC, SYC14-TB, SYC14-REF

Source: ANAMAR (2014)

Lipids were analyzed in the pre-exposure tissues of each species in accordance with the QAPP. Results can be found in Tables 25 through 42 of the ANAMAR (2014) report.

6.3 Comparison to FDA Action Levels

Tissue chemistry results were compared to action levels published by FDA (2001 and 2011). The tissues tested did not exceed FDA action levels for any analyte tested.

6.4 Comparison to Reference Sediment Bioaccumulation

In accordance with the Green Book, bioaccumulation of metals, PAHs, dioxins, and organotins were evaluated using statistical comparisons of mean concentrations in project tissues relative to that of the reference using the software program ToxCalc v5.0.32 (Tidepool Scientific LLC). The statistical treatment determined relative distribution and variances among the samples tested. In the case of an abnormal distribution or unequal variance among samples, the data were addressed by a reciprocal transformation and then re-evaluated.

6.4.1 Macoma nasuta

Wet weight analytical results in *M. nasuta* tissues are presented in Section 3.7.2 and in Tables 28, 32, 36, and 40 of the ANAMAR (2014) report.

M. nasuta tissues from sample SYC14-AC had mean concentrations of beryllium, lead, silver, thallium, zinc, total PAHs, total low molecular weight (LMW) PAHs, total high molecular weight (HMW) PAHs, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, fluoranthene, pyrene, and octachloro-dibenzo-dioxin that were statistically significantly greater than that of the reference tissue.

In addition, *M. nasuta* tissues from sample SYC14-AC had mean concentrations of copper, lead, zinc, total HMW PAHs, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, pyrene, and total dioxin TEQs that were greater than either the ecological effects threshold or the South Atlantic Bight background.

M. nasuta tissues from sample SYC14-TB had mean concentrations of beryllium, copper, lead, silver, zinc, total PAHs, total LMW PAHs, total HMW PAHs, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, fluoranthene, pyrene, total organotins, n-butyltins and octachloro-dibenzo-dioxin that were statistically significantly greater than that of the reference tissue.

In addition, *M. nasuta* tissues from sample SYC14-TB had mean concentrations of copper, lead, zinc, total PAHs, total HMW PAHs, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, pyrene, and total dioxin TEQs that were greater than either the ecological effects threshold or the South Atlantic Bight background.

Exhibit 18 provides a summary of the samples and analytes that were either statistically significantly greater than in the reference or are greater than the ecological effects threshold or the South Atlantic Bight background concentration.

Exhibit 18. *Macoma nasuta*: Summary of Mean Wet Weight Analytes Detected above the MRL and Statistically Significantly Greater than That of the Reference or Greater than the Ecolgical Effects Threshold or the South Atlantic Bight Background Concentration

Analyte:	**Mean Concentration**				
	SYC14-AC	**SYC13-TB**	**SYC14-REF**	**Eco. Effects Threshold[1]**	**South Atlantic Bight Background[1]**
	Mean Concentration (mg/kg)			**Concentration (mg/kg)**	
Beryllium	**0.0081**	**0.0062**	0.0038	x	<0.19
Copper	*3.73*	***4.65***	*3.56*	0.2	1.2-2.9
Lead	***0.287***	***0.216***	*0.130*	0.1	0.05-0.77
Silver	0.0375	**0.0473**	0.0370	1.0	<0.96
Thallium	**0.0043**	0.0016	0.0011	0.3	<0.10
Zinc	*18.6*	*17.4*	*17.9*	11.6	10-20
	Mean Concentration (µg/kg)			**Concentration (µg/kg)**	
Total LMW PAHs	**10**	**14**	7.2	x	60.0
Total HMW PAHs	***76***	***172***	7.2	x	60.0
Total PAHs	**103**	***219***	18	40000	170
Anthracene	2.2	**4.8**	0.38	x	<20
Benzo(a)anthracene	**12**	***31***	1.3	x	<20
Benzo(a)pyrene	**10**	***22***	1.5	x	<20
Benzo(b)fluoranthene	***23***	***49***	1.5	x	<20
Benzo(k)fluoranthene	**9.0**	**18**	1.3	x	<20
Chrysene	**9.9**	***29***	0.78	x	<20
Fluoranthene	***27***	***64***	2.7	8.8	<20
Pyrene	***35***	***69***	2.0	x	<20
OCDD	**19.3**	**23.4**	6.0	x	x
Dioxin/Furan TEQ (ng/kg)	*0.987*	*2.32*	*1.15*	x	0.32-0.36
Total Organotins as Tin (µg/kg)	NA	**18**	13	x	x
n-Butyltin Cation (µg/kg)	NA	**24**	16	x	x

[1] Values are from the SERIM (Appendix H)

x = No ecological effects threshold or South Atlantic bight background concentrations published for this parameter

Concentrations in bold indicate that result is statistically significantly greater than the reference.

Concentrations that are underlined indicate results that are statistically significantly greater than the reference and average reference values that are below the MRL.

Concentrations that are italicized indicate the result is greater than either the ecological effects threshold or the South Atlantic Bight background concentration.

6.4.2 Neanthes virens

Wet weight analytical results for *N. virens* tissues are presented in Section 3.7.2 and in Tables 27, 31, 35, and 39 of the ANAMAR (2014) report.

N. virens tissues from sample SYC14-AC had mean concentrations of nickel, zinc, total HMW PAHs, fluoranthene, pyrene, and total dioxin TEQs that were statistically significantly greater than that of the reference tissue.

In addition, *N. virens* tissues from sample SYC14-AC had mean concentrations of zinc and total dioxin TEQs that were greater than either the ecological effects threshold or the South Atlantic Bight background.

N. virens tissues from sample SYC14-TB had mean concentrations of total high molecular weight PAHs, fluoranthene, pyrene, and total dioxin TEQs that were statistically significantly greater than that of the reference tissue.

In addition, *N. virens* tissue from sample SYC14-TB had mean concentrations of zinc and total dioxin TEQs that were greater than either the ecological effects threshold or the South Atlantic Bight background.

Exhibit 19 provides a summary of the samples and analytes that are either statistically significantly greater than the reference or are greater than the ecolgical effects threshold or the South Atlantic Bight background concentration.

Exhibit 19. *Neanthes virens*: Summary of Mean Wet Weight Analytes Detected above the MRL and Statistically Significantly Greater than That of the Reference or Greater than the Ecolgical Effects Threshold or the South Atlantic Bight Background Concentration

Analyte:	**Mean Concentration (mg/kg)**			**Concentration (mg/kg)**	
	SYC14-AC	**SYC13-TB**	**SYC14-REF**	**Eco. Effects Threshold[1]**	**South Atlantic Bight Background[1]**
	Mean Concentration (mg/kg)			**Concentration (mg/kg)**	
Nickel	**0.308**	0.187	0.164	2.2	1.6-3.5
Zinc	***39.5***	*28.2*	17.2	0.3	20-27
	Mean Concentration (µg/kg)			**Concentration (µg/kg)**	
Total HMW PAHs	**17**	**23**	7.4	x	60.0
Fluoranthene	**6.2**	**10**	1.3	12.8	<20
Pyrene	**7.4**	**9.4**	1.2	x	<20
Dioxin/Furan TEQ (ng/kg)	***1.70***	***1.32***	0.37	x	0.18-0.44

[1] Values are from the SERIM (Appendix H)

Concentrations in bold indicate that result is statistically significantly greater than the reference.

x = No ecological effects threshold or South Atlantic bight background concentrations published for this parameter

Concentrations that are underlined indicate results that are statistically significantly greater than the reference and average reference values that are below the MRL.

Concentrations that are italicized indicate the result is greater than either the ecological effects threshold or the South Atlantic Bight background concentration.

6.5 Additional Bioaccumulation Evaluation Factors

Analyte concentrations in tissues from project samples found to be statistically significantly greater than that of the reference sediment were further evaluated using guidance from Section 6.3 of the Green Book, which provides factors to evaluate LPC compliance.

6.5.1 Factors 1 and 2: The Number of Species and Number of Contaminants for Which Bioaccumulation from the Dredge Material Was Statistically Greater than That of the Reference Material

Bioaccumulation was performed in two species, *M. nasuta* and *N. virens*. Both had concentrations of contaminants in the project samples that statistically exceeded the concentrations in the reference sample. Exhibit 20 shows the total number of analytes in each sample that were statistically greater than those in the reference by species.

Exhibit 20. Number of Results Greater than the Reference Per Sample

Value	*Macoma nasuta*		*Neanthes virens*	
	SYC14-AC	**SYC14-TB**	**SYC14-AC**	**SYC14-TB**
Statistically Greater than in the Reference	14	18	6	4

6.5.2 Factor 3: Magnitude by Which Bioaccumulation from the Dredge Material Exceeds That of the Reference Material

Exhibit 20 shows the percentage of contaminant in each sample compared to the reference, e.g. for beryllium in SYC14-AC, the value is 213, which indicates that beryllium is 213%, or 2.13 times the concentration in the reference. The actual concentrations for each project sample and the reference are shown in Exhibits 17 and 18.

Exhibit 21. Contaminant Levels Compared to the Reference

Analyte	Species	Percent Concentration of the Reference	
		SYC14-AC	SYC13-TB
Beryllium	*M. nasuta*	**213**	**163**
Copper	*M. nasuta*	105	**131**
Lead	*M. nasuta*	**221**	**166**
Silver	*M. nasuta*	101	**128**
Thallium	*M. nasuta*	**391**	145
Zinc	*M. nasuta*	104	97
Total LMW PAHs	*M. nasuta*	**139**	**194**
Total HMW PAHs	*M. nasuta*	**1056**	**2389**
Total PAHs	*M. nasuta*	**572**	**1217**
Anthracene	*M. nasuta*	579	**1263**
Benzo(a)anthracene	*M. nasuta*	**923**	**2385**
Benzo(a)pyrene	*M. nasuta*	**667**	**1467**
Benzo(b)fluoranthene	*M. nasuta*	**1533**	**3267**
Benzo(k)fluoranthene	*M. nasuta*	**692**	**1385**
Chrysene	*M. nasuta*	**1269**	**3718**
Fluoranthene	*M. nasuta*	**1000**	**2370**
Pyrene	*M. nasuta*	**1750**	**3450**
OCDD	*M. nasuta*	**322**	**390**
Dioxin/Furan TEQ	*M. nasuta*	86	202
Total Organotins as Tin	*M. nasuta*	NA	**138**
n-Butyltin Cation	*M. nasuta*	NA	**150**
Nickel	*N. virens*	**188**	114
Zinc	*N. virens*	**230**	164
Total HMW PAHs	*N. virens*	**230**	**311**
Fluoranthene	*N. virens*	**477**	**769**
Pyrene	*N. virens*	**617**	**783**
Dioxin/Furan TEQ	*N. virens*	**459**	**357**

Bold values indicate the result is statistically significantly greater than the reference.

6.5.3 Factor 4: Toxicological Importance of the Contaminants Whose Bioaccumulation from the Dredge Material Statistically Significantly Exceeded That of the Reference

Except as noted, the contaminants and effects listed here are shown in http://water.epa.gov/polwaste/sediments/cs/biotesting_index.cfm EPA (2000). Most of the text below is copied directly from EPA (2000), and references are available through that document.

Beryllium

Beryllium is a naturally occurring metal with several important industrial uses. The available literature on the effects of beryllium on marine life is limited. *Element Concentrations Toxic to Plants, Animals, and Man* (http://pubs.usgs.gov/bul/1466/report.pdf, 1979) suggests that the limit for animals is 0.5 mg/kg body weight.

