ENVIRONMENTAL IMPACT STATEMENT APPENDIX M: Sediment Quality Evaluation

SAVANNAH HARBOR EXPANSION PROJECT

Chatham County, Georgia and Jasper County, South Carolina

January 2012

(Revised July 2012)

US Army Corps of Engineers
Savannah District
South Atlantic Division

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Sediment Quality Evaluation

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Executive Summary

Savannah District has prepared a sediment quality evaluation assessing potential contaminant impacts associated with the proposed Savannah Harbor Expansion Project (SHEP). The evaluation also establishes whether management actions need to be taken to ensure the proposed placement of project sediments within the dredged material containment areas (DMCAs) would occur in a manner protective of human health and the environment. The evaluation followed tiered approach guidance prepared jointly by the US Army Corps of Engineers and the US Environmental Protection Agency.

The evaluation reviewed and summarized the findings of a number of sediment quality investigations/assessments performed for the SHEP. The effort began with a broad look at potential contaminants and used the tiered approach to identity potential contaminants of concern for the project sediments.

In 1997, sediment core samples were collected and examined for sediment physical and chemical properties. The sampling area covered the entire area proposed for harbor deepening, extending from deep water in the ocean to the Kings Island Turning Basin (Station 103+000). Parameters investigated included metals, PCBs, PAHs, petroleum hydrocarbons, phenols, pesticides, dioxin congeners, cyanide, organotins, and nutrients.

The evaluation found that most of the sediments provided no reason for concern over potential contaminant-related impacts associated with the proposed dredging and dredged sediment placement. However, three potential issues were identified.

One issue involved sediments near the old RACON Tower site. Subsequent sampling conducted in 2005 revealed that sediments at that location do not pose potential for contaminant-related environmental impacts.

The second issue pertained mostly to whether the sediment chemistry data for pesticides, PAHs and phenols, especially achieved detection limits, were adequate for comparison to screening criteria. This issue was addressed during the 2005 sampling. The confirmatory sampling within the channel revealed there was no potential sediment contaminant concerns related to pesticides, PAHs, phenols, or metals other than cadmium.

The final issue involved the concentration and distribution of cadmium within the new work sediments. Sampling was conducted in 2005 to address this issue. Cadmium was found to occur naturally in unusually high levels within Miocene clays that would be

excavated during the SHEP dredging. Evaluation of the laboratory results could not rule out the potential for adverse impacts from sediments with elevated cadmium levels in some reaches of the channel.

Therefore, additional sampling and detailed analyses were conducted in 2007. The potential pathways by which cadmium might enter the environment were evaluated. Pathways of particular concern were identified to be exposure of cadmium-containing clays within the channel with subsequent movement of cadmium into the river ecosystem, and potential environmental impacts associated with placement of cadmium-containing sediments within the DMCAs.

The detailed Tier III studies in 2007 included the following:

- Sediment Profile Imaging to locate/verify exposed Miocene clays and assess the potential existence of benthic communities in the clay;
- Side scan sonar survey to identify and map bottom characteristics in the channel;
- Benthic community assessment;
- Sediment sample collection (vibracoring 6 ft into Miocene clay at four locations in the navigation channel, reference sediment sampling, and upland reference soil sampling);
- Collecting dredging water from one location in the Federal navigation channel and one receiving water location in Fields Cut;
- Compositing and processing sediment cores to create “high cadmium” and “low cadmium” composite samples for further testing;
- Analytical testing of bulk sediment, standard elutriates, effluent elutriates, dredging water, and receiving water samples;
- Analytical testing of porewater and SLRP samples at the high cadmium locations only;
- Aquatic bioaccumulation studies and plant uptake studies using high and low cadmium composites; and
- Risk evaluation and report preparation.

These studies found that sediments with a minimum cadmium concentration of about 29.8 ppm could potentially produce environmental impacts to birds feeding 100 percent of the time in these sediments. These studies also found when these wet sediments are dried, cadmium becomes much more mobile, with cadmium concentrations as low as 14 ppm potentially causing environmental impacts.

The evaluations concluded that SHEP project sediments from Stations +90+000 to +80+125, +57+000 to 51+000, and +45+000 to +6+375 (found to contain layers averaging 14 ppm cadmium or greater) should be isolated within the DMCAs and covered with other new work sediment to ensure they are not exposed to the environment. This procedure would ensure the sediments stay moist and are not relocated for use as dike raising materials, since that action would cause the sediments to dry and the cadmium to become mobile. Sediments from other reaches, including the bar channel, averaged from <1 to <5 ppm cadmium and were found to present minimal risk to the environment and therefore not require special management when placed in a

DMCA. The results of these assessments show there should be no contaminant-related concerns associated with placement of bar channel sediments in the nearshore. However, placement of dredged material into the nearshore sites has been removed from the project. .

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Sediment Quality Evaluation

Savannah Harbor Expansion Project (SHEP)

1.0 Introduction

This sediment quality evaluation was conducted to assess potential contaminant-related impacts associated with the proposed Savannah Harbor Expansion Project (SHEP). This evaluation considers sediments to be removed throughout the entire extent of the project and proposed sediment placement alternatives, and determines whether management actions need to be taken to place those sediments within the dredged material containment areas (DMCAs)/dredged material confined disposal facilities (CDFs) under the jurisdiction of the Savannah District of the US Army Corps of Engineers to ensure protection of human health and the environment. This report follows tiered approach guidance contained in the *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore, or Upland Confined Disposal Facilities – Testing Manual* (UTM) prepared jointly by the US Army Corps of Engineers and the US Environmental Protection Agency (USACE 2003).

This evaluation reviews and summarizes the findings of a number of sediment quality investigations/assessments performed for the SHEP. These investigations/assessments include:

1. Sediment sampling in 1997 by ATM (Applied Technology and Management). Dredged Material Environmental Effects Evaluation, Savannah Harbor Deepening. Prepared by Applied Technology and Management, Inc., for the Georgia Ports Authority, Final Draft, April 22, 1998 (ATM, 1998).

2. 2005 sampling by CESAS, including grab samples at the RACON tower site, and channel cores divided into 2-ft lifts.

3. TCLP procedures conducted on archived 2005 samples (contracted out by CESAS-EN in 2006).

4. Savannah Harbor Expansion Dredged Material Evaluation, Phase 1, Draft. CESAM-PD-EC, February 2006, PD-EC 2006a.

5. Savannah Harbor Expansion Dredged Material Evaluation Screening Analysis to Evaluate Potential Environmental Impacts of Cadmium. ERDC, July 06

6. Conceptual Model developed by CESAM-PD-EC in 2006, PD-EC, 2006b.

7. Ecological Risk Assessment by CENWO-HX-S, June 2006.

8. Human Health Risk Assessment by CENWO-HX-S, 2006.

9. Assessment of Wet Sediment Leachate and Potential Groundwater Interactions within Confined Disposal Facilities, Potential for Wet Sediments to Impact the Upper Floridan Aquifer, CESAS-EN-GG, 2 Aug 06.

10. Sediment Quality Evaluation Phase II – Cadmium, for Savannah Harbor Expansion Project, CESAM-PD-EC, 1 Sept 06, PD-EC 2006c, and 7 Sep 2006 Addendum, PD-EC 2006d.

11. Results of pore water analyses on two samples taken from the high cadmium stations (Stations +26+000 and +26+500) 2006 and analyzed by USGS, USGS Memorandum, 27 March 2007.

12. 2007 sampling by EA (EA Engineering, Science, and Technology). Savannah Harbor Expansion Project Phase II Sediment Evaluation, Savannah, GA. Prepared for the U.S. Army Corps of Engineers, Savannah District by EA Engineering, Science, and Technology, Sparks, MD, January 2008 (EA, 2008).

These studies began with a broad look at potential contaminants and used the tiered approach to identity contaminants of concern for the Savannah Harbor Expansion Project (SHEP). Cadmium was identified as the only contaminant of concern and was found to occur naturally in unusually high levels within Miocene clays that would be excavated during the SHEP dredging. All of the potential pathways by which cadmium might enter the environment were evaluated. Pathways of particular concern were identified to be exposure of cadmium containing clays within the channel with subsequent movement of cadmium into the river ecosystem, and potential environmental impacts associated with placement of cadmium containing sediments within the DMCAs/CDFs. Primary potential DMCA impacts were identified to be worker exposure, leachate and groundwater impacts, and movement of cadmium to wildlife that inhabit the confined disposal facilities.

The potential availability of cadmium and conditions under which cadmium might be released from the clay substrate were found to be determinate factors driving potential environmental impacts. When the Miocene clays are in a wet environment, release of cadmium was found to be minimal. Therefore, risks to the river aquatic ecosystem are expected to be minimal and risks to the aquatic environment within the DMCAs are expected to be minimal with the exception of birds feeding 100 percent of the time within a DMCA. Movement of cadmium to groundwater is also expected to be minimal. Cadmium was found to be much more available in dried and oxidized sediment, conditions expected to occur if the sediments are placed in a DMCA, allowed to dry, and later used to raise dikes in the manner of the District's normal maintenance operations.

Potential environmental risks associated with sediments containing about 4.6 ppm cadmium were found to be minimal, whereas potential impacts associated with dried sediments containing about 14 ppm cadmium could not be discounted.

Therefore, it is recommended that SHEP new work sediments from Stations +90+000 to +80+125, +57+000 to 51+000, and +45+000 to +6+375 (found to contain layers averaging 14 ppm cadmium or greater) be isolated within the DMCAs and covered with sediment in a manner that will ensure they are not exposed to the environment. This procedure would ensure the sediments stay isolated and are not relocated for subsequent use as dike raising materials. Such sediments placed on the dikes would be expected to dry and the cadmium become mobile. Sediments from other reaches (averaging from <1 to <5 ppm cadmium) are found to present minimal risk to the environment and do not require special management.

The remainder of this evaluation reviews data and evaluations from the above mentioned reports, describes the process by which contaminants of concern were narrowed to cadmium, and presents justification for the recommended management technique.

2.0 Background: Determination of Contaminants of Concern

2.1 Radiological Screening

The project area is located downstream from the Savannah River Site, where radioactive materials are processed. Releases of radioactive materials from the site have been documented over the years, raising concern as to whether such releases could cause accumulation of these materials within the sediments that are to be removed from the project area. The likelihood of this occurring has been considered improbable; nevertheless, a decision was made to screen selected sediment samples that were collected during the 2002 investigations for gross radioactivity.

All results were measured in milli-Rems per hour (mRem/hr). Background values varied between 0.01 and 0.03 mRem/hr. Values from the sediment samples ranged from 0.02 to 0.04 mRem/hr. These results are consistent with background values, with only a few samples exhibiting an increase of 0.01 mRem/hr over the background range. The slight increase in some samples was expected, as the soils encountered are known to contain phosphatic and glauconitic minerals, along with other clays, that exhibit naturally-occurring radiation levels above background. The results are two magnitudes below acceptable action levels approved by OSHA and the EPA that range between 1 mRem/hr and 5mRem/hr. Based on these results, it is believed that the levels of gross radioactivity measured in the samples is naturally occurring and poses no hazard to the environment. The complete report is included as part of the *Dredged Material Physical Analysis Report* included in the Engineering Investigations Supplemental Materials C.2.4.c.

2.2 Phase 1, Tier 1 EIS

In 1997, as part of the Tier 1 EIS process, approximately 31 sediment core samples for sediment physical and chemical evaluation were taken from the channel and bend widener new work material and most of the core samples contained sufficient sediment for analyses. The sampling area covered the entire area proposed for harbor deepening at that time. It extended from deep water in the ocean (Station -60+000B) to the Kings Island Turning Basin (Station 103+000). Parameters investigated included metals, PCBs, PAHs, petroleum hydrocarbons, phenols, pesticides, dioxin congeners, cyanide, organotins, and nutrients. Results of these investigations were reported as part of the 1998 Tier I EIS for the Expansion Project and the April 23, 1998 "Dredged Material Environmental Effects Evaluation, Savannah Harbor Deepening", prepared by ATM for the Georgia Ports Authority (ATM, 1998). That study also included a review of previous sediment testing in Savannah Harbor. The results for metals from that study are shown in Tables 1 to 4, below. Table 5 shows relevant marine sediment screening criteria.

Table 1. Metal Sediment Concentrations Kings Island (Station +103) to Talmadge Bridge (Station +79) Sampled 1997, dry wt.mg/kg (ATM, 1998)

Sample No.	103NW	T01NW	095NW	090NW	085NW	080NW	W01NW	W02NW
Stations *	103	99.5	95	90	85	80	102.5	88.2
Aluminum	16000	6410	6860	22500	6050	6070	1930	7750
Iron	25600	16000	14600	21200	12700	9530	6240	11300
Antimony	<4.8	<3.2	<2.7	<3.8	<2.9	<2.9	<3.8	<2.6
Arsenic	10	5	3	9.9	5.3	1.6	<1.9	2.7
Beryllium	<1.2	<0.79	<0.68	1.3	<0.72	<0.74	<0.94	<0.66
Cadmium	*<0.7*	0.7	<0.4	8.5	5.5	5.1	<0.6	<0.4
Chromium	39.6	22.7	19.9	*162*	33.7	36.3	4.8	13.4
Copper	14.7	12.2	8.3	16.6	6.3	3.8	<4.7	6.1
Lead	15.8	5.6	3.1	5.8	3	2.3	2.1	7.8
Manganese	808	223	148	189	413	361	233	160
Mercury(7471)	0.07	<0.016	<0.014	<0.019	<0.014	<0.015	0.02	0.1
Nickel	12	13.8	10.8	*30.8*	11.2	7.4	<2.8	4
Selenium	<2.4	<1.65	<1.4	<2.2	<1.4	<1.5	<1.9	<1.3
Silver	<0.48	<0.32	<0.27	<0.38	<0.29	<0.29	<0.38	<0.26
Thallium	<0.48	<0.32	<0.27	<0.38	<0.29	<0.29	<0.26	<0.26
Zinc	72.2	44.4	34.4	95.3	49.3	34.5	10.4	20.2

* Stations in 1000's feet above Station 0+000.

Table 2. Metal Sediment Concentrations Talmadge Bridge (Station +79) to Elba Island (Station +50) Sampled 1997, dry wt. mg/kg (ATM, 1998)

Sample No.	075NW	W03NW	W04NW	C07NW	W05NW	W06NW
Station*	75	77	71	65	54	50.8
Aluminum	4200	26700	21500	17200	10300	15100
Iron	8400	32200	30700	17100	14400	21500
Antimony	<3.2	<5.1	<5.9	<3.4	<4.2	<4.3
Arsenic	3.6	*15.8*	*14.5*	*9.5*	*7.8*	*10.4*
Beryllium	<0.81	<1.3	<1.5	<0.94	<1.00	<1.1
Cadmium	<0.5	*<0.8*	<0.9	4.7	2.5	<0.7
Chromium	12.3	51.1	15.6	*63.6*	24.2	33.8
Copper	4.5	17.5	14.6	11.9	6.3	11.5
Lead	7.2	24.5	20.1	12.5	8.1	16.6
Manganese	311	860	998	338	376	426
Mercury(7471)	0.02	<0.26	<0.029	<0.017	0.03	0.05
Nickel	4.1	15.9	13.2	15.9	6.9	9.1
Selenium	<1.6	<2.6	<2.9	<1.7	<2.1	<2.2
Silver	<0.32	<0.51	<0.59	<0.34	<0.42	<0.43
Thallium(7841)	<0.32	<0.51	<0.59	<0.34	<0.42	<0.43
Zinc	26.4	90.7	80.3	13.6	43.6	45.2

* Stations in 1000's feet above Station 0+000.

Table 3. Metal Concentrations Elba Island (Station +50) to Mouth of Harbor (Station 0+000) (ATM, 1998)

Sample No.	W07NW	045NW	W08NW	W09NW	015NW	W10NW	005NW
Stations*	46.2	45	35.2	29.2	15	10.6	5
Aluminum	5520	1100	13600	13100	8220	3390	2290
Iron	11500	8370	20500	17500	16600	6650	4030
Antimony	<3.2	<2.4	<4.5	<3.4	<3.4	<3.1	<2.6
Arsenic	5.7	3.7	*11*.4	9.9	7	4.1	2.9
Beryllium	<0.81	<0.59	<1.1	<1.0	1.1	<0.77	<0.65
Cadmium	<0.5	<0.4	*<1.1*	*<0.9*	*<0.9*	<0.5	0.48
Chromium	15.1	4.8	32.6	29.4	23.6	9.6	17.9
Copper	<4.0	<2.9	9.2	9	5.9	<3.8	<3.2
Lead	5.4	1.2	14.9	11.2	10	4.2	1.9
Manganese	275	38.4	488	252	297	140	58.9
Mercury(7471)	<0.016	0.01	0.13	<0.017	<0.017	<0.015	<0.013
Nickel	4.3	3.4	9	10.3	9	2.3	5
Selenium	<1.6	<1.2	<2.3	<1.7	<1.7	<1.5	<12.3
Silver	<0.32	<0.24	<0.45	<0.34	<0.34	<0.31	<0.26
Thallium(7841)	<0.32	<0.24	<0.45	<0.34	<0.34	<0.31	<0.26
Zinc	18.5	9.6	42.1	69.5	36.4	13.6	12.6

* Stations in 1000's feet above Station 0+000.