Copper

Up to 29 copper species can be present in aqueous solution in the pH range from 6 to 9. Aqueous copper speciation and toxicity depend on the ionic strength of the water. The hydroxide species and free copper ions are mostly responsible for toxicity, while copper complexes consisting of carbonates, phosphates, nitrates, ammonia, and sulfates are weakly toxic or nontoxic. Copper in the aquatic environment can partition to dissolved and particulate organic carbon. The bioavailability of copper also can be influenced to some extent by total water hardness. Bioavailability of copper in sediments is controlled by the acid-volatile sulfide (AVS) concentration.

The free copper ions are the most bioavailable inorganic forms, although they account for only a minor proportion of the total dissolved metal. The concentration of copper found in interstitial water is usually much lower than that in surface water. The amount of bioavailable copper in sediment is controlled in large part by the concentration of AVS and organic matter. A considerable number of aquatic species are sensitive to dissolved concentrations of copper in the range of 1-10 µg/L. Metal metabolism by aquatic biota has significant affects on metal accumulation, distribution in tissues, and toxic effects. Concentration of copper in benthic organisms from contaminated areas can be one to two orders of magnitude higher than normal. Copper is accumulated by aquatic organisms primarily through dietary exposure. However, most organisms retain only a small proportion of the heavy metals ingested with their diet.

For copper, physiological effects cited in EPA 2000 in *Mytilus edulis*, a bivalve species similar to *M. nasuta*, begin to occur at 12 mg/kg, which is approximately three times the concentration found in the project tissue samples. In addition, the levels of copper found in the pre-exposure samples were approximately 85% of the concentrations found in the higher of the 2 project samples for *M. nasuta*.

Lead

Lead is a poisonous contaminant with substantial research available of its effects on aquatic species. According to the literature cited, zebra mussels show physiological effects at 2 to 6 mg/kg and effects on mortality at concentrations ranging from 2 to 200 mg/kg. These levels are a minimum of a factor of approximately 6 above the concentration found in the tissue samples.

Nickel

Bioaccumulation of nickel is most pronounced in sediments when the ratio of simultaneously extracted metals to acid-volatile sulfide (SEM/AVS) is greater than 1. Although nickel concentrations in animals from sediments with SEM/AVS ratios >1 were approximately 2- to 10-fold greater than nickel concentrations in benthic organisms from sediments with SEM/AVS ratio <1, nickel uptake (tissue concentration) was proportional to the concentration in sediment. Ankley et al. have shown that bioaccumulation of nickel from the sediment by Lumbriculus variegatus was not predictable based on total sediment metal concentration, but was related to the sediment SEM/AVS ratio. Nickel is considered in some cases to be an essential nutrient for numerous animal species and humans.

Studies with the clam *Cerastoderma edule* show an LC_{50} of 56.6 mg/kg, which is approximately 100-200 times the levels found in the project tissue samples for both species.

Silver

Silver does not appear to be a highly mobile element under typical conditions in most aquatic habitats. Tissue residue-toxicity relationships can also vary because organisms may sequester metal in different forms that might be analytically measurable as tissue residue, but might actually be stored in available forms within the organism as a form of detoxification. Whole-body residues also might not be indicative of effects concentrations at the organ level because concentrations in target organs, such as the kidneys and liver, can be 20 times greater than whole body residues. The application of “clean” chemical analytical and sample preparation techniques is also critical in the measurement of metal tissue residues. Exposure of rainbow trout to three different silver salts revealed that silver, introduced as silver nitrate, was 15,000 and 11,000 times more toxic than silver chloride and silver thiosulfate. However, all three forms of dissolved silver were taken up by rainbow trout and accumulated in the tissue. Extremely high levels of silver were found in livers of fish exposed to silver as silver chloride and silver thiosulfate. Hogstrand et al. attributed low toxicity to these two forms to production of metallothionein, a small cysteine-rich, intracellular protein that avidly binds most metals.

Studies with various shellfish show effects ranging from 1,650 mg/kg to over 2,500 mg/kg, with no effects as high as at least 800 mg/kg. The concentrations found in the *M. nasuta* that were statistically significantly greater than the reference were below 0.05 mg/kg.

Thallium

Thallium is a naturally occurring metal with several important industrial uses. The available literature on the effects of thallium on marine life is limited. *Element Concentrations Toxic to Plants, Animals, and Man* (http://pubs.usgs.gov/bul/1466/report.pdf, 1979) suggests that the limit for animals is 0.003 mg/kg body weight.

Zinc

Zinc does not appear to be a highly mobile element under typical conditions in most aquatic habitats. Tissue residue-toxicity relationships can also be variable because organisms sequester metals in different forms that are measurable as tissue residue but can actually be stored in unavailable forms within the organism as a form of detoxification. Whole-body residues also might not be indicative of effects concentrations at the organ level because concentrations in target organs, such as the kidneys and liver, can be 20 times greater than whole body residues. The application of “clean” chemical analytical and sample preparation techniques is also critical in the measurement of metal tissue residues. After evaluating the effects of sample preparation techniques on measured concentrations of metals in the edible tissue of fish, Schmitt and Finge concluded that there was little direct value in measuring copper, zinc, iron, or manganese tissue residues in fish because they do not bioaccumulate to any appreciable extent. It has also been suggested that there is no compelling evidence to support inordinate concern about zinc as a putative toxic agent in the environment, and in fact there is considerable evidence that zinc deficiency is a serious, worldwide human health problem that outweighs the potential problems associated with accidental, self-imposed, or environmental exposure to zinc excess.

Studies with various shellfish show no effects on mortality of development to at least 130 mg/kg. The concentration found in the *M. nasuta* sample that was statistically significantly greater than the reference was approximately 40 mg/kg.

Dioxin TEQ and OCDD

Dioxins and furans are toxic compounds that are formed by combustion in the presense of organic material and chlorine. These compounds are commonly found in paper and pulp mill waste, but can also be found in naturally occurring events such as forest fires. The most toxic dioxin form is 2,3,7,8-TCDD. Other dioxin congeners may also be present, and the ones that have the greatest impact on the environment share the 2,3,7,8 substitution pattern, but may also include additional chlorines on the benzene chain. The World Health Organization has developed toxicity equivalence factors (TEFs) to indicate the toxicity of the congener with respect to 2,3,7,8-TCDD. As a general rule, the greater the number of chlorine atoms attached to the benzene molecule, the lower its overall toxicity, based on the TEFs. The TEQ is then calculated as the sum of all the dioxin congeners, where the congener result is multiplied by the TEF. The calculation for the dioxin TEQ is shown below.

$$\text{TEQ} = \Sigma\,[C_i] \times \text{TEF}_i$$

Where

- C_i = Individual TCDD or DLC concentration in environmental media
- TEF_i = TEF assigned for TCDD
- TEQ = TCDD toxicity equivalence

If the concentration in the congener is below the laboratory detection limit reported as ND, then the detection limit is used in place of C_i. This will provide a worst-case scenario for dioxin TEQ concentrations.

Dioxin TEQ and OCDD are normalized to 2,3,7,8-TCDD upon the application of the TEF. The polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) each consist of 75 isomers that differ in the number and position of attached chlorine atoms. The PCDDs and PCDFs are polyhalogenated aromatic compounds that exhibit several properties common to this group of compounds. These compounds tend to be highly lipophilic, and the degree of lipophilicity is increased with increasing ring chlorination. In general, the PCDDs and PCDFs exhibit relative inertness to acids, bases, oxidation, reduction, and heat, increasing in environmental persistence and chemical stability with increasing chlorination. Because of their lipophilic nature, PCDDs and PCDFs have been detected in fish, wildlife, and human adipose tissue, milk, and serum. Each isomer has its own unique chemical and toxicological properties. The most toxic of the PCDD and PCDF isomers is one of the 22 possible congeners of tetrachlorodibenzo-p-dioxin. TEFs have been developed by EPA relating the toxicities of other PCDD and PCDF isomers to that of 2,3,7,8-TCDD. The biochemical mechanisms leading to the toxic response resulting from exposure to PCDDs and PCDFs are not known in detail, but experimental data suggest that an important role in the development of systemic toxicity resulting from exposure to these chemicals is played by an intracellular protein, the Ah receptor. This receptor binds halogenated polycyclic aromatic molecules, including PCDDs and PCDFs. In several mouse strains, the expression of toxicity of 2,3,7,8-TCDD-related compounds (including cleft palate formation, liver damage, effects on body weight gain, thymic involution, and chloracnegenic response) has been correlated with their binding affinity for the Ah receptor and with their ability to affect several enzyme systems.

In natural systems, PCDDs and PCDFs are typically associated with sediments, biota, and the organic carbon fraction of ambient waters. Congener-specific analyses have shown that the 2,3,7,8-substituted PCDDs and PCDFs were the major compounds present in most sample extracts. Results from limited epidemiology studies are consistent with laboratory-derived threshold levels to 2,3,7,8-TCDD impairment of reproduction in avian wildlife. Population declines in herring gulls (*Larus argentatus*) on Lake Ontario during the early 1970s coincided with egg concentrations of 2,3,7,8-TCDD and related chemicals expected to cause reproductive failure based on laboratory experiments (2,3,7,8-TCDD concentrations in excess of 1,000 picograms per gram (pg/g). Improvements in herring gull reproduction through the mid-1980s were correlated with declining 2,3,7,8-TCDD concentrations in eggs and lake sediments. Based on limited information on isomer-specific analysis of animals at different trophic levels, it appears that at higher trophic levels (i.e., fish-eating birds and fish), there is a selection of the planar congeners with the 2,3,7,8-substituted positions.

PCDDs and PCDFs are accumulated by aquatic organisms through exposure routes that are determined by the habitat and physiology of each species. With log K >5, exposure through ingestion of contaminated food becomes an important route for uptake in comparison to respiration of water. The relative contributions of water, sediment, and food to uptake of 2,3,7,8-TCDD by lake trout in Lake Ontario was examined by exposing yearling lake trout to Lake Ontario smelt and sediment from Lake Ontario along with water at a 2,3,7,8-TCDD concentration simulated to be at equilibrium with the sediments. Food ingestion was found to contribute approximately 75% of total 2,3,7,8-TCDD. There have been a number of bioconcentration studies of 2,3,7,8-TCDD using model ecosystem and single species exposure. Although there is variation in the actual log bioconcentration factor (BCF) values, in general, the algae and plants have the lowest BCF values, on the order of a few thousand. A value of 4.38 has been reported for the snail *Physa* sp. Crustacea and insect larva appear to have the next highest BCF values, followed by several species of fish, with the highest log BCF value of 4.79.

Exposure of juvenile rainbow trout to 2,3,7,8-TCDD and -TCDF in water for 28 days resulted in adverse effects on survival, growth, and behavior at extremely low concentrations. A no-observed-effects concentration (NOEC) for 2,3,7,8-TCDD could not be determined because exposure to the lowest dose of 0.038 ng/L resulted in significant mortality. A number of biological effects have been reported in fish following exposure to 2,3,7,8-TCDD, including enzyme induction, immunological effects, wasting syndrome, dermatological effects, hepatic effects, hematological effects, developmental effects, and cardiovascular effects.

A review of the concentrations of dioxins shows that while the calculated TEQ levels exceed the reference, most of the contribution comes from non-detected dioxin and furan congeners. For these congeners, the method detection limit was used in the calculation above, and the actual concentrations were likely much lower, and will also lead to a total TEQ that is also likely much lower than the value reported. In addition, the concentration of the most toxic congener, 2,3,7,8 TCDD was not detected in any project tissue sample at or above the method detection limit, with the exception of 1 tissue replicate. The concentration found for this replicate was less than twice the method detection limit.