Table 4. Metal Concentrations in the Bar Channel (ATM, 1998)

Sample No.	005NW	015NW	W01NW	W02NW	035NW	075NW
Stations*	-5	-15	-19	-39.5	-35	-75
Aluminum	2510	2780	11300	1200	3020	3830
Iron	2600	2840	18100	2910	4600	3650
Antimony	<2.7	<2.7	<3.1	<2.5	<2.7	<2.6
Arsenic	3.3	3.4	*8.7*	3.6	6.4	12
Beryllium	<0.67	<0.68	<0.78	<0.62	<0.68	<0.64
Cadmium	0.68	*1.5*	<0.5	<0.4	<0.4	**24.3**
Chromium	20.2	39.4	20	7.1	9.2	35.9
Copper	3.9	5.6	8.1	<3.1	<3.4	5.5
Lead	1.3	1.7	11.3	1.8	2.9	2.3
Manganese	25.2	13.9	436	33.6	63	38.4
Mercury(7471)	<0.013	<0.014	0.04	<0.012	<0.014	0.04
Nickel	6.8	8.9	5.9	1.9	3.1	9
Selenium	<1.3	<1.4	<1.6	<1.2	<1.4	<1.3
Silver	<0.27	<0.27	<0.31	<0.25	<0.27	<0.26
Thallium(7841)	<0.27	<0.27	<0.31	<0.25	<0.27	<0.27
Zinc	12.2	16.3	26.3	8	10.1	51.4

* Stations in 1000's feet above Station 0+000.

Table 5. Sediment Screening Criteria (mg/kg), from Buchman, 1999

	TEL	ERL	ERM	AET
Aluminum				1800
Iron				220000
Antimony				9.3
Arsenic	7.2	8.2	70	35
Beryllium				
Cadmium	0.68	1.2	9.6	3
Chromium	52.3	81	370	62
Copper	18.7	34	270	390
Lead	30.2	46.7	218	400
Manganese				260000
Mercury(7471)	0.13	0.15	0.71	0.41
Nickel	15.9	20.9	51.6	110
Selenium				1
Silver	0.73	1	3.7	3.1
Thallium(7841)				
Zinc	124	150	410	410

The following paragraphs contain summaries of findings that were made based on the above 1997 data and data obtained more recently. Most metals were eliminated as potential contaminants of concern after comparing the observed sediment levels to sediment screening criteria (Table 5). The only metal found to be of concern at that time was potential cadmium contamination at the old RACON tower site. Therefore, cadmium was the only heavy metal that was included in the 2005 confirmatory testing. The following paragraphs describe the metals most likely to be considered potential contaminants of concern and the findings and conclusions eliminating them from further consideration.

2.2.1 Arsenic

The 1997 sampling found some new work sediments would be expected to contain arsenic above possible effects sediment screening levels, but below probable effects levels. However, average concentrations in the new work sediments are expected to be below screening levels. Furthermore, the observed levels are similar to levels observed in maintenance sediments (1.7 to 17 ppm) and the harbor reference area (14 ppm)(ENSR, 2003). No additional environmental impacts are expected due to new work sediment arsenic levels and no additional evaluation is warranted.

2.2.2 Chromium

This metal was found above possible effect sediment screening levels, but below probable effects levels for only one 1997 sample. Therefore, the 1997 sampling results were considered to indicate the potential for environmental effects was minimal. However, some additional investigation of chromium was continued in later studies to confirm this. For example, consideration is warranted of how easily it might be released from the sediment to the environment. Such an assessment would guide one’s expectation of environmental impacts. If the majority of the element is tightly bound within the sediment, the potential for environmental impact should be minimal. EA (2008) conducted sequential extraction procedures (SEP) to estimate how tightly chromium is bound to the new work sediments. The low cadmium composite found chromium at 134 and 139 ppm. SEP analyses found 92.1 and 91.9 percent existed in the sulfide and residual fractions. The chromium is considered to be tightly bound when it exists in these fractions. The high cadmium composite found chromium at 126 and 146 ppm. SEP analyses of the high cadmium sediments found 91.1 and 89.1 percent existed in the sulfide and residual fractions. These percentages are even higher in the dried soil. These data indicate chromium would not be available or expected to produce adverse environmental impacts. No further investigation of chromium is warranted.

2.2.3 Manganese

In the 1997 sampling, this metal was found below sediment screening levels (AET, Buchman, 1999). Because of its low potential for bioaccumulation, manganese is not expected to cause environmental impacts. However, additional study of the potential availability of manganese in new work sediments was performed by EA (2008). SEP procedures conducted by EA found 16 to 32 percent of manganese is either in the sulfide or residual fractions. These percentages are about the same for dried soil (27-28 percent). The low Cd sediment showed 10-12 percent of manganese in the exchangeable fraction. The high Cd sediment showed only 4-5 percent in the exchangeable fraction. The dried soils showed 10-20 percent in the exchangeable fraction. These data indicate that some manganese would be expected to be available in both aquatic and upland environments. However, because of its low potential for bioaccumulation, potential environmental impacts are expected to be minimal, so no further consideration of manganese is warranted.

2.2.4 Nickel

This metal was found above no effect sediment screening levels, but below probable effects levels, in only one 1997 sample. As in the case of the other metals found above no effects screening criteria during the 1997 sampling, EA (2008) conducted SEP procedures for nickel. The SEP procedures conducted by EA (2008) found 48 to 54 percent of nickel in the wet sediment and dried soil is either in the sulfide or residual fractions. These data indicate at least half of the sediment/soil nickel would not be available to aquatic life or upland plants. However, because of its potential to bioaccumulate, nickel was included in the bioaccumulation and plant uptake studies.

The bioaccumulation study found both *Macoma* and *Nereis* accumulated nickel and produced wet weight tissue nickel concentrations of 0.48 to 0.69 ppm. These results were significantly higher than reference. These results are discussed in Sections 4.2.5 and 4.3.1.5. These results are below the lowest NOAEL in the ERED vertebrate database except for a frog (2.0 mg/kg wet wt. for the Rainbow Trout). The highest sediment nickel concentration was 30.8 mg/kg and the inner harbor sample average was 11.6 mg/kg. The Terrestrial Toxicity Database (USACHPPM, chppm-www.apgea.army.mil) shows a lowest tissue NOAEL of 63 mg/kg and 35 ppm soil concentration as a concentration below which adverse effects should not occur. These data are thought to show minimal environmental concern regarding potential environmental impacts associated with nickel concentrations in the proposed new work sediments.

2.2.5 Zinc

The 1997 study found zinc below no effect screening criteria. However, because zinc was found above no effect screening criteria in the high cadmium composite, EA (2008) also conducted SEP procedures for zinc on the new work composites. Exchangeable and carbonate fractions are the most available fractions in an aquatic state. As Tables 6 and 7, show, the amount of zinc in these fractions is small, indicating little environmental concern for zinc in an aquatic environment. When sediments oxidize, the hydroxide and organic fractions can become available. The washed and dried sediments showed a loss of zinc from the hydroxide fraction, and an increase in the exchangeable and carbonate fractions. These data indicate zinc is unlikely to become available to aquatic life but could become a little more available under some oxidizing conditions. The aquatic bioaccumulation study found that *Macoma* accumulated zinc at concentrations slightly above reference. *Macoma* in the low sediment composite showed zinc concentrations of 10.2 ppm, which was significantly higher than the 9.32 ppm found in organisms grown in the reference sediment (EA, 2008, Table 8-7). This minimal difference shows that new work sediments are unlikely to produce any additional environmental impacts related to zinc in an aquatic environment. The plant uptake study found zinc did bioaccumulate in plants under oxidizing conditions. The Terrestrial Toxicity Database (USACHPPM) lists for zinc 140 mg/kg as a soil concentration below which adverse effects should not occur and a lowest NOAEL of 100 mg/kg. Table 6 shows zinc levels associated with the sediments containing elevated levels of cadmium. These results indicate a potential concern for possible effects of zinc associated with sediments containing elevated cadmium levels when placed in a dry environment. The results of potential plant uptake of zinc are discussed at Section 4.3.1.5.

2.2.6 Selenium

The 1997 sampling found no detection of selenium in the new work sediments, but showed MDLs for selenium above published possible effects criteria (Apparent Effects Threshold = 1 mg/kg). Previous O&M sampling has found selenium to be non-detectable with MDLs ranging from 0.83 to 1.0 mg/kg (ENSR, 2003). Because selenium has not been found in O&M sediments and the achieved MDLs for the new work sediments were not greatly above 1 mg/kg (in the range of 1.2 to 2.4 mg/kg), the potential for environmental effects was deemed minimal. Selenium was tested for in the river water and elutriate samples. Dissolved concentrations were similar to the river water concentrations, thus confirming the potential for selenium environmental impacts to be minimal.

Table 6. Zinc Sediment Concentrations from SEP Fractions (EA, 2008), mg/kg

	Exchange-able	Carbon-ate	Organic	Hydrox-ide	Sulfide	Residual	Total*1	Total*2	Total*3
High Cd Comp	0.65	3.8	35.8	121	31.8	10.7	191	130	163.5
High Cd Comp Dup	0.7	3.3	33.8	119	29.2	11.1	210	164	159.3
High Cd Comp Wash/Dry	1.9	5.6	31.9	114	70.7	13.1	219	171	197.8
Low Cd Comp	0.75	3.8	22.7	71.7	31.4	15.4	146	100	117.9
Low Cd Comp Dup	0.75	3.8	23.7	71.2	33.6	13.1	146	92.1	117.9
Low Cd Comp Wash/Dry	1.4	5.7	22.9	59.5	37	8.5	132	93.1	105

*1 Microwave digestion
*2 Total standard digestion
*3 Total relatively unavailable (hydroxide, sulfide, residual) (microwave digestion)

Table 7. Zinc, Percentages from SEP Fractions (EA, 2008), mg/kg

	Exchange-able	Carbon-ate	Organic	Hydroxide	Sulfide	Residual	Total*
High Cd Comp	0.3	1.9	17.6	59.4	15.6	5.30	80.2
High Cd Comp Dup	0.4	1.7	17.1	60.4	14.8	5.6	80.8
High Cd Comp Wash/Dry	0.8	2.4	13.4	48.1	29.8	5.5	83.4
Low Cd Comp	0.5	2.6	15.6	49.0	21.6	10.6	81.2
Low Cd Comp Dup	0.5	2.6	16.2	48.7	23.0	9.0	80.7
Low Cd Comp Wash/Dry	1.0	4.2	17.0	44.1	27.4	6.3	77.8

* Total relatively unavailable (hydroxide, sulfide, and residual fractions)

2.2.7 Cadmium

During the 1997 sampling, cadmium was detected between ERLs and ERMs at several inner harbor stations and above ERM at a station near the old RACON tower site (-75+000). It was determined that cadmium warranted additional investigation through the Phase 2 verification sampling. Additional investigations are covered at Sections 2.3.2.1 and 3.0.

2.2.8 Other Potential Contaminants of Concern

2.2.8.1 PCBs. The 1997 sampling (ATM 1998) found total PCBs were below available no effect sediment screening criteria and therefore of no environmental concern. No further investigation of PCBs was warranted.

2.2.8.2 Pesticides. In the 1997 sampling, observed pesticide levels were found to be below available screening criteria. However, questions existed about attained detection limits. Further analysis or documentation was needed, see Section 2.3.3.3.

2.2.8.3 Phenols. In the 1997 sampling, phenolic compounds were not detected, but some detection limits were above available sediment screening criteria. Further analysis or documentation was needed, see Section 2.3.3.1.

2.2.8.4 PAHs. In the 1997 sampling, one bend widener sample showed some PAHs above threshold effects screening criteria, but below probable effects levels. Unacceptable adverse effects were determined to be unlikely because only a few PAHs were observed above the effects thresholds and the observed concentrations were relatively low. Additional sampling (verification samples) was planned to more clearly define the sediment levels of these parameters and their potential for environmental impact. PAHs and cadmium were detected in a sample taken at about Station 75+000 near the old RACON Tower where a spill of fuel, batteries, and paint lacquer occurred in November 1996. Additional sampling at the RACON tower site and sediment testing was planned to clearly determine whether concentrations of cadmium and PAHs in this area would impact the Expansion Project, see Section 2.3.3.2.

2.2.8.5 Dioxins. The 1997 sampling (ATM 1998) found 2378 PCDD/PCDF dioxin congeners in new work sediments. Since calculated TBPs (theoretical bioaccumulation potentials) were less than reference values, there was no reason for environmental concern. No further investigation of dioxins was warranted.

2.2.8.6 Organotins. The 1997 sampling (ATM 1998) detected low levels of butyltins throughout the harbor. Other studies (see ATM, 1998) showed conflicting results, so additional testing of these parameters was planned through the Phase 2 verification sampling. EA reviewed existing project data on butyltins and concluded "it is not expected that there are any risks associated with any exposure to the sediment, or to soil should the sediment be utilized for upland placement" (EA, 2007). No further investigation of butyltins was warranted.

2.2.8.7 Petroleum Hydrocarbons. The 1997 sampling (ATM 1998) detected total recoverable petroleum hydrocarbons at levels ranging from <10 ppm to 70 ppm. These levels were considered minor, but warranted additional investigation through the Phase 2 verification sampling, see Section 2.3.2.2.

2.2.8.8 Cyanide. The ATM sampling in 1997 found no detection of cyanide in any sediment samples or elutriates. Detection limits ranged from 1.2 to 2.9 mg/kg for the sediment samples and 0.01 mg/L for the elutriates. No further investigation of cyanide was warranted.

2.2.8.9 Nutrients. Nutrients were not considered to present an environmental hazard and additional evaluation was not performed.

2.3 SHEP Phase 2 Testing

2.3.1 Goals

Results of the first set of sediment sampling and analysis (1997) for the Expansion Project left open some questions concerning the potential for contaminant-related impacts associated with the proposed dredging and dredged material placement.

One set of questions involved the old RACON Tower site. Do the sediments around the old RACON Tower site pose a potential for environmental impacts due to the proposed Expansion dredging? The 2005 sampling included twenty grab samples taken in the RACON Tower area to answer that question. These samples were analyzed for cadmium and PAHs.

The second set of questions pertained mostly to whether the sediment chemistry data, especially achieved detection limits, were adequate for comparison to screening criteria. To address this set of questions, the 2005 sampling included six confirmatory samples spread along the length of the channel to be analyzed for pesticides, PAHs, and phenols.

As a result of sampling and testing unrelated to the SHEP but which occurred after the 1998 evaluation, additional questions arose concerning the concentration and distribution of cadmium within the new work sediments (these questions are addressed in Section 3.0). To address this issue, the 2005 sampling included collection of approximately 350 samples for cadmium analysis taken at 2-ft intervals from 45 cores distributed throughout the harbor, but concentrating in areas believed to contain Miocene clays. Sampling intervals (measured from MLW) were assigned letter designations as follows: -42 ft to -44 ft (a), -44 ft to -46 ft (b), -46 ft to -48 ft (c), -48 ft to -50 ft (d), -50 ft to -52 ft (e), -52 ft to -54 ft (f), -54 ft to -56 ft (g), -56 ft to -57 ft (h). A subset of these samples was subjected to both standard extraction and total digestion techniques to determine if the cadmium was tightly bound to the sediment. Should these analyses show cadmium exists in the new work sediments at levels of concern, additional testing would have to be performed at a later time to address specific environmental concerns associated with the specific dredged material placement options under consideration.

In addition, since the Tier 1 EIS was written, the depth of potential impact of a hydraulic cutterhead dredge was clarified. In general, a cutterhead dredge usually disturbs and mixes sediment below the level it is capable of removing. In the case of a large cutterhead dredge, this disturbance depth can be 3 to 4 feet below the final channel depth that is actually attained, depending on the size of the dredge. To account for this increased disturbance depth, the target depth for all core samples for the Phase 2 (2005) sediment sampling and analysis was 3 feet below the expected removal depth (see Table 8, below). For example, the core depth would be the authorized depth, plus 2 feet of overdepth, any additional amount of Advance Maintenance, and 3 feet of disturbance depth. Table 9 shows the difference between the core depths achieved by the 1997 sampling and the calculated disturbance depth. The failure to reach disturbance depth in 1997 would be corrected in the next round of testing.

Table 8. Channel Depths (in feet MLW)

STATION (1000 FT)	AUTH DEPTH	ADV MAINT	ALLOW OVER-DEPTH	SEDIMENT REMOVAL DEPTH	DISTURBANCE DEPTH*1	TOTAL O&M DREDGING DEPTH*2
112.5 to 105.5	30	2	2	34	3	37
105.5 to 103	36	2	2	40	3	43
103 to 102	42	0	2	44	3	47
102 to 70	42	2	2	46	3	49
70 to 37	42	4	2	48	3	51
37 to 35	42	6	2	50	3	53
35 to 26	42	4	2	48	3	51
26 to 0	42	2	2	46	3	49
0 to 14B	42	2	2	46	3	49
14B to 60B	44	0	2	46	3	49
24B to 32B south ½	44	2	2	48	3	51
29B to 41.5B [3]	44	100-ft widener	2	46	3	49
Oysterbed Island Turning Basin	40	0	2	42	3	45
Fig I TB	34	4	2	40	3	43
Marsh I TB	34	0	2	36	3	39
Kings I TB	42	8	2	52	3	55
Argyle I TB	30	0	2	32	3	35
Port W TB	30	0	2	32	3	35
Sediment Basin: 0 to 2+000	38	0	2	40	3	43
Sediment Basin: 2+000 to 13.3	40	0	2	42	3	45

NOTES:
*1 Depth below the intake of a cutterhead hydraulic dredge but which the cutterhead disturbs during dredging.
*2 Total Dredging depth includes the depth that is disturbed by a cutterhead dredge. This is deeper than the depth to which sediment is actually removed, as it includes the disturbance depth.
*3 These advance maintenance sections are currently under environmental review and do not presently have environmental clearances. CESAD approved an additional advance maintenance feature in the entrance channel in June 2003 that would be located between Stations -24+000(B) to -41+500(B). It has not yet been implemented, but CESAS is seeking funds for the initial construction.