Total Organotins and n-Butyltin

Tri-substituted organotins (such as tributyltin [TBT]) are most commonly used as pesticides in commercial and agricultural applications. TBT is widely used as a preservative for timber and wood, textiles, paper, and leather. The use of marine paints containing TBT compounds as toxic additives has been found to be very effective in eliminating fouling problems. TBT-based antifouling paints typically contain up to 20% by weight of a suitable TBT or triphenyltin toxicant, which is slowly leached into the surrounding water in the immediate vicinity of the hull. The active lifetime of these paints is usually 1 to 2 years, after which time the vessel must be repainted.

The toxicity of organotins increases with progressive introduction of organic groups bonding with the tin atom. Thus, the high toxicity of TBT led to its use as a fungicide, bactericide, and algicide. TBT-containing antifouling paints were recognized as up to 100 times more effective than copper-based antifouling paints. In fact, studies have demonstrated that TBT is deleterious at concentrations far lower than indicated for other marine pollutants. Consequently, TBT has been used in antifouling paints since the early 1960s and gained widespread application on all types of vessels in the 1970s and 1980s. Shell-thickening in oysters (*Crassostrea gigas*) has been reported in some areas of France since the outset of its introduction in that country in 1968. TBT leaching from the ship hulls into the water appeared to be the major pathway of entry into the aquatic environment. Other sources of TBT in the aqueous environment include releases of fugitive paint and paint chips from vessel repair and dry-dock facilities. TBT is likely to partition between suspended particles in the water column and sediments, although up to 99% of the TBT may reside in the sediments. TBT-contaminated sediments can represent a substantial source of organotin to aquatic receptors. TBT has a significant lipid solubility and thus a high affinity for bioaccumulation. Some organisms, including fishes, crustaceans, bivalves, and microorganisms, have the ability to bioconcentrate TBT to concentrations which are orders of magnitude higher than the exposure concentration.

Acute effects of TBT have been observed in the water column at concentrations of 1 ng/L. This concentration has been associated with reduced reproduction in snails. Histological alterations were observed in young European minnows exposed to an aqueous TBT concentration of 0.8 µg/L. Reduced growth was noted in long-term exposures of rainbow trout yolk sac fry to 0.2 µg/L TBT, resulting in an estimated NOEC of 0.04 µg/L. Immunotoxic effects were observed in guppies at 0.32 µg/L TBT. In studies of *Acartia tonsa*, reductions in survival in acute tests were observed at 0.029 µg/L; NOECs and LOECs for survival during chronic tests were 0.024 and 0.017 µg/L, respectively.

As a group, mollusks are among the most sensitive to TBT. Gastropod snails exhibit anatomical abnormalities referred to as imposex, the superimposition of male characteristics onto a normal female reproductive system. Growth in oyster spat is inhibited at aqueous concentrations of 0.15 µg/L, and shell thickening has been reported at 0.2 µg/L. Other effects in oysters include abnormal veliger development, malformation of trocophores, larval anomalies, perturbation in food assimilation, and high mortality. Some freshwater and marine bivalves are able to tolerate short-term TBT exposure due to their ability to isolate themselves from the irritating environment by closing their valves.

TBT concentrations in sediments can be from one to several thousand times higher than concentrations found in the overlying water. Bivalve populations can be eliminated when sediment TBT concentrations exceed 0.8 µg/g. No sediment criteria exist for TBT, and effects range low and effects range median ranges are unavailable. However, studies indicate that mollusks respond to sediment concentrations of TBT as low as 10 ng/g, while some copepod crustaceans, echinoderms, polychaetes, tunicates, phytoplankton, and fish respond to sediment TBT concentrations between 10 and 100 ng/g.

While concentrations of n-butyltin and total organotins (which is primarily a contribution of n-butyltin) in *M. nasuta* exceeded the reference concentration, the overall effects on marine organisms are not readily available in the literature. The results for TBT, which is the most toxic form of the compound, are statistically below concentrations in the reference.

Anthracene

Anthracene is one of several LMW PAHs. The available data on toxicity effects are limited and do not include marine life. Testing has shown that mice exposed to 308 mg/kg anthracene have offspring with birth defects.

Benzo(a)anthracene

The acute toxicity of hydrocarbons, including benzo(a)anthracene, to both freshwater and saltwater crustaceans is largely nonselective, i.e., it is not primarily influenced by molecular structure, but is rather controlled by organism-water partitioning which, for nonpolar organic chemicals, is in turn a reflection of aqueous solubility. The toxic effect is believed to occur at a relatively constant concentration within the organism. Toxicity of benzo(a)anthracene, as well as chrysene and pyrene, to striped bass (*Morone saxatilis*) decreased as water salinity increased. Bioavailability of sediment-associated PAHs, e.g., benzo(a)anthracene, has been observed to decline with increased contact time. The majority of investigations have shown that aquatic organisms are able to release PAHs from their tissues rapidly when they were returned to a clean environment. Mussels exposed to contaminated sediment rapidly accumulated benzo(a)anthracene, reaching maximum concentrations at day 20. The concentration factors for mussels exposed to 675 ng/g of benzo(a)anthracene in sediment ranged from 2,470 to 35,700. Benzo(a)anthracene was rapidly taken up by the aquatic plant *Fontinalis antipyretica*, and the uptake kinetics plateaued between 48 and 168 hours of exposure. Roy et al. suggested that slow elimination of benzo(a)anthracene from the plant tissue may be due to low aqueous solubility. Sediment-associated benzo(a)anthracene can be accumulated from two sources: interstitial water and ingested particles. The accumulation kinetics of benzo(a)anthracene suggest that uptake occurs via the sediment interstitial water and ingested material and is controlled by desorption from sediment particles and dissolved organic matter. After 24 hours exposure, benzo(a)anthracene was accumulated by *Daphnia pulex* mostly from the water, while LMW PAHs such as naphthalene and phenanthrene were accumulated primarily through algal food.

Bioaccumulation of LMW LMWPAHs from sediments by *Rhepoxynius abronius* (amphipod) and *Armandia brevis* (polychaete) was similar; however, a large difference in tissue concentration between these two species was measured for HMW PAHs, including benzo(a)anthracene. Meador et al. concluded that the LMW PAHs were available to both species from interstitial water, while sediment ingestion was a much more important uptake route for the HMW PAHs.

The authors also indicated that bioavailability of the HMW HMWPAHs to amphipods was significantly reduced due to their partitioning to dissolved organic carbon.

Benzo(a)pyrene

Bioavailability of sediment-associated PAHs, including benzo(a)pyrene, has been observed to decline with increased contact time. Oikari and Kukkonene established a relationship between dissolved organic matter, including the percentage of hydrophobic acids, and accumulation of benz(a)pyrene. They observed that the bioavailability of benzo(a)pyrene decreases in waters with dissolved organic carbon having more HMWhydrophobic acids. The reduced bioavailability has been observed for benzo(a)pyrene accumulation from field-collected sediments compared with laboratory-spiked sediments. Mean accumulation of benzo(a)pyrene declined by a factor of three in *Chironomus riparius* exposed to sediment stored for 1 week versus sediment stored for 8 weeks. The concentrations of benzo(a)pyrene in whole sediment and pore water were 0.27 to 80.9 ng/g and 0.004 to 0.913 mg/mL, respectively. Short-term exposures (24 hours) to 1 mg/L benzo(a)pyrene averaged 8.27 nanomoles in fish tissue. Of this total, 67% was accumulated in the gallbladder or gut, indicating rapid metabolism and excretion.

The bioaccumulation of benzo(a)pyrene can be influenced by lipid reserves. In an experiment conducted by Clements et al. , chironomidae larvae rapidly accumulated benzo(a)pyrene from spiked sediment and tissue concentrations were directly proportional to sediment concentrations. However, the level of benzo(a)pyrene in bluegill that were fed contaminated chironomids was generally low, indicating either low uptake or rapid metabolism. According to McCarthy , accumulation of hydrophobic chemicals like benzo(a)pyrene in aqueous systems appears to depend on the amount of chemical in solution and on the amount sorbed to particles entering the food chain. Uptake and accumulation of benzo(a)pyrene was reduced by 97% due to sorption to organic matter.

Studies that report body burdens of the parent compound may, depending on the species, grossly underestimate total bioaccumulation of benzo(a)pyrene and its metabolites. Kane-Driscoll and McElroy concluded that the body burden of the parent compound may represent less than 10% of the actual total body burden of the parent plus metabolites. The accumulation kinetics of benzo(a)pyrene suggest that uptake occurs largely via the sediment interstitial water and is controlled by desorption from sediment particles and dissolved organic matter. Accumulation of benzo(a)pyrene from water was not affected by the simultaneous presence of naphthalene or PCBs. Kolok et al. showed that the concentration of benzo(a)pyrene equivalents in shad (*Dorosoma cepedianum*) increases when the fish ventilate water turbid with benzo(a)pyrene-spiked sediments. Also, the turbid water, not sediment ingestion, appears to be a significant source of benzo(a)pyrene for gizzard shad.

Bioaccumulation of LMW PAHs from sediments by *Rhepoxynius abronius* (amphipod) and *Armandia brevis* (polychaete) was similar; however, a large difference in tissue concentration between these two species was measured for HMW PAHs, including benzo(a)pyrene. Meador et al. concluded that the LMW PAHs were available to both species from interstitial water, while sediment ingestion was a much more important uptake route for the HMW PAHs. The authors also indicated that bioavailability of the HMW PAHs to amphipods was significantly reduced due to their partitioning to dissolved organic carbon.

Studies with various shellfish show limited effects on mortality of development to at least 161 µg/kg. The concentrations found in the *M. nasuta* sample that were statistically significantly greater than in the reference were approximately 10 and 22 µg/kg.

Benzo(b)fluoranthene and Benzo(k)fluoranthene

The acute toxicity of hydrocarbons, including benzo(b)fluoranthene, to both freshwater and saltwater crustaceans is largely nonselective, i.e., it is not primarily influenced by molecular structure, but rather is controlled by organism-water partitioning which, for nonpolar organic chemicals, is in turn a reflection of aqueous solubility. The toxic effect is believed to occur at a relatively constant concentration within the organism.

Bioavailability of sediment-associated PAHs, e.g., benzo(b)fluoranthene, has been observed to decline with increased contact time. The majority of investigations have shown that aquatic organisms are able to release PAHs from their tissues rapidly when they were returned to a clean environment. The apparent effects threshold concentration of 4,500 ng/g was established for benzo(b)fluoranthene based on effects observed in the marine amphipod *Rhepoxynius abronius*.

Bioaccumulation of LMW PAHs from sediments by *Rhepoxynius abronius* (amphipod) and *Armandia brevis* (polychaete) was similar, however, a large difference in tissue concentration between these two species was measured for HMW PAHs, including benzo(b)fluoranthene. Meador et al. concluded that the LMW PAHs were available to both species from interstitial water, while sediment ingestion was a much more important uptake route for the HMW PAHs. The authors also indicated that the bioavailability of the HMW PAHs to amphipods was significantly reduced due to their partitioning to dissolved organic carbon.

The acute toxicity of hydrocarbons, including benzo(k)fluoranthene, to both freshwater and saltwater crustaceans is largely nonselective, i.e., it is not primarily influenced by molecular structure, but rather is controlled by organism-water partitioning which, for nonpolar organic chemicals, is in turn a reflection of aqueous solubility. The toxic effect is believed to occur at a relatively constant concentration within the organism.