Table 9. 1997 Sampling Depths (ATM 1998)

Harbor Location	Sample	Station* (1000 feet)	Penetration	Core Depth	Disturbance Depth*
SHIH	103NW	103	4	-45.9	-53
SHIH	W01NW	102.5	9.5	-33	-53
SHIH	T01NW	99.5	2	-43	-55
SHIH	095NW	95	8	-52.7	-55
SHIH	090NW	90	3	-47.8	-55
SHIH	085NW	85	7	-52.4	-55
SHIH	080NW	80	4.5	-48.2	-55
SHIH	W02NW	88.2	11	-31.8	-55
SHIH	075NW	75	11	-51.1	-55
SHIH	W03NW	77	11	-42.1	-55
SHIH	W04NW	71	12	-47.1	-55
SHIH	C07NW	"25 to 65"	"2.5 to 5"	"-43 to-49"	"-57 to-59"
SHIH	W05NW	54	5	-42.2	-57
SHIH	W06NW	50.8	12	-38.3	-57
SHIH	W07NW	46.2	10	-19.4	-57
SHIH	045NW	45	3	-47.4	-57
SHIH	W08NW	35.2	12	-40.1	-59
SHIH	W09NW	29.2	11	-31.1	-57
SHIH	015NW	15	6	-49.3	-55
SHIH	005NW	5	12	-55.1	-55
SHIH	W10NW	10.6		-42.3	-55
SHBC	005NW	-5		-44.2	-55
SHBC	015NW	-15		-48.8	-55
SHBC	W01NW	-19		-40.2	-55
SHBC	W02NW	-39.5		-43.3	-57
SHBC	035NW	-35		-50.9	-55

* For a 6-foot deepening.

2.3.2 RACON Tower Testing Results

The Tier I Expansion sampling (1997) collected sediment near the RACON/light tower site at Station -75+000 in the bar channel. Cadmium and low molecular weight (LMW) PAH compounds were detected in that sediment, presumably from a fuel, battery, and paint lacquer spill that occurred in November 1996. While the PAH compounds that were encountered were not found at concentrations normally associated with benthic effects, the cadmium concentration was detected above probable effects levels (ATM, 2004, p. 5). To further investigate the potential for environmental impacts from dredging in this area during the proposed Expansion Project, additional grab samples were taken in the vicinity of the site and analyzed for PAHs and cadmium.

2.3.2.1 Cadmium. In the second round of testing, twenty sediment samples were taken in a circular area at distances of 300 to 1500 meters from the old RACON tower site and analyzed for cadmium to define the distribution of cadmium in the area. No cadmium was detected in any of the samples, with the MDL at 0.30 ppm or less. These samples were also analyzed for aluminum and iron. Aluminum values ranged from about 600 to 4500 ppm, with the lowest values found mostly to the south of the tower near the channel. Iron values ranged from about 560 to 1850 ppm, with the highest values mostly to the NE and SW of the tower site. These data indicate no environmental concerns related to metal concentrations near the RACON tower site.

2.3.2.2 PAHs. PAH's were analyzed in four samples taken at 300 meters from the tower site along N, S, E, and W radii. Low molecular weight totals for detected PAHs ranged from 2.4 to 3.6 ppb. High molecular weight totals for detected PAHs ranged from 0.07 to 6.7 ppb, except for the sample taken 300m east of the tower site, which showed a high molecular weight PAH total of 23.6 ppb. These observed values are well below TELs (Threshold Effects Levels) for both low molecular weight PAHs (311.7 ppb) and high molecular weight PAHs (655.34 ppb).

These data show no contaminants in the area of the RACON tower site at levels of concern and no additional investigations at the site by the Savannah Harbor Expansion Project are warranted. Available evidence indicates that sediments in the vicinity of the RACON tower site do not pose any environmental concerns related to the proposed Expansion Project work.

2.3.3 Confirmatory Sampling

This section reviews the list of potential contaminants of concern remaining after the Phase 1 sampling in 1997 and the results of the six Phase 2 confirmatory samples taken in 2005, and presents findings which eliminated concern for all contaminants except cadmium. The discussion is presented by contaminant.

2.3.3.1 Phenols. The 1997 sampling (ATM 1998) detected no phenols, but some detection limits were above no effects sediment screening criteria. Therefore, analysis for phenols was included for the six confirmatory samples taken during the 2005 sampling. No phenols were detected. Five of the samples achieved very low MDLs (0.2 to2.6 ug/kg). The other sample (bar channel sample at Station -63+000) showed higher MDLs (from 1 to 13 ug/kg). These MDL's were all below marine sediment screening criteria except for 2, 4, 5 trichlorophenol in the bar channel Station -63+000 sample, where the MDL of 7.23 ug/kg exceeded the AET of 3 ug/kg. The lowest and highest MDL's achieved for the six samples are listed in the table below. These results indicate minimal concern for potential environmental effects due to phenols and further investigation of phenols was judged to not be warranted.

Table 10. Confirmatory Sampling Phenol Results for All Samples (SH083+000 (A+B), SH065+000 (D), SH025+282(B), SHBC027+000(C), SHBC045+000 (B), SHBC063+000 (F))

ANALYTE	RESULT	LOWEST MDL	HIGHEST MDL	AET*	UNITS
4-Chloro-3-methylphenol	U	0.389	2.07		µg/kg
2,4,6-Trichlorophenol	U	1.07	5.68	6	µg/kg
2,6-Dichlorophenol	U	0.565	3.01		µg/kg
2,4-Dichlorophenol	U	0.565	3.01	5	µg/kg
2-Nitrophenol	U	0.560	2.98		µg/kg
3-Methylphenol (m-Cresol)	U	0.493	2.63		µg/kg
4-Methylphenol (p-Cresol)	U	0.493	2.63	100	µg/kg
2,4-Dimethylphenol	U	0.418	2.22	18	µg/kg
2-Methylphenol (o-Cresol)	U	0.237	1.26	8	µg/kg
Phenol	U	0.190	1.01	130	µg/kg
4-Nitrophenol	U	1.28	6.82		µg/kg
2,4,5-Trichlorophenol	U	1.36	**7.23**	3	µg/kg
2-Methyl-4,6-dinitrophenol	U	1.59	8.46		µg/kg
2-Chlorophenol	U	0.195	1.04	8	µg/kg
Pentachlorophenol	U	1.42	7.55	17	µg/kg
2,4-Dinitrophenol	U	2.65	13.4		µg/kg

* Buchman, 1999.

2.3.3.2 PAHs. The 1997 sampling (ATM 1998) found one bend widener sample above sediment threshold effects screening criteria. PAHs were also detected in one sample taken at about Station -75+000 near the old RACON Tower where a spill of fuel, batteries, and paint lacquer occurred in November 1996.

PAHs were analyzed during the 2005 “confirmatory” sampling (Tables 11 and 12). Neither the low molecular weight totals nor the high molecular weight totals approached threshold effects levels. These results indicate no concern for potential environmental effects due to PAHs and no further investigation of PAHs occurred related to the confirmatory sampling.

Table 11. PAHs Upper Harbor 2005 Testing (ppb (ug/kg))

	SH083+000 (A+B)			SH065+000 (D)			SH025+282 (B)			SH025+282 (Z)	
Analyte	Result	MDL		Result	MDL		Result	MDL		Result	MDL
1-Methylnaphthalene	0.81	0.55	J	1.10	0.58	J	0.39	0.32	J	0.72	0.31
2-Methylnaphthalene	1.20	0.75	J	1.60	0.78	J	0.66	0.43	J	1.10	0.42
Acenaphthene	1.30	0.36	J	7.80	0.37			0.20	U	0.30	0.20
Acenaphthylene	2.00	0.49	J	4.20	0.51	J		0.28	U	0.54	0.27
Anthracene	4.50	0.49	J	7.20	0.51			0.28	U	0.27	0.27
Benz(a)anthracene	12.00	0.36		21.00	0.37		0.28	0.20	J	0.24	0.20
Benzo(a)pyrene	13.00	0.49		19.00	0.51		0.59	0.28	J	0.27	0.27
Benzo(b)fluoranthene	17.00	1.10		20.00	1.20		0.60	0.60	J	0.87	0.59
Benzo(g,h,i)perylene	10.00	0.51		13.00	0.53		0.45	0.29	J	0.29	0.29
Benzo(k)fluoranthene	15.00	0.73		20.00	0.76		0.49	0.42	J	0.41	0.41
Chrysene	17.00	0.90		22.00	0.95			0.51	U	1.50	0.50
Dibenz(a,h)anthracene	2.30	0.58	J	3.10	0.60	J		0.33	U	0.32	0.32
Fluoranthene	40.00	0.75		54.00	0.78		1.20	0.43	J	5.00	0.42
Fluorene	1.50	0.42	J	4.70	0.44	J		0.24	U	0.66	0.24
Indeno(1,2,3-cd)pyrene	13.00	0.53		17.00	0.56		0.45	0.30	J	0.33	0.30
Naphthalene	5.60	0.75		6.10	0.78		4.40	0.43	J	3.70	0.42
Phenanthrene	8.80	0.73		12.00	0.76		0.44	0.42	J	5.40	0.41
Pyrene	38.00	0.79		45.00	0.83		1.20	0.45	J	2.20	0.44
LMW TOTAL, TEL=311	25.71			44.70			5.89			12.69	
HMW TOTAL, TEL=655	177.30			234.10			5.26			11.43	

Table 12. PAHs Bar Channel 2005 Testing (ppb (ug/kg)

		SHBC -27+ 000(C)		SHBC -45+ 000(B)		SHBC -63+ 000(F)		
Analyte		MDL	Flag	MDL	Flag	Result	MDL	Flag
1-Methylnaphthalene	L	0.340	U	0.310	U	0.340	0.320	J
2-Methylnaphthalene	L	0.460	U	0.420	U	0.470	0.440	J
Acenaphthene	L	0.220	U	0.200	U		0.210	U
Acenaphthylene	L	0.300	U	0.270	U		0.280	U
Anthracene	L	0.300	U	0.270	U		0.280	U
Benz(a)anthracene	H	0.220	U	0.200	U	1.000	0.210	J
Benzo(a)pyrene	H	0.300	U	0.270	U	0.780	0.280	J
Benzo(b)fluoranthene	H	0.640	U	0.590	U	1.100	0.610	J
Benzo(g,h,i)perylene	H	0.310	U	0.280	U	0.700	0.300	J
Benzo(k)fluoranthene	H	0.440	U	0.400	U	0.810	0.420	J
Chrysene	H	0.550	U	0.500	U	0.990	0.530	J
Dibenz(a,h)anthracene	H	0.350	U	0.320	U		0.330	U
Fluoranthene	H	0.460	U	0.420	U	2.000	0.440	J
Fluorene	L	0.260	U	0.230	U		0.250	U
Indeno(1,2,3-cd)pyrene	H	0.320	U	0.300	U	0.650	0.310	J
Naphthalene	L	0.460	U	0.420	U	1.000	0.440	J
Phenanthrene	L	0.440	U	0.400	U	0.580	0.420	J
Pyrene	H	0.480	U	0.440	U	1.500	0.460	J
LMW TOTAL, TEL=311						2.39		
HMW TOTAL, TEL=655						9.53		

2.3.3.3 Pesticides. The 1997 sampling (ATM 1998) found pesticides were below potential effects screening criteria and therefore of no environmental concern. However, pesticides results in the 1997 sampling often had somewhat elevated reporting limits. These results also showed scattered low concentrations of several pesticides (see Table 13, below). Therefore, analysis of pesticide concentrations was added to the confirmatory sampling.

The confirmatory sampling (Tables 14 and 15, below) shows detection of only two pesticides, beta-BHC (5.554 ug/kg) in the upper harbor sample at Station 83+000, and gamma-BHC (lindane) (2.109 ug/kg) in the upper harbor sample at Station 65+000. Buchman (1999) does not list screening criteria for beta-BHC. ATM (2004) lists a consensus Threshold Effects Level (TEC) for beta-BHC of 5.1 ug/kg. Since this level was observed in only one sample, this substance is not expected to be widespread and project sediments would be expected to average much less than this screening value. Therefore, no environmental impacts are expected due to beta-BHC.

Buchman lists lindane at a TEL of 0.32 ug/kg and a PEL of 0.99 ug/kg. ATM (2004) lists a consensus TEC for gamma-BHC (lindane) of 0.80 ug/kg. The observed level of lindane at Station 83+000 is above these screening levels. However, the observed level (2.109 ug/kg) is less than one of the reference values (3.989 ug/kg). Moreover, since this level was observed in only one sample, this substance is not expected to be widespread and the overall project sediments would be expected to average much less than the screening values. Therefore, no environmental impacts are expected due to gamma-BHC (lindane).

Table 13. Pesticides Detected in New Work Sediments during 1997 Sampling (all detections J flagged) ppb (ug/kg)

SAMPLE	SHIH W03NW	SHIH 075NW	SHIH W05NW	SHIH W06NW	SHBC 035NW	SHBC 075NW	SHIH R02
Station #	+77+100	+75+000	+54+000	+50+800	-35+000	-75+000	Reference
Aldrin	0.50	0.125	U	0.15	U	U	U
4,4’ DDE	U	U	U	0.71	U	U	U
4,4’ DDT	U	0.33	U	U	U	U	U
Dieldrin	U	0.16	U	U	0.12	0.10	0.13
Endrin	U	0.39	0.24	0.29	U	U	0.085
Endrin aldehyde	U	0.25	U	U	U	U	U
Heptachlor	U	0.13	U	U	U	U	U

Table 14. Pesticides Upper Harbor 2005 Testing

		SH083 + 000 (A+B)		SH065 + 000 (D)		SH025 + 282 (B)	
ANALYTE	UNITS	RESULT	MDL	RESULT	MDL	RESULT	MDL
2,4'-DDD	µg/kg	U	1.460	U	1.450	U	0.404
2,4'-DDE	µg/kg	U	1.460	U	1.450	U	0.404
2,4'-DDT	µg/kg	U	1.460	U	1.450	U	0.404
4,4'-DDD	µg/kg	U	4.850	U	4.830	U	1.340
4,4'-DDE	µg/kg	U	4.850	U	4.830	U	1.340
4,4'-DDT	µg/kg	U	4.850	U	4.830	U	1.340
Aldrin	µg/kg	U	0.485	U	0.483	U	0.067
alpha-BHC	µg/kg	U	0.097	U	0.097	U	0.067
alpha-Chlordane	µg/kg	U	0.097	U	0.097	U	0.067
Beta-BHC	µg/kg	**5.554**	0.485	U	0.483	U	0.067
Chlordane (Technical)	µg/kg	U	3.880	U	3.870	U	1.610
cis-Nonachlor	µg/kg	U	0.058	U	0.058	U	0.040
delta-BHC	µg/kg	U	0.485	U	0.483	U	0.067
Dieldrin	µg/kg	U	0.194	U	0.193	U	0.134
Endosulfan I	µg/kg	U	0.097	U	0.097	U	0.067
Endosulfan II	µg/kg	U	0.194	U	0.193	U	0.134
Endosulfan sulfate	µg/kg	U	0.194	U	0.193	U	0.134
Endrin	µg/kg	U	0.194	U	0.193	U	0.134
Endrin aldehyde	µg/kg	U	0.194	U	0.193	U	0.134
Endrin ketone	µg/kg	U	0.194	U	0.193	U	0.134
gamma-BHC (Lindane)	µg/kg	U	0.485	**2.109**	0.483	U	0.067
gamma-Chlordane	µg/kg	U	0.097	U	0.097	U	0.067
Heptachlor	µg/kg	U	0.485	U	0.483	U	0.067
Heptachlor epoxide	µg/kg	U	0.097	U	0.097	U	0.067
Hexachlorobenzene	µg/kg	U	0.058	U	0.058	U	0.040
Methoxychlor	µg/kg	U	0.970	U	0.967	U	6.710
Mirex	µg/kg	U	0.058	U	0.058	U	0.404
Oxychlordane	µg/kg	U	0.058	U	0.058	U	0.040
Toxaphene	µg/kg	U	3.880	U	3.870	U	1.610