The majority of investigations have shown that aquatic organisms are able to release PAHs, e.g., benzo(k)fluoranthene, from their tissues rapidly when they were returned to clean environment. The apparent effects threshold concentration of 4500 ng/g for benzo(k)fluoranthene was established based on effects observed in the marine amphipod *Rhepoxynius abronius*. Bioaccumulation of LMW PAHs from sediments by *Rhepoxynius abronius* (amphipod) and *Armandia brevis* (polychaete) was similar; however, a large difference in tissue concentration between these two species was measured for HMW PAHs, including benzo(k)fluoranthene. Meador et al. concluded that the LMW PAHs were available to both species from interstitial water, while sediment ingestion was a much more important uptake route for the HMW PAHs. The authors also indicated that bioavailability of the HMW PAHs to amphipods was significantly reduced due to their partitioning to dissolved organic carbon.

The effects threshold levels are not present in the available literature for these compounds.

Chrysene

The results from the laboratory experiments performed by Harkey indicated that accumulation of chrysene from elutriates was significantly lower than that from whole sediment, and the elutriate-sediment accumulations followed a downward curve over time. A similar curve was observed for pore-water-to-sediment accumulation ratios. The concentrations of chrysene in whole sediment and pore water were 34.2 ng/g and 0.305 mg/mL, respectively. Uptake rate coefficients for *Diporeia* spp. were highest in pore water (244.3 µg/g/hour) and lowest in elutriate (55.2 µg/g/hour). The authors concluded that aqueous extracts of whole sediment did not accurately represent the exposure observed in whole sediment.

When compared to the whole sediment, the aqueous extracts of whole sediment underexposed the organisms, even after adjusting accumulation to the fraction of organic carbon contained in the test media. While the total chrysene concentration in the sediment stayed constant, total concentration decreased appreciably in pore water and elutriate over the course of the exposure, and it is likely that the bioavailability concentrations in these media also decreased. Benthic amphipods, *Gammarus pulex*, exposed to sediments containing PAHs and water spiked with sediment extract from PAH-contaminated sediment accumulated chrysene in direct proportion to exposure concentrations.

Studies show no effective increase in mortality up to at least 2.6 mg/kg body weight. The levels found in the project samples had concentrations of 0.01 and 0.03 mg/kg.

Fluoranthene and Pyrene

Fluoranthene and pyrene are HMW PAHs. According to EPA (2000), PAHs are readily metabolized and excreted from live organisms. Concentrations at which mortal or physiological effects occur in similar species range from 513 to 4,248 mg/kg for individual PAHs.

For fluoranthene, physiological effects cited in EPA (2000) in *Mytilus edulis*, a bivalve species similar to *Macoma nasuta*, begin to occur at 0.112 mg/kg, which is approximately two to five times the concentration found in the project tissue samples.

For pyrene, physiological effects begin to occur at 189 mg/kg in *Mytilus edulis*. This concentration is about 2,700 to 5,400 times greater than that found in the project tissue samples.

Fluoranthene and pyrene are categorized as non-carcinogens. However, additional literature at http://www.nature.nps.gov/hazardssafety/toxic/pahs.pdf indicates that they are co-carcinogens, meaning that though neither is directly carcinogenic, they can enhance the effects of a contaminant that is carcinogenic.

Total PAHs

Although there do not appear to be any standard accepted criteria for levels of total PAHs ingested by humans (Agency for Toxic Substances and Disease Registry 1996), some previously proposed criteria were obtained from Eisler (1987). These criteria were derived from laboratory experiments using mice and rats. The proposed criteria are controversial due to the lack of a standard representative PAH mixture for test purposes, the difficulty in quantification of the health risks caused by the additive or synergistic effects of individual PAH analytes and other sources, and the paucity of data on the effects of chronic exposure. In addition, generalizations were made on the effects of total PAHs based heavily on data derived from the known effects of just one PAH analyte, benzo(a)pyrene. Lastly, wide variations exist in the capacity of humans and other animals to metabolize carcinogens using enzymes, and this interaction between enzymes and carcinogenic PAH analytes is the most significant process leading to carcinogenesis from PAHs (Eisler 1987). The recommended upper limit for the intake of food containing PAHs is 16 g/day or 4150 g/year, assuming a total food intake of 1600 g/day with an adult body mass of 70 kg and a total PAH concentration in the food of 1 to 10 µg/kg.

Although laboratory experiments using mice and rats have shown that both short-term and long-term PAH exposure can cause negative effects on the skin, body fluids, and immune system, these effects have not yet been well documented in humans. Similarly, although reproductive problems and birth defects in mice have been linked to the ingestion of high levels of PAHs, the effects of PAHs on human reproductive processes remain poorly understood. Despite the paucity of evidence showing a direct link between exposure to PAHs and health effects in humans, a percentage of people who have been chronically exposed to PAHs have developed cancer (Agency for Toxic Substances and Disease Registry 1996), and it is reasonable to assume that a correlation exists. Of the incidences of cancer among people with a history of chronic exposure, most involve either inhalation or topical adsorption as the primary exposure route; thus, the effects of PAH ingestion on humans is even more poorly known.

Because fishes are typically able to rapidly metabolize PAHs, concentrations of PAHs in fish tissues are usually low (Lawrence and Weber 1984, Eisler 1987). HMW PAHs do not appear to accumulate in fish tissue according to West et al. (1984), with the exception of benzo(a)pyrene, which is found in higher amounts in the skin tissue of fish than in other tissues (USEPA 1980). Thus, it appears that the consumption of fish may not be an important contributor of PAHs in humans. However, PAHs can be generated during the cooking or smoking process, and the ingestion of fish skin tissues may be a significant contributor of benzo(a)pyrene. It is important to note that the speed at which PAH metabolites are eliminated is dependent on water temperature and on the species of fish.

PAHs are much more toxic to crustaceans than they are to teleost (bony) fishes. In general, shellfish tend to metabolize PAHs much more slowly and to eliminate PAHs and PAH metabolites (some of which are toxic to other organisms and to people) slowly, compared to the speed of these processes in fishes. In most cases, PAH concentrations that are acutely toxic to aquatic organisms are several orders of magnitude higher than concentrations in sediments from most contaminated sites, and their limited bioavailability typically makes them significantly less toxic than PAHs in solution (Neff 1979).

6.5.4 Factor 5: Phylogenetic Diversity of the Species in Which Bioaccumulation for the Dredge Material Statistically Exceeded Bioaccumulation from the Reference Material

The species tested were *Macoma nasuta* and *Neanthes virens*, which are recommended in the Green Book and labeled as “Examples of Appropriate Test Species for Determining Potential Bioaccumulation from Whole Sediment Tests.” The basic recommendations include requirements that a burrowing polychaete and a deposit-feeding bivalve mollusk be tested. The test organisms are important in the region ecologically, represent species that provide adequate biomass for analysis, and are detritus feeders, which ingest sediments.

6.5.5 Factor 6: Propensity for the Contaminants with Statistically Significant Bioaccumulation to Biomagnify within Aquatic Food Webs

Beryllium

Information about the biomagnification of beryllium is not readily available in the literature (EPA 2000).

Copper

Little evidence exists to support the general occurrence of biomagnification of copper in the aquatic environment. Copper is taken up by aquatic organisms primarily through dietary exposure (EPA 2000).

Lead

Although lead is bioavailable to aquatic species, no evidence is presented that lead will biomagnify in aquatic environments (EPA 2000).

Nickel

Little evidence exists to support the general occurrence of biomagnification of nickel in the aquatic environment (EPA 2000).

Silver

Little evidence exists to support the general occurrence of biomagnification of silver within marine or freshwater food webs. Silver uptake by aquatic organisms appears to be almost entirely from the dissolved form. When silver was bound to algal cell membranes, it could not be dislodged by either mechanical disruption or leaching at low pH; therefore, silver bound to algal cells is likely unassimilable by higher organisms (EPA 2000).

Thallium

Information about the biomagnification of thallium is not readily available in the literature.

Zinc

Most studies reviewed contained data that suggest that zinc is not a highly mobile element in aquatic food webs, and there appears to be little evidence to support the general occurrence of biomagnification of zinc within marine or freshwater food webs. A log biomagnification factor of 2.90 was determined for the midge *Chironomus riparius* (EPA 2000).

Tributyltin

Biomagnification of TBT does not appear to be significant in aquatic systems. Although TBT is accumulated or concentrated to a very high degree in lower trophic level organisms, dietary uptake in higher trophic level organisms appears to be counteracted by biotransformation in the liver (EPA 2000).

Dioxins

No specific food chain multipliers were identified for 2,3,7,8-TCDF. Food chain multiplier information was only available for 2,3,7,8-TCDD. Biomagnification of 2,3,7,8-TCDD does not appear to be significant between fish and their prey. Limited data for the base of the Lake Ontario lake trout food chain indicated little or no biomagnification between zooplankton and forage fish. Biomagnification factors based on invertebrate species consumed by fish are probably close to 1.0 because of the 2,3,7,8-TCDD biotransformation by forage fish. Biomagnification factors greater than 1.0 might exist between some zooplankton species and their prey due to the lack of 2,3,7,8-TCDD biotransformation in invertebrates (EPA 2000).

Anthracene

Food chain multipliers for chrysene in aquatic organisms were not found in the literature (EPA 2000).

Benzo(a)anthracene

Food chain multipliers for chrysene in aquatic organisms were not found in the literature (EPA 2000).

Benzo(a)pyrene

Trophic transfer of benzo(a)pyrene metabolites has been demonstrated between polychaetes and bottom-feeding fish. The diatom *Thalassiosira pseudonana* cultured in 10 µg/L of benzo(a)pyrene and subsequently fed to larvae of the hard clam *Mercenaria mercenaria* accumulated 42.2 µg/g, while clams accumulated only 18.6 µg/g. The rate of direct uptake by the algae was thus approximately 20 times faster than the rate of trophic transfer. Dobroski and Epifanio concluded that direct uptake and trophic transfer (2 µg/g/day) are equally important in accumulation of benzo(a)pyrene (EPA 2000).

Benzo(b)fluoranthene

Food chain multipliers for benzo(b)fluoranthene in aquatic organisms were not found in the literature (EPA 2000).

Benzo(k)fluoranthene

An ecotoxicological in situ study conducted at the Baltic Sea showed that the tissue residue concentration of benzo(k)fluoranthene decreased with increasing trophic level. The relatively high theoretical flux through the food chain was not possible to detect (EPA 2000).

Chrysene

Food chain multipliers for chrysene in aquatic organisms were not found in the literature. Log bioaccumulation factor values found in the literature ranged from -0.68 for the clam *Macoma nasuta* to 4.31 for the amphipod *Pontoporeia hoyi* (EPA 2000).

Fluoranthene, Pyrene, and Total PAHs

PAHs are readily metabolized and excreted from living organisms, indicating low biomagnification effects in the environment.

6.5.6 Factor 7: Magnitude of Toxicity and Number and Phylogenetic Diversity of Species Exhibiting Greater Mortality in the DredgeMaterial Than in the Reference Material

Mortality in the project samples exceeded mortality in the reference sample in *Macoma nasuta* in sample SYC14-AC only. All other project samples had mortalities less than or equal to the reference. Mortality ranged from 0% to 2% in *N. virens* and from 7% to 9% in *Macoma nasuta*. These ranges include the mortality for the reference sediment as well as the project sediment.

6.5.7 Factor 8: Magnitude by Which Contaminants Whose Bioaccumulation from the Dredge Material Exceeds That from the Reference Material Also Exceed the Concentrations Found in Comparable Species Living in the Vicinity of the Proposed Disposal Site

Exhibit 22 shows the percentage of each sample and analyte that exceeded either the ecological effects threshold or the South Atlantic Bight background concentration. The value shown is the percentage of the concentration of the contaminant compared to the screening level, e.g., for copper in SYC14-AC compared to the ecological effects threshold, the value is 1865, which indicates that beryllium was 1865%, or 18.65 times the concentration in the reference. The actual concentrations for each project sample and the reference are shown in Exhibits 17 and 18. Where a range is given, such as the South Atlantic Bight background concentration for copper, the comparison was made using the lower of the two values.