Table 15. Pesticides Bar Channel 2005 Testing

		SHBC027+000(C)		SHBC045+000 (B)		SHBC063+000 (F)	
ANALYTE	UNITS	'RESULT	'MDL	'RESULT	'MDL	'RESULT	'MDL
2,4'-DDD	µg/kg	U	0.460	U	0.069	U	1.400
2,4'-DDE	µg/kg	U	0.460	U	0.069	U	1.400
2,4'-DDT	µg/kg	U	0.460	U	0.069	U	1.400
4,4'-DDD	µg/kg	U	1.530	U	0.139	U	2.810
4,4'-DDE	µg/kg	U	1.530	U	0.139	U	2.810
4,4'-DDT	µg/kg	U	1.530	U	0.139	U	2.810
Aldrin	µg/kg	U	0.077	U	0.069	U	0.070
Alpha-BHC	µg/kg	U	0.077	U	0.069	U	0.070
Alpha-Chlordane	µg/kg	U	0.077	U	0.069	U	0.070
beta-BHC	µg/kg	U	0.077	U	0.069	U	0.070
Chlordane (Technical)	µg/kg	U	1.840	U	1.660	U	1.400
cis-Nonachlor	µg/kg	U	0.046	U	0.069	U	0.070
Delta-BHC	µg/kg	U	0.077	U	0.069	U	0.070
Dieldrin	µg/kg	U	0.153	U	0.139	U	0.140
Endosulfan I	µg/kg	U	0.077	U	0.069	U	0.070
Endosulfan II	µg/kg	U	0.153	U	0.139	U	0.140
Endosulfan sulfate	µg/kg	U	0.153	U	0.139	U	0.140
Endrin	µg/kg	U	0.153	U	0.139	U	2.810
Endrin aldehyde	µg/kg	U	0.153	U	0.139	U	2.810
Endrin ketone	µg/kg	U	0.153	U	0.139	U	2.810
gamma-BHC (Lindane)	µg/kg	U	0.077	U	0.069	U	0.070
gamma-Chlordane	µg/kg	U	0.077	U	0.069	U	0.070
Heptachlor	µg/kg	U	0.766	U	0.069	U	0.070
Heptachlor epoxide	µg/kg	U	0.077	U	0.069	U	0.070
Hexachlorobenzene	µg/kg	U	0.046	U	0.069	U	0.070
Methoxychlor	µg/kg	U	7.660	U	0.693	U	0.702
Mirex	µg/kg	U	0.460	U	0.069	U	0.070
Oxychlordane	µg/kg	U	0.046	U	0.069	U	0.070
Toxaphene	µg/kg	U	1.840	U	1.660	U	1.400

Pesticide levels in the reference samples taken during confirmatory sampling were either non-detect or very low. The three outer reference samples showed no detection of pesticides. Each sample is listed below, along with the range of detection limits. All values are ug/kg dry wt.(ppb).

SHRF OU (0.153 to 6.14, 30.7 for methoxychlor)
SHRF MD (0.159 to 7.65)
SHRF IN (0.173 to 4.16)

The three inner reference samples showed mostly no detection of pesticides, except for two samples that showed small amounts of gamma-BHC (lindane). Each sample is listed below, along with the range of detection limits, and values for lindane. All values are ug/kg dry wt.(ppb).

SHWRF 01 (0.1112 to 4.48), lindane = 3.989.
SHWRF 02 (0.099 to 1.980), lindane = 0.268J
SHWRF 03 (0.188 to 7.540, 37.7 for methoxychlor), lindane = <3.770(U)

In summary, very low levels of a number of pesticides have been detected in Savannah Harbor sediments in scattered parts of the harbor from time to time. This is also true for sediments from the Savannah Harbor reference areas. Environmental effects due to these low levels are expected to be minimal and no contaminant related impacts from pesticides would be expected due to the proposed Savannah Harbor dredging and dredged material placement.

2.3.3.4 Metals. The 1997 sampling (ATM 1998) found some metals (cadmium, chromium, manganese, nickel, zinc) occurred in new work sediments above no effect sediment screening levels, but below probable effects levels. The one exception was the discovery of cadmium at Station -75+000 near the RACON Tower spill (discussed above). These data overall indicate little potential for sediment contaminant-related environmental impacts due to proposed new work channel dredging or dredged material placement. Elimination of other metals as contaminants of concern is covered above in Section 2.2. However, subsequent unrelated testing indicated the potential for cadmium to occur in new work sediments above probable effects sediment screening criteria. These results led to the decision to identify cadmium as a contaminant of concern warranting additional investigation during the Phase 2 sampling. The identification of cadmium as a contaminant of concern is discussed in detail in Section 3.0.

3.0 Identification of Cadmium as a Contaminant of Concern

In February 2006, Savannah District completed an evaluation of sediments that may be excavated to deepen the Savannah Harbor Navigation Project as part of the Savannah Harbor Expansion Project. That evaluation reviewed the information obtained on the physical and chemical properties of the sediments that may be removed by the Expansion Project. That information included results of the 1997 and 2005 sampling. The evaluation concluded that: (1) there is sufficient reason to believe that cadmium is a contaminant of concern (COC) in the proposed SH Expansion Project since it occurs above concentrations of potential concern (available sediment screening criteria) in portions of the proposed dredge material, and (2) this warrants a more detailed evaluation of potential COC (cadmium) effects both inside and outside the DMCAs (Savannah Harbor Expansion Dredged Material Evaluation, Phase 1, PD-EC, 2006a). The process leading up to the decision to conduct further testing and risk evaluation is described below.

3.1 1997 Sediment Sampling

The first observation of cadmium in harbor sediments at levels of concern was in 1997. The following table (Table 16) contains a list of the ten sediment samples collected in 1997 during the Tier 1 studies in which cadmium was detected. The other approximately 18 new work samples showed no detection of cadmium. Using marine sediment screening levels (Buchman, 1999), some of these values were above the Threshold Effects Level (TEL) of 0.676 ppm (mg/kg), Effects Range Low (ERL) of 1.2 ppm (mg/kg), and Probable Effects Level (PEL) of 4.2 ppm (mg/kg). However, none were above the Effects Range Median (ERM) of 9.6 mg/kg, except for the sample taken near the RACON tower (SHBC075NW). These data indicated little overall concern for potential environmental impacts due to expected average cadmium concentrations in the Expansion sediments, but did warrant additional investigation of the RACON tower site.

Table 16. Cadmium Levels Detected during 1997 Sediment Testing for Savannah Harbor Expansion*

SAMPLE DESIGNATION	SAMPLE NUMBER	CADMIUM CONCENTRATION (mg/kg)
SHIHT01NW	76256-3	0.7
SHIH090NW	76256-6	8.5
SHIH085NW	76256-1	5.5
SHIH080NW	76256-2	5.1
SHIHC07NW Composite	76415-20	4.7
SHIHW05NW	76415-8	2.5
SHIH005NW	76415-5	0.48
SHBC005NW	76415-3	0.68
SHBC015NW	76415-10	1.5
SHBC075NW (Archive)	76415A-1	14
SHBC075NW	76415-1	24.3

* Samples taken in October and November, 1997

3.2 Savannah Harbor Advance Maintenance Widener

At approximately the same time in 1997, sediment testing and evaluation was conducted for an unrelated proposed action in the harbor. The testing was conducted in September 1997, as part of an environmental assessment of a proposed advance maintenance widener. Sediment samples were collected between Stations +35+000 and +37+000 (Area 1) and between Stations 0+000 and -14+000 (Area 2) (GEL, 1997).

Two cores, one to -45 feet MLW and one to -46.5 feet MLW were composited for the Area 1 NW (new work) sample. The two cores were taken from Stations 37+100 and 36+100. Four cores (to -45 to -47 feet MLW) were taken in the bar channel from Stations -5+300 to -12+500 for the Area 2 new work sample. The Area 1 new work sample showed a cadmium level of 6.96 mg/kg. The Area 2 new work sample showed cadmium at a level of 0.939 mg/kg. Since the observed cadmium level in the sediments in the Area 1 new work sample (Stations 37+100 to 36+000) was less than the ERM value of 9.6 mg/kg and the relatively small amount of new work sediment would be expected to mix with overlying O&M sediment during the dredging process, the potential for cadmium-related impacts from the dredging and disposal within a DMCA was considered minimal and no additional evaluation was performed.

3.3 Southern LNG Proposed Turning Basin, November 2000 (ATM, 2000)

As part of the dredged material evaluation for a turning basin to be constructed by Southern LNG in the Savannah River adjacent to the navigation channel, three berth cores and three turning basin cores were collected and analyzed for contaminants in November 2000. The berth cores returned cadmium values of 4.94 mg/kg, 3.79 mg/kg, and 13.1 mg/kg. The turning basin cores returned cadmium values of <0.17, <0.40, and 11.4 mg/kg. Since the observed level of cadmium in some of the cores was above the ERM value of 9.6, additional testing was conducted by Southern LNG to more clearly identify the location and extent of cadmium concentrations above the ERM value of 9.6 mg/kg.