Exhibit 22. Magnitude of Results that Exceeded Either the Ecological Effects Threshold or the South Atlantic Bight Background Concentration

Analyte	Species	Percent SYC14-AC Result of Eco. Effects Threshold / South Atlantic Bight Background		Eco. Effects Threshold	South Atlantic Bight Background
		SYC14-AC	SYC13-TB		
Copper	*M. nasuta*	1865/311	2325/388	0.2	1.2-2.9
Lead	*M. nasuta*	287/574	216/432	0.1	0.05-0.77
Zinc	*M. nasuta*	160/x	150/174	11.6	10-20
Total HMW PAHs	*M. nasuta*	x/127	x/287	x	60
Total PAHs	*M. nasuta*	0.2/60	1/129	40000	170
Benzo(a)anthracene	*M. nasuta*	x/60	x/155	x	<20
Benzo(a)pyrene	*M. nasuta*	x/50	x/110	x	<20
Benzo(b)fluoranthene	*M. nasuta*	x/115	x/245	x	<20
Chrysene	*M. nasuta*	x/50	x/145	x	<20
Fluoranthene	*M. nasuta*	307/135	727/320	8.8	<20
Pyrene	*M. nasuta*	x/175	x/345	x	<20
Dioxin/Furan TEQ (ng/kg)	*M. nasuta*	x/308	x/725	x	0.32-0.36
Zinc	*N. virens*	13200/198	9400/141	0.3	20-27
Dioxin/Furan TEQ (ng/kg)	*N. virens*	x/944	x/733	x	0.18-0.44

x = no value for the indicated analyte and screening criteria

6.5.8 Bioaccumulation Risk Assessment Modeling System (BRAMS)

Model runs were conducted to evaluate the potential for risks to human health and ecological health from PAHs of concern in the dredged sediment by using the BRAMS program modules BEST and Trophic Trace. Guidance was followed from the Trophic Trace users manual by von Stackelberg et al. (2004) and the BRAMS users guide by Baker and Vogel II (2012). Most of the recommended inputs for the mid-Atlantic region in ANAMAR (in review [BRAMS Program Modules, BEST and Trophic Trace: A Guide to Suggested Input Values by Region]) were used. Analyte-specific and project-specific input values are summarized and discussed below along with the results of each model run. Appendix A contains files for the BEST and Trophic Trace model runs.

6.5.8.1 Bioaccumulation Evaluation Screening Tool (BEST) Model

Invertebrate mean lipid concentrations were calculated from values in Tables 25 and 26 of ANAMAR (2014) for N. virens and M. nasuta. As recommended by EPA Region 4, lipid mean concentrations were used in place of sets of multiple lipid values for use in trapezoidal fuzzy number calculations.

Chemical parameters applicable to EPA Region 4 were imported into the model from MS Excel. Input values for the model predators and the mid-Atlantic resident seafood consumer remained unchanged from those of the mid-Atlantic region BEST template in ANAMAR (in review [BRAMS Program Modules, BEST and Trophic Trace: A Guide to Suggested Input Values by Region]) except that lipid concentrations were entered only as mean values. Mean lipid concentrations, in place of sets of values for use in trapezoidal fuzzy number calculations, were used for each of the four predator categories (mollusk, crustacean, finfish, shark) recommended by EPA Region 4.

A risk assessment was conducted separately using reference tissue concentrations. The results were then incorporated into the SYC14-TB risk assessment for comparison. A non-cancer risk threshold of 1 was used as recommended in the BRAMS users guide (Baker and Vogel II 2012). Although the BRAMS users guide also recommended a cancer risk threshold of 1 x 10^{-4}, a threshold value of 1 x 10^{-3} was recommended by EPA Region 1 and has been used previously by that region because of the conservative assumptions used in the BEST model. Based on the experience of EPA Region 1 in conducting risk evaluations for dredged sediment using BEST, the value of 1 x 10^{-3} was chosen as the cancer risk threshold for use in this project.

For the first model run, mean and maximum tissue analysis results for sample SYC14-TB were calculated from the five replicate samples and imported directly into the BEST model from MS Excel. A second run of the model was conducted after omitting tissue results for arsenic, based on arsenic found in the pre-exposure tissues. Results from the two models are presented in the exhibits below.

6.5.8.2 BEST Results Using All Tissue Analytes

Most of the maximum results of the BEST model run using all tissue analytes exceeded the cancer risk and non-cancer risk thresholds. However, the maximum results of the reference tissue concentrations met or exceeded that of the project sample (SYC14-TB) in every scenario. The results of bioaccumulation tests using M. nasuta tissue exceeded that from N. virens tissue for all categories of seafood consumer. Consuming shark resulted in higher levels of risk than consuming ocean quahog, shrimp, or marine finfish.

Overall, the results of the BEST model run using all analyte results in tissue suggest that, while there is cancer and non-cancer risk associated with disposal of SYC sediment in the ODMDS, the risk associated with the reference sediment is greater than that of the SYC sediment. Exhibit 23 summarizes maximum cancer and non-cancer risk using all analyte results in tissues for each category of seafood consumer.

Exhibit 23. Maximum Cancer and Non-Cancer Risk Values for Mid-Atlantic Seafood Consumers Based on BEST Model Run Using All Analyte Results

Consumer	Maximum Cancer Risk	Maximum Non-cancer Risk
Average Mid-Atlantic Resident Seafood Consumer		
Consuming ocean quahog	SYC14-TB: 0.00051 Reference: 0.0005	SYC14-TB: **1.05098** Reference: **1.05919**
Consuming shrimp	SYC14-TB: 0.00012 Reference: **0.0043**	SYC14-TB: 0.26377 Reference: 0.98425
Consuming finfish	SYC14-TB: 0.00096 Reference: **0.00327**	SYC14-TB: **2.13835** Reference: **7.52332**
Consuming shark	SYC14-TB: 0.00055 Reference: **0.01488**	SYC14-TB: **1.22191** Reference: **34.19691**
Male Mid-Atlantic Seafood Consumer, 20+ Years Old		
Consuming ocean quahog	SYC14-TB: 0.00048 Reference: 0.00047	SYC14-TB: **1.00338** Reference: **1.01122**
Consuming shrimp	SYC14-TB: 0.00011 Reference: 0.00041	SYC14-TB: 0.55483 Reference: 0.93967
Consuming finfish	SYC14-TB: 0.00092 Reference: **0.00313**	SYC14-TB: **2.04149** Reference: **7.18257**
Consuming shark	SYC14-TB: 0.00053 Reference: **0.0142**	SYC14-TB: **1.16657** Reference: **32.64803**
Female Mid-Atlantic Seafood Consumer, 20+ Years Old		
Consuming ocean quahog	SYC14-TB: 0.00025 Reference: 0.00024	SYC14-TB: 0.50993 Reference: 0.51392
Consuming shrimp	SYC14-TB: 0.0001 Reference: 0.00017	SYC14-TB: 0.22652 Reference: 0.38363
Consuming finfish	SYC14-TB: 0.00051 Reference: **0.00172**	SYC14-TB: **1.12596** Reference: **3.96146**
Consuming shark	SYC14-TB: 0.00027 Reference: **0.00738**	SYC14-TB: **3.30676** Reference: **16.96275**

Results in bold exceed either the cancer risk threshold (1 x 10^{-3}) recommended by EPA Region 1 or the non-cancer risk threshold (1) recommended in the BRAMS users guide (Baker and Vogal II 2012).

6.5.8.3 BEST Results Excluding Arsenic

A second BEST model run was conducted after excluding arsenic concentrations from the analysis to determine if much of the toxicity came from arsenic.

None of the maximum results of the BEST model run (excluding arsenic) exceeded the cancer risk threshold. Additionally, none of the results exceeded the non-cancer risk for the project sample. The maximum non-cancer risk values of the reference tissue exceeded those of the project sample in every scenario.

Overall, the results of the BEST model run excluding arsenic indicate that most of the health risk for sample SYC14-TB and the reference was due to arsenic concentrations found in the pre-exposure tissue. Exhibit 24 summarizes cancer and non-cancer risk (excluding arsenic) for each of the three seafood consumer categories.

Exhibit 24. Maximum Cancer and Non-Cancer Risk Values for Mid-Atlantic Seafood Consumers Based on BEST Model Run (Excluding Arsenic)

Consumer	Maximum Cancer Risk	Maximum Non-Cancer Risk
Average Mid-Atlantic Resident Seafood Consumer		
Consuming ocean quahog	SYC14-TB: 0.00002 Reference: 3.259 x 10^{-6}	SYC14-TB: 0.03854 Reference: 0.03881
Consuming shrimp	SYC14-TB: 0.00001 Reference: 2.958 x 10^{-6}	SYC14-TB.: 0.02416 Reference.: 0.0392
Consuming finfish	SYC14-TB: 0.00009 Reference: 0.00002	SYC14-TB.: 0.18122 Reference: 0.29961
Consuming shark	SYC14-TB: 0.00013 Reference: 0.0001	SYC14-TB: 0.27716 Reference: **1.36185**
Male Mid-Atlantic Seafood Consumer, 20+ Years Old		
Consuming ocean quahog	SYC14-TB: 0.00002 Reference: 3.112 x 10^{-6}	SYC14-TB: 0.0368 Reference: 0.03705
Consuming shrimp	SYC14-TB: 0.00001 Reference: 3.102 x 10^{-6}	SYC14-TB: 0.02307 Reference: 0.03742
Consuming finfish	SYC14-TB: 0.00001 Reference: 0.00002	SYC14-TB: 0.17301 Reference: 0.28604
Consuming shark	SYC14-TB: 0.00002 Reference: 0.00011	SYC14-TB: 0.2646 Reference: **1.30017**
Female Mid-Atlantic Seafood Consumer, 20+ Years Old		
Consuming ocean quahog	SYC14-TB: 9.705 x 10^{-6} Reference: 1.581 x 10^{-6}	SYC14-TB: 0.0187 Reference: 0.01883
Consuming shrimp	SYC14-TB:4.442 x 10^{-6} Reference: 1.153 x 10^{-6}	SYC14-TB: 0.00942 Reference: 0.01528
Consuming finfish	SYC14-TB: 0.00005 Reference: 0.00001	SYC14-TB: 0.09542 Reference: 0.15776
Consuming shark	SYC14-TB: 0.00006 Reference: 0.00005	SYC14-TB: 0.13748 Reference: 0.67552

Results in bold exceed either the cancer risk threshold (1 x 10^{-3}) recommended by EPA Region 1 or the non-cancer risk threshold (1) recommended in the BRAMS users guide (Baker and Vogal II 2012).

6.5.8.4 BEST Results with Pre-Exposure Arsenic Levels Only

Given that the non-cancer risk in the original run showed levels greater than the recommended upper limit of 1, the model was run again using only the concentration of arsenic in the pre-exposure tissue to demonstrate that the non-cancer risk from arsenic was already sufficiently high to exceed the model limits. The levels found in the pre-exposure samples for this project were comparable to levels found in past projects, and are also comparable to the background levels provided in Appendix H of the SERIM. These organisms are captured from the wild for use in the bioaccumulation procedure. In addition, the concentration found in *Neanthes virens* pre-exposure tissues was greater than the concentrations found in the project tissues, indicating that arsenic was higher in the animals' native environment than in the project sediment, and that the animals were able to purge arsenic from their system in the project sediment rather than increase the level in their system. If the arsenic is removed as shown in Exhibit 24, the non-cancer risk decreases to well below 1. Exhibit 25 shows the cancer and non-cancer risk using just the concentrations found in the pre-exposure tissues.

Exhibit 25. Maximum Cancer and Non-cancer Risk Values for -Mid-Atlantic Seafood Consumers Based on BEST Model Run Using Only Pre-Exposure Arsenic Levels

Consumer	Maximum Cancer Risk	Maximum Non-Cancer Risk
Average Mid-Atlantic Resident Seafood Consumer		
Consuming ocean quahog	Pre-exposure: 0.00042	Pre-exposure: 0.72128
Consuming shrimp	Pre-exposure: 0.00014	Pre-exposure: 0.30539
Consuming finfish	Pre-exposure: **0.00103**	Pre-exposure: **1.07863**
Consuming shark	Pre-exposure: **0.00158**	Pre-exposure: **3.50321**
Male Mid-Atlantic Seafood Consumer, 20+ Years Old		
Consuming ocean quahog	Pre-exposure: 0.0004	Pre-exposure: 0.68861
Consuming shrimp	Pre-exposure: 0.00013	Pre-exposure: 0.29156
Consuming finfish	Pre-exposure: 0.00098	Pre-exposure: **1.02977**
Consuming shark	Pre-exposure: **0.00151**	Pre-exposure: **3.34454**
Female Mid-Atlantic Seafood Consumer, 20+ Years Old		
Consuming ocean quahog	Pre-exposure: 0.0002	Pre-exposure: 0.34996
Consuming shrimp	Pre-exposure: 0.00005	Pre-exposure: 0.11903
Consuming finfish	Pre-exposure: 0.00054	Pre-exposure: **1.20611**
Consuming shark	Pre-exposure: 0.00078	Pre-exposure: **1.7377**

Results in bold exceed either the cancer risk threshold (1 x 10^{-3}) recommended by EPA Region 1 or the non-cancer risk threshold (1) recommended in the BRAMS users guide (Baker and Vogal II 2012).

Risk assessment modeling has only recently been used for projects within EPA Region 4, although EPA Region 1 appears to routinely use at least the BEST model. In May 2014, Anamar employed this approach with another project in the southeast on the Atlantic Coast (in that instance, Florida). Most of the results of the Florida project using the BEST model exceeded cancer and non-cancer risk thresholds. ANAMAR worked closely with EPA Region 4 to identify sources of toxicity and identified arsenic as the primary cause of much of the toxicity in the Florida samples. It has been well documented that high arsenic levels occur in the geology of the region, including Florida (Chen et al. 2001), and the source of the high levels of arsenic is natural deposits of phosphate rather than pollution (Vallette-Silver et al. 1999). Further, bioaccumulation of arsenic in marine fauna such as bivalves off Florida were due to natural deposits of phosphate (Vallette-Silver et al. 1999). The Florida samples did not exceed any risk thresholds with the BEST model once arsenic was excluded. EPA Region 4 later signed off on the sediment evaluation and the dredging permit was obtained.

6.5.8.5 Trophic Trace Model

Invertebrate lipid concentrations were taken from Tables 24 and 26 of ANAMAR (2014) for *N. virens* and *M. nasuta* and from Couturier et al. (2013) for all zooplankton. All predator parameters are those recommended for the mid-Atlantic region in ANAMAR (in review [BRAMS Program Modules, BEST and Trophic Trace: A Guide to Suggested Input Values by Region]) for use with the Charleston Harbor ODMDS.

The lowest available no observed adverse effects level (NOAEL) and lowest observed adverse effects level LOAEL input values were selected for predators in the Trophic Trace model. The lowest applicable concentration was chosen from the results of a literature search. Only endpoint values resulting from taxonomically relevant species were used. For example, only endpoints resulting from studies of crustaceans were used for the crustacean predators in the model. Endpoint values resulting from absorption or exposure to water were not used since the concentrations given as the NOAEL or LOAEL are those of the water rather than the concentration within tissue. The most applicable endpoint values appear to be those resulting from ingestion of the contaminant and from injection of the contaminant, since the NOAEL and (or) LOAEL values can be related to concentrations found in prey items rather than concentrations in the environment around the predator. The NOAELs and LOAELs used in the Trophic Trace modeling effort are indicated in Exhibit 26.

Exhibit 26. NOAEL and LOAEL Input Values for Predators in Trophic Trace Model Run

Predator Species	Chemical	Endpoint, Value (mg/kg)	Source, Notes
Ocean quahog	Fluoranthene	NOAEL: 1.29	Roper et al. (1997) in ERED, survival in *Dreissena polymorpha* via combined routes
Ocean quahog	Fluoranthene	LOAEL: 0.22	Ertman et al. (1995) in ERED, reproduction in *Mytilus edulis* via combined routes
Ocean quahog	Pyrene	NOAEL: 1.08	Roper et al. (1997) in ERED, survival in *Dreissena polymorpha* via combined routes
All crustaceans	Fluoranthene	NOAEL: 20.23	Lotufo (1998) in ERED, behavior in copepod *Coullana* sp. via combined routes
All crustaceans	Fluoranthene	LOAEL: 60.67	Lotufo (1998) in ERED, behavior in copepod *Coullana* sp. via combined routes
All crustaceans	Pyrene	NOAEL: 890	Landrum et al. (1994) in ERED, physiology in amphipod *Diporeia* spp. via combined routes
All fishes	Fluoranthene	NOAEL: 20	van der Weiden et al. (1994) in ERED, biochemistry in common carp via injection
All fishes	Pyrene	LOAEL: 20	van der Weiden et al. (1994) in ERED, biochemistry in common carp via injection
All fishes	Total PAHs	NOAEL: 0.38	Meador et al. (2006) in ERED, growth in juv. pink salmon via ingestion
Eggs of all (egg-laying) fishes	Total PAHs	NOAEL: 0.2	Heintz et al. (1999) in ERED, mortality in pink salmon embryos via combined routes
All birds	Pyrene	NOAEL: 434.4	Gurney et al. (2005), growth in mallard via combined routes

Cancer slope factors were available only for benzo(a)anthracene and benzo(b)fluoranthene (USEPA 2000, IRIS database [http://www.epa.gov/IRIS/]). Two cancer risk scenarios were generated for each of the remaining PAH analytes along with total LMW PAHs, total HMW PAHs, and total PAHs by using the slope factors for benzo(a)anthracene and benzo(b)pyrene (one of the most potent PAHs) for each PAH analyte and analyte group. The use of toxicity values from benzo(b)pyrene for PAH groups is a technique EPA has used in the past (Nisbet and LaGoy 1992). The resultant incremental lifetime cancer-risk values likely represent an overestimation of cancer risk and therefore should be viewed as a worst-case scenario.

Oral reference dose values were available for only acenaphthene, fluoranthene, and pyrene (USEPA 2000, IRIS database [http://www.epa.gov/IRIS/]). Oral reference dose inputs for the remaining PAHs were taken from pyrene and acenaphthene in order to represent the full range of reference values.

It is generally accepted that biota sediment accumulation factor (BSAF) values should be used based on the species of interest and should be site-specific whenever possible (Burkhard et al. 2010). However, taxa-specific and site-specific BSAF data for use with this project could not be found in the literature and experimentation to determine project-specific BSAF values for each analyte was beyond the scope of this sediment evaluation. Burkhard et al. (2010) instructed researchers to avoid the use of BSAF values near the extreme ends (very low or very high) relative to other BSAF values for a given analyte. Although BSAF values are given in Thorsen (2003) for individual PAH analytes as well as for LMW PAHs (as petrogenic-source PAHs) and

HMW PAHs (as pyrogenic-source PAHs), these BSAF values were applicable only to mussels and perhaps also to other bivalves. The Thorsen (2003) BSAF were not appropriate for this evaluation because the Trophic Trace model uses several non-bivalve taxa. A default BSAF value of 1.7 for hydrophobic organic contaminants was taken from von Stackelberg et al. (2004) and used for all PAHs.

Since most PAHs are hydrophobic, an octanol-water partition coefficient (K_{ow}) value was used in place of a BCF value as suggested by von Stackelberg et al. (2004). Analyte-specific K_{ow} and K_{oc} values were obtained from USEPA (2000), but values could not be found for total LMW PAHs, total HMW PAHs, and total PAHs. The K_{ow} and K_{oc} values were estimated for total LMW PAHs, total HMW PAHs, and total PAHs from K_{ow} and K_{oc} values for acenaphthene (the only LMW PAH to exceed screening benchmarks), a mean of the three HMW PAHs that exceeded benchmarks, and a mean of the five PAH analytes that exceeded benchmarks, respectively. Exhibits 27 and 28 summarize the analyte-specific and project-specific input values used in the Trophic Trace model run.

Exhibit 27. Analyte-Specific Chemical Input Values Used in theTrophic Trace Model Run

Parameter	Input Value(s)	Source(s), Notes
1-Methylnaphthalene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
2-Methylnaphthalene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Acenaphthene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Acenaphthylene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene

Parameter	Input Value(s)	Source(s), Notes
Anthracene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Benzo(a)anthracene	Cancer slope factor: 1.2 mg/kg/day Reference dose: 0.3, 0.6 mg/kg/day BSAF: 1.7 Log K_{ow}: 5.70 Log K_{oc}: 5.60 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004), Excel spreadsheet “BEST_Chemical_Inputs_Region4”; reference dose from pyrene and acenaphthene
Benzo(a)pyrene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 6.11 Log K_{oc}: 6.01 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Benzo(b)fluoranthene	Cancer slope factor: 1.2 mg/kg/day Reference dose: 0.3, 0.6 mg/kg/day BSAF: 1.7 Log K_{ow}: 6.20 Log K_{oc}: 6.09 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004), Excel spreadsheet “BEST_Chemical_Inputs_Region4”; reference dose from pyrene and acenaphthene
Benzo(g,h,i)perylene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 6.70 Log K_{oc}: 6.59 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Benzo(k)fluoranthene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 6.20 Log K_{oc}: 6.09 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Chrysene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 5.70 Log K_{oc}: 5.60 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene

Parameter	Input Value(s)	Source(s), Notes
Dibenzo(a,h)anthracene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Fluoranthene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.04 mg/kg/day BSAF: 1.7 Log K_{ow}: 5.12 Log K_{oc}: 5.03 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Fluorene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Indeno(1,2,3-cd)pyrene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Naphthalene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 3.92 Log K_{oc}: 3.85 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Phenanthrene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.06 mg/kg/day BSAF: 1.7 Log K_{ow}: 4.55 Log K_{oc}: 4.47 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004); cancer slope factors from benzo(a)anthracene and benzo(a)pyrene
Pyrene	Cancer slope factor: 1.2, 7.3 mg/kg/day Reference dose: 0.03 mg/kg/day BSAF: 1.7 Log K_{ow}: 5.11 Log K_{oc}: 6.01 L/kg of organic carbon	USEPA (2000), von Stackelberg et al. (2004), Excel spreadsheet “BEST_Chemical_Inputs_Region4”; cancer slope factors from benzo(a)anthracene and benzo(a)pyrene

Exhibit 28. Project-Specific ODMDS Environment and Chemical Inputs Used in the Trophic Trace Model Run

Parameter	Input Value(s)	Source, Notes
Total carbon in sediment (%)	0.065 (minimum) 0.27 (mean [Dam Neck ODMDS]) 1.0 (mean [New Wilmington Harbor ODMDS]) 1.33 (maximum)	USEPA (2010), unpublished data from Dam Neck ODMDS*
Dissolved carbon in water (mg/L)	0.60 (minimum) 0.63 (mean) 0.66 (maximum)	Pan et al. (2014)
Particulate carbon in water (mg/L)	4.8 (minimum) 6.5 (mean) 8.6 (maximum)	ANAMAR (2011) [TSS], Krismaswami and Lal (1977) [correlation coefficient]
Water temperature (°C)	4.2 (mean [Mar 1981, Norfolk ODMDS]) 13.9 (mean [Dec–May]) 24.1 (mean [Jun–Nov]) 28.3 (mean [100 max. values 2012–2013])	Alden et al. (1982), NOAA (2014a)
Chemical of concern table		
Total LMW PAHs	0.078 µg/kg	Table 6 of ANAMAR (2014), all concentrations are for total fraction in sediment (no data are available for PAHs in water) converted to mg/kg from µg/kg
Total HMW PAHs	0.572 µg/kg	
Total PAHs	0.998 µg/kg	
1-Methylnaphthalene	0.0023 mg/kg	
2-Methylnaphthalene	0.0037 mg/kg	
Acenaphthene	0.0027 mg/kg	
Acenaphthylene	0.024 mg/kg	
Anthracene	0.041 mg/kg	
Benzo(a)anthracene	0.081 mg/kg	
Benzo(a)pyrene	0.096 mg/kg	
Benzo(b)fluoranthene	0.15 mg/kg	
Benzo(g,h,i)perylene	0.057 mg/kg	
Benzo(k)fluoranthene	0.056 mg/kg	
Chrysene	0.11 mg/kg	
Dibenzo(a,h)anthracene	0.015 mg/kg	
Fluoranthene	0.13 mg/kg	
Fluorene	0.0068 mg/kg	
Indeno(1,2,3-cd)pyrene	0.061 mg/kg	
Naphthalene	0.0056 mg/kg	
Phenanthrene	0.016 mg/kg	
Pyrene	0.14 mg/kg	

* Data from Dam Neck was received 07/30/14 as raw laboratory data with a method reporting limit (MDL) of 0.13%, yet values below the MDL were reported. It was decided to treat values lower than the MDL as 0.5 x 0.13% = 0.065%. The mean and minimum TOC values from Dam Neck were calculated taking this into account.

Results of the risk assessment using PAH concentrations from sample SYC14-TB for the mid-Atlantic seafood consumer were within the acceptable ranges for cancer risk (≤1 x 10^{-4}) and non-cancer risk (≤1) as given by von Stackelberg et al. (2002, 2004) and Baker and Vogel II (2012), with the exception of total PAHs. Maximum incremental lifetime cancer risk was calculated at 0.00012 (for total PAHs) and maximum non-cancer risk was calculated at 0.00005 (for pyrene). If the alternate lifetime cancer risk value of 1 x 10^{-3} is used as discussed in Section 6.5.8.1, then no calculated value exceeds the risk threshold. Because there were no exceedances of the acceptable risk standards for any individual PAH and the result for total PAHs was only slightly above the acceptable standard under a worst-case scenario (0.00012 compared to 0.00010, assuming predators foraging exclusively at the ODMDS and consumers eating 100% contaminated seafood caught at the ODMDS), the results of the Trophic Trace model suggest that human health effects of ocean disposal of the dredged material would be minimal and are likely insignificant. Results of the human health risk assessment of the Trophic Trace model run are given in Exhibit 29.

Exhibit 29. Cancer and Non-cancer Risk from PAHs in Sample SYC14-TB for Mid-Atlantic Consumers Based on Trophic Trace Model Run (assuming that most predators use the site 100% of their lives)

Analyte	Incremental Lifetime Cancer Risk		Hazard Risk (Non-Cancer)	
Total PAHs	Min.:	2.969 x 10^{-8}	Min.:	3.668 x 10^{-8}
	Max.:	0.00012	Max.:	0.00005
Total LMW PAHs	Min.:	1.409 x 10^{-10}	Min.:	1.741 x 10^{-10}
	Max.:	9.47 x 10^{-8}	Max.:	1.652 x 10^{-7}
Total HMW PAHs	Min.:	2.052 x 10^{-8}	Min.:	2.535 x 10^{-8}
	Max.:	0.00009	Max.:	0.00004
1-Methylnaphthalene	Min.:	4.406 x 10^{-12}	Min.:	5.443 x 10^{-11}
	Max.:	1.139 x 10^{-8}	Max.:	2.313 x 10^{-8}
2-Methylnaphthalene	Min.:	7.088 x 10^{-12}	Min.:	8.756 x 10^{-11}
	Max.:	1.832 x 10^{-8}	Max.:	3.72 x 10^{-8}
Acenaphthene	Min.:	1.574 x 10^{-9}	Min.:	9.226 x 10^{-8}
	Max.:	1.578 x 10^{-7}	Max.:	3.204 x 10^{-7}
Acenaphthylene	Min.:	4.598 x 10^{-11}	Min.:	5.68 x 10^{-10}
	Max.:	2.767 x 10^{-8}	Max.:	2.413 x 10^{-7}
Anthracene	Min.:	7.854 x 10^{-11}	Min.:	9.703 x 10^{-10}
	Max.:	2.03 x 10^{-7}	Max.:	4.123 x 10^{-7}
Benzo(a)anthracene	Min.:	5.986 x 10^{-9}	Min.:	7.394 x 10^{-9}
	Max.:	4.992 x 10^{-6}	Max.:	0.00001
Benzo(a)pyrene	Min.:	1.223 x 10^{-8}	Min.:	1.511 x 10^{-7}
	Max.:	0.00009	Max.:	0.00018
Benzo(b)fluoranthene	Min.:	1.953 x 10^{-8}	Min.:	2.413 x 10^{-8}
	Max.:	0.00003	Max.:	0.00007
Benzo(g,h,i)perylene	Min.:	1.193 x 10^{-8}	Min.:	1.474 x 10^{-7}
	Max.:	0.00014	Max.:	0.00029
Benzo(k)fluoranthene	Min.:	7.877 x 10^{-9}	Min.:	9.731 x 10^{-8}
	Max.:	0.00006	Max.:	0.00013
Chrysene	Min.:	8.129 x 10^{-9}	Min.:	1.004 x 10^{-7}
	Max.:	0.00004	Max.:	0.00008

Analyte	**Incremental Lifetime Cancer Risk**		**Hazard Risk (Non-Cancer)**	
Dibenzo(a,h)anthracene	Min.:	2.873 x 10^{-11}	Min.:	3.55 x 10^{-10}
	Max.:	7.427 x 10^{-8}	Max.:	1.508 x 10^{-7}
Fluoranthene	Min.:	3.247 x 10^{-9}	Min.:	6.016 x 10^{-8}
	Max.:	0.00001	Max.:	0.00004
Fluorene	Min.:	1.303 x 10^{-11}	Min.:	1.609 x 10^{-10}
	Max.:	3.367E-8	Max.:	6.837 x 10^{-8}
Indeno(1,2,3-cd)pyrene	Min.:	1.169 x 10^{-10}	Min.:	1.444 x 10^{-9}
	Max.:	3.02 x 10^{-7}	Max.:	6.134 x 10^{-7}
Naphthalene	Min.:	1.073 x 10^{-11}	Min.:	1.325 x 10^{-10}
	Max.:	2.773 x 10^{-8}	Max.:	5.631 x 10^{-8}
Phenanthrene	Min.:	1.27 x 10^{-10}	Min.:	1.568 x 10^{-9}
	Max.:	3.471 x 10^{-7}	Max.:	7.049 x 10^{-7}
Pyrene	Min.:	3.661 x 10^{-9}	Min.:	9.045 x 10^{-8}
	Max.:	0.00001	Max.:	0.00005

The risk value results presented in Exhibit 29 were calculated from PAH concentrations in sample SYC14-TB along with quantitative values for parameters including those in Exhibits 27 and 28. The range of values for each analyte is due to fuzzy number arithmetic by the model using algorithms that conform to EPA and USACE guidance (Baker and Vogel II 2012). The use of fuzzy number calculations is a way of characterizing uncertainty from variability in parameters (von Stackelberg et al. 2004). Some parameters used in the Trophic Trace model for SYC14-TB have multiple numeric values to account for variability. Three values (triangular fuzzy numbers) are used to quantify parameters having a possible range of values along with a single most-likely value. An example of a triangular fuzzy number set is 0.60, 0.63, and 0.66 mg/L for dissolved carbon in water obtained from regional data in Pan et al. (2014). Four values (trapezoidal fuzzy numbers) are used to quantitatively describe parameters having a possible range and a most-likely range of values. An example of trapezoidal fuzzy numbers is 4.2°C, 13.9°C, 24.1°C, and 28.3°C for regional water temperature obtained from Alden et al. (1982) and NOAA (2014). Thus, minimum risk value results in Exhibit 29 for sample SYC14-TB were calculated by the model using the lowest values of fuzzy number sets. Maximum risk values of sample SYC14-TB are calculated using the highest values of fuzzy number sets.

Results in Exhibit 29 were based on a site use factor of 1 for most predators used in the model, meaning that these taxa were assumed by the model to spend their entire lives at the Charleston Harbor ODMDS. The only exception was for the Atlantic sharpnose shark which had a site use factor range of 0.6 to 0.8 (60% to 80% site use) to help account for the highly migratory habits of this wide-ranging and temperature-driven species (Castro 2011). Most species inhabiting the ODMDS spend early stages of their lives in habitats such as estuaries, and some also undertake seasonal migrations ranging over a relatively large area. Therefore, the site use factor of 1 represents a worst case scenario for use with this model. There are currently no alternative risk thresholds for use with Trophic Trace.

All results of the risk assessment for marine and avian predators were within the acceptable range for toxicity quotients (≤1), indicating no significant potential for adverse impacts to wildlife. The highest toxicity quotient was 0.70577 (for total PAHs in fish eggs). Results of the risk assessment for ocean quahog, crustaceans, fishes and fish eggs, and birds are given in Exhibit 30.

Exhibit 30. Ecological Risk for Ocean Quahog, Crustaceans, Fishes, and Birds Based on Trophic Trace Model Run

Analyte	NOAEL Toxicity Quotient	LOAEL Toxicity Quotient
Ocean Quahog		
Fluoranthene	Min.: 0.006 Max.: 0.11507	Min.: 0.0035 Max.: 0.67473
Pyrene	Min.: 0.00075 Max.: 0.14418	Data not available
Crustaceans		
Fluoranthene	Min.: 9.185×10^{-6} Max.: 0.00004	Min.: 5.501×10^{-6} Max.: 0.00004
Pyrene	Min.: 5.804×10^{-7} Max.: 2.549×10^{-6}	Data not available
Fishes		
Total PAHs	Min.: 0.0007 Max.: 0.24475	Data not available
Fluoranthene	Min.: $2..651 \times 10^{-6}$ Max.: 0.00089	Data not available
Pyrene	Data not available	Min.: 2.484×10^{-6} Max.: 0.00089
Fish Eggs (embryos)		
Total PAHs	Min.: 0.00307 Max.: 0.70577	Data not available
Birds		
Pyrene	Min.: 1.886×10^{-7} Max.: 4.384×10^{-6}	Data not available

6.6 Bioaccumulation Summary and Determination

The bioaccumulation potentials of contaminants were evaluated through a 28-day whole sediment exposure test using *M. nasuta* and *N. virens*. Samples from SYC were evaluated for target analytes including metals, PAHs, and organotins. No sample exceeded FDA action levels for the analytes and taxa tested. Analyte concentrations found to be statistically significantly greater in project samples than in the reference were further evaluated. Project sample tests having more than three replicate results below the MRL do not require assessment (as per Section 7.5.1 of the SERIM) and were not included in this sediment evaluation.

PAHs of concern in sample SYC14-TB were further evaluated through the BRAMS program using the BEST and Trophic Trace modules. Sample SYC14-TB was selected since it contained elevated PAHs. Final BEST results suggest that much of the toxicity in SYC14-TB is due to the presence of arsenic rather than the high PAH concentrations, and there is little or no health risk to the seafood consumer. Trophic Trace results indicate no non-cancer risk and very low cancer risk from ocean disposal of SYC sediment. Results of the Trophic Trace model run also indicated no significant potential for adverse impacts to wildlife. None of the compounds evaluated exceeded applicable FDA action levels. The information above indicates that concentrations of contaminants found in the material proposed for ocean disposal are not expected to have unacceptable effects on marine organisms or human health.

6.6.1 Risks to Human Health

The cancer risk assessment components of the BEST and Trophic Trace model runs indicate acceptable levels of risk for an average seafood consumer in South Carolina. The cancer risk sums that were estimated for this project are below the risk thresholds of 1×10^{-3} (for BEST results [recommended by EPA Region 4]) when arsenic was excluded. Most of the index risk values from Trophic Trace were below the 1×10^{-4} threshold recommended by von Stackelberg et al. (2002, 2004) and Baker and Vogel II (2012). In addition, this risk assessment was environmentally conservative, i.e., protective to human consumers. For example, the assumptions that a mid-Atlantic seafood consumer consumes bivalves, crab, finfish, and shark from the Charleston Harbor ODMDS every week of the year and that the predators feed exclusively on invertebrate prey at the disposal site, or ate other predators that consumed these invertebrates, overestimate true risk.

Furthermore, although South Carolina-caught seafood is available in most seafood markets of the state, a significant portion of the seafood available in South Carolina is imported from outside the state, including the northwestern Atlantic, northeastern Pacific, and aquaculture-raised products from Central America and Asia. Locally caught seafood is relatively expensive to purchase regularly, making it unlikely that the average seafood consumer will eat only fresh local seafood. It is also unlikely that most seafood consumers obtain their seafood by catching it themselves at the Charleston Harbor ODMDS given its distance from shore.

For these reasons, particularly considering the conservative nature of this risk assessment, these test results indicate that the dredge material does not have the potential for significant undesirable effects in humans. The results for this project indicate that non-carcinogenic risk also proved to be inconsequential for the human consumer, with all non-cancer risk values being below the threshold of 1 in BEST and Trophic Trace modeling scenarios.

6.6.2 Risks to the Local Ecology

Aquatic effects information resulting from a literature review indicate that the highest tissue levels accumulated in the dredged material bioaccumulation tests were below all relevant no-effects levels available. The concentrations of each steady-state-corrected contaminant accumulated in the *N. virens* and *M. nasuta* test organisms were found to be below potential effects levels.

A final step in the evaluative process goes beyond assessing the individual test results in order to look at the results as a whole to provide an opportunity for an integrated assessment of the individual test results.

The chemicals of concern that accumulated in the tissues of *N. virens* and *M. nasuta* test organisms in concentrations that exceeded those of the reference are indicated in the suitability determination. Although some of the contaminants that were bioaccumulated in the tests can be toxicologically important, in no case did they accumulate to toxicologically important concentrations, even when conservative assumptions were used to evaluate the test results, as described above. PAHs were all within acceptable aquatic and avian effects ranges using such conservative approaches and analyses as discussed previously in this sediment evaluation. The materials tested met the minimum acceptable levels for bioaccumulation criteria. Thus, an evaluation of the solid phase bioaccumulation test results for the dredged material as a whole considering the factors in the Green Book would not indicate a different outcome from that shown by the individual test results i.e., that the material does not have the potential for significant undesirable effects due to bioaccumulation.

Taking into account all of the above information, it is determined that there is no potential for significant undesirable effects due to bioaccumulation as a result of the presence of individual chemicals or of the solid phase of the dredged material as a whole. Therefore, it is concluded that the solid phase of the material proposed for disposal meets the ocean disposal requirements at 40 CFR §227.6(c)(3) and §227.27(b).

7 NON-TESTING-RELATED REGULATORY ISSUES: SUBPARTS B, C, D, AND E OF 40 CFR PART 227

7.1 Compliance with 40 CFR Part 227 Subpart B-Environmental Impact

7.1.1 40 CFR §227.4 Criteria for Evaluation Environmental Impact

The applicable prohibitions, limits, and conditions set forth in 40 CFR §227.4 have been satisfied as described in Sections 4 through 6 of this evaluation on elutriate, suspended particulate, and benthic determinations.

7.1.2 40 CFR §227.5 Prohibited Materials

The proposed dredge material has been evaluated and found to meet the criteria of the ocean dumping regulations. The material approved for disposal does not contain any of the following prohibited items:

- High-level radioactive waste;
- Material used for radiological, chemical, or biological warfare;
- Materials whose composition and properties have been insufficiently described to enable application of 40 CFR Part 227 Subpart b;
- Inert synthetic or natural materials that may float or remain in suspension so as to materially interfere with fishing, navigation, or other use of the ocean;
- Medical waste as prohibited by MPRSA §102(a).

7.1.3 40 CFR §227.7 Limits Established for Specific Wastes or Waste Constituents

The material to be disposed of has been evaluated, and it has been determined that the constituents listed in this section (pathogens, biological pests, and non-indigenous species) are not present other than in trace amounts as described in Sections 4 through 6 of this evaluation.

7.1.4 40 CFR §227.9 Limitations on Quantities of Waste Materials

40 CFR §227.9 provides that substances that may cause damage to the ocean environment due to the quantities in which they are dumped, or that may seriously reduce amenities, may be dumped only when the quantities to be dumped at a single time and place are controlled to prevent long-term damage to the environment or amenities.

Based on the scenarios described in Section 4.3 of this evaluation, the proposed dredge material would not result in long-term damage to amenities or the environment due to the quantities and locations in which it would be dumped. The material would be disposed of at the Charleston ODMDS.

The proposed dredge material has been tested and found to meet the requirements of 40 CFR §227.6 and §227.27 as described in Sections 4 through 6 of this evaluation. In addition, disposal operations will be managed to ensure that dumping takes place within the site boundaries in accordance with the current Charleston ODMDS SMMP by USEPA and USACE. It is concluded that the proposed disposal would not cause long-term damage to amenities or the environment due to the quantities in which the sediment would be dumped.

7.1.5 40 CFR §227.10 Hazards to Fishing, Navigation, Shorelines, or Beaches

With regard to the disposal of dredged material, 40 CFR §227.10 states that the site and conditions must be such that there is no unacceptable interference to fishing or navigation, and no unacceptable danger to shorelines or beaches may result from dredged material disposal. The project sediments proposed for dumping would not interfere with fishing or navigation or pose unacceptable danger to shorelines or beaches. The Environmental Impact Statement and site designation for the Charleston Harbor ODMDS by USEPA (1983), and information previously outlined in this report, fully support compliance of the project sediments with 40 CFR §227.10.

7.2 Compliance with 40 CFR Part 227, Subpart C - Need for Ocean Dumping

Shipyard Creek, LLC is a private entity desiring EPA concurrence and a USACE permit for offshore disposal of dredged material. Prior testing and application for an upland disposal permit was not approved due to capacity issues in the proposed confined disposal facility. The final determination on whether to grant the permit will be made in the USACE Statement of Findings.

7.3 Compliance with Part 227, Subpart D - Impact of the Proposed Dumping on Aesthetic, Recreational, and Economic Values

40 CFR Part 227 Subpart D sets forth the factors to be considered when evaluating the impact of proposed dumping on aesthetic, recreational, and economic values, including the potential for affecting recreational and commercial uses and values of living marine resources.

The factors specifically considered include recreation and commercial uses; water quality; the nature and extent of disposal operations; visible characteristics of the material to be disposed of; and the presence of pathogens, toxic chemicals, bioaccumulative chemicals, or any other constituent that can affect living marine resources of recreational or commercial value. These factors would be used in an overall assessment of the proposed dumping on aesthetic, recreational, or economic values and possible alternative methods of disposal or recycling. See 40 CFR §§227.17–19, excerpted below.

i. Referencing the Environmental Impact Statement for Canaveral Harbor

Chapter 2 of the *Environmental Impact Statement (EIS) for Savannah, GA, Charleston, SC, and Wilmington, NC, Ocean Dredged Material Disposal Site Designation* by USEPA (1983) discusses the potential impacts of disposal on recreational and commercial fisheries, shore-based recreation, and cultural resources. The only items above that need to be specifically addressed in this document are the visible characteristics of the material and the possible presence of pathogens.

ii. Visible Characteristics

Both dredging units tested were determined to be primarily silt and clay (ANAMAR 2014). Given that the material will be disposed of in the ODMDS and out of sight of most citizens, adverse impacts to the aesthetics of the area are not expected to occur.

iii. Presence of Toxins and Bioaccumulative Chemicals

Potential toxic substances and bioaccumulative chemicals are addressed in Section 6 above.

iv. Presence of Pathogens

There are no known sources of potential pathogens as presented in 40 CFR §227.7 that could specifically impact the project sediments. Limits on pathogens are briefly discussed in Section 7.1.3 above. 40 CFR §227.7(c) contains a larger discussion of pathogens and dredge material.

7.4 Compliance with Part 227, Subpart E - Impact of the Proposed Dumping on Other Uses of the Ocean

40 CFR Part 227 Subpart E sets forth the factors to be considered in evaluating the impacts of the proposed dumping on other uses of the ocean, including long-range impacts. Specifically, the uses considered include, but are not limited to, commercial and recreational fishing in open-ocean areas, coastal areas, and estuarine areas; recreation and commercial navigation; actual or anticipated exploitation of living and non-living marine resources; and scientific research and study. An overall assessment of the proposed dumping on the temporary and long-range effects on other uses of the ocean would include irreversible or irretrievable commitment of resources that would likely result from the proposed dumping.

8 MPRSA SECTION 103 PERMIT CONDITIONS

The MPRSA Section 103 report written by ANAMAR (2013) provides conditions to ensure that disposal will be in compliance with the Charleston Harbor ODMDS SMMP (USEPA and USACE 2012). Additional conditions, listed below, were taken from the SMMP.

- A hopper, cutter, or mechanical dredge can be used
- Disposal of material must not exceed 9,000 cy using a hopper or cutter or mechanical dredge
- Disposal location must be no less than 330 feet inside the ODMDS boundaries in accordance with 40 CFR §227.28
- Disposal vessel speed and operation must be in compliance with the most recent USACE South Atlantic Division Endangered Species Act Section 7 consultation regional biological opinion for dredging of channels and borrow areas in the southeastern United States
- Post-disposal bathymetric survey must occur within 30 days of project completion
- Biannual bathymetric survey of the entire ODMDS must occur
- Monitoring and recording of disposal locations are necessary
- Disposal summary report due within 90 days following project completion
- Additional generic special permit conditions are found in Appendix C of the SMMP

9 DETERMINATION

The proposed project is not expected to significantly degrade or endanger human health, welfare, or amenities; the marine environment; ecological systems; or economic potential. There is limited available local upland disposal capacity.

The proposed new work material for SYC was found to be acceptable for ocean disposal.

The proposed action is in compliance with the requirements of 40 CFR Parts 220–227 and may be implemented.

Charleston District MPRSA Section 103 Coordination:

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Robin Socha

10 REFERENCES

Note: References from the Environmental Residue Effects Database (ERED) can be found at http://el.erdc.usace.army.mil/ered/Bibliography.cfm?EREDRef=Y.

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