3.4 Southern LNG Proposed Turning Basin, Sampling February 2001 (ATM, 2001), SLNG(2001)

In a second round of sediment sampling and evaluation for the proposed turning basin, ATM developed a sampling and analysis plan for Southern LNG in which five cores were collected in February 2001, divided into 2.5 foot sections and analyzed for cadmium. Observed cadmium concentrations by elevation are shown in the following Table 17 in mg/kg dry wt. This work showed that elevated cadmium levels existed in the deeper new work sediments. In subsequent negotiations between the District and Southern LNG, it was determined that sediment below -35 feet MLW on the South Carolina side of the Federal Project would be placed in the applicant's DMCA, as well as sediment below -45 ft MLW on the Georgia side of the Federal Project. Their data showed that sediments above -35 ft MLW that were destined for a Federal Project DMCA would be expected to contain <4.12 mg/kg cadmium and that sediment above -45 ft MLW on the Georgia side and also destined for a Federal Project DMCA would be expected to contain 6.7 mg/kg cadmium or less. The applicant further indicated that sediments deposited within their DMCA (on Elba Island) and containing 12.8 to 83 mg/kg cadmium would be maintained "in as dry as possible a state so as not to create an attractive nuisance for shorebirds".

Table 17. Southern LNG Turning Basin - Cadmium Sediment Core Concentrations by Elevation (ATM, 2001)(mg/kg dry wt)

APPROXIMATE						
TOP ELEVATION OF CORES –MLW (FT)	BOTTOM ELEVATION OF CORES -MLW (FT)	CORE VC-1	CORE VC-2	CORE VC-4	CORE VC-6	CORE VC-7
		STATIONS (feet)				
		40+000	38+000	38+750	39+000	37+000
31	34	0.7		1.2		4.1
33.5	36.5	0.9				13.7
36	39.5	1.2			1.57	17.1
38.5	42	1.7		29.6	1.1	17.3
41	44.5	1.8	1	30.9	2	14
43.5	47	5.4	1.6		6.7	14.1
46	49.5	24.1	1.6		24.2	83
48.5	52	24.5	23.7		27.9	

3.5 Implications of Southern LNG Sediment Findings for SHEP Sediment Testing and Evaluation

Results of the 2001 sediment sampling program by ATM at Southern LNG suggested that elevated cadmium levels might be associated with a clay layer described as Miocene Unit A. ATM analyzed geotechnical boring data from the harbor to predict where this layer might be encountered during the Expansion Project. The goal of the proposed sampling plan was to characterize the potential distribution and concentration of cadmium in the proposed Expansion new work sediments. Due to the unknown nature of the distribution and concentration of cadmium within the Federal Project and the lack of funds for a more comprehensive set of analyses, it was determined that the second round of sediment testing (Phase 2) would consist of only physical and chemical testing. The testing would include two different metals extraction procedures to assess whether the cadmium was tightly bound to the sediments and thus unavailable for potential environmental impacts. If cadmium were found to be tightly bound to the sediment matrix, that finding would be good evidence to expect cadmium would not be released to plants, animals, or water when the sediments were placed in a DMCA. It could then be concluded that sediment concentrations of cadmium above the ERM level would not pose significant potential for environmental impact when placed in a DMCA.

3.6 Phase 2 Sediment Sampling for Cadmium Concentrations by Depth

Sampling in 2005 collected approximately 350 sediment samples at 2-foot intervals from 45 cores distributed throughout the harbor, but concentrating in areas believed to contain Miocene clays. These samples were also analyzed for aluminum, iron, TOC (total organic carbon) and acid volatile sulfides.

Material existed above -46 feet MLW at only a few stations.. Cores of that material represented O&M sediments that accumulate within the channel regularly and are the impetus for the annual maintenance dredging of the navigation channel. These O&M samples all showed cadmium levels of about 2 ppm or less.

The most down-river station in the harbor found with elevated cadmium is Station 10+000, where cadmium shows up at 19.2 ppm in the -46 to -48 foot layer. This layer also showed cadmium at concentrations of about 10 to 20 ppm between Stations 28+000 and 36+000. The next upriver sampling location is Station 24+000, where high levels of cadmium (58 – 62 ppm) were found only at depth (in the -54 to -57 foot interval). The next few upriver stations (to Station 26+000) show high cadmium concentrations (40 ppm) in the -48 to -50 foot layer, with deeper layers increasing in cadmium concentration up to 70 ppm in the -54 to -56 foot layer. The deepest interval (-56 to -57 foot) showed less cadmium (30 to 7 ppm) in a decreasing trend with depth while moving upstream to Station 28+000. This cyclical pattern of increasing then decreasing cadmium concentrations is repeated four or five times as one examines sampling Stations, moving upstream (see Figures 1-4, below).

Proceeding upstream, cadmium concentrations show a pattern of generally decreasing peaks and lows that is reflected in each of the 2-foot layers. This pattern shows decreasing peaks and wider intervals between peaks proceeding upstream. The pattern deteriorates somewhat in the deepest layer (either -56 to -57-foot, or -56 to -58-foot), although less data exist for these intervals. At some stations the peak concentrations tend to decrease with depth, while other stations show lower concentrations at the surface and higher concentrations at depth.

Station 32+000 shows very low cadmium concentrations (1 ppm or less) throughout the sediment column (down to -57 feet MLW). Proceeding upstream from Stations 32+000 to 40+000 there is another spike in cadmium concentrations between Stations 34+000 to 36+000, with the -48 to -50 foot layer showing a lower peak concentration (12 ppm) than the deeper layers (about 20 ppm).

The cyclical nature of the data suggest the layers containing cadmium may show a wave-like pattern, with the more inland sediments exhibiting decreasing cadmium concentrations. Data from four depth intervals presented in the following four figures show the cyclical nature of cadmium concentrations in the harbor sediments.

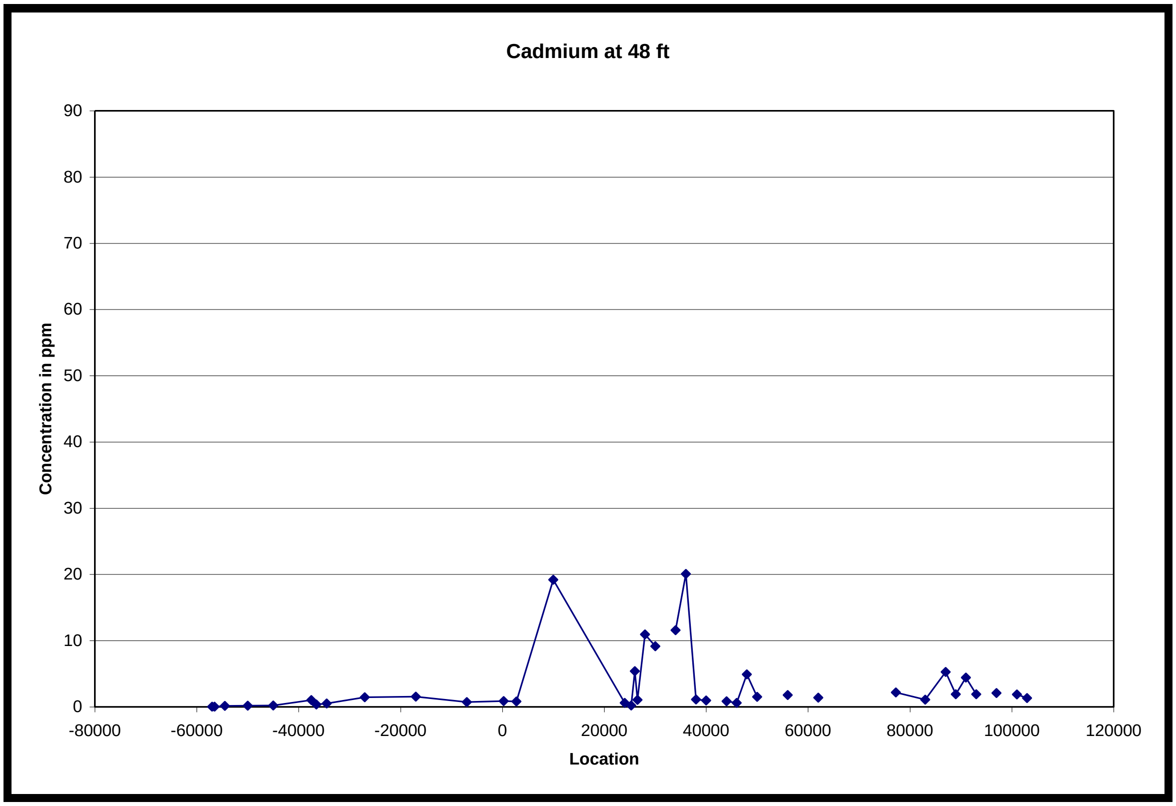

Figure 1. Cadmium distribution in the core segment from -46 to -48 feet MLW, 2005 sampling.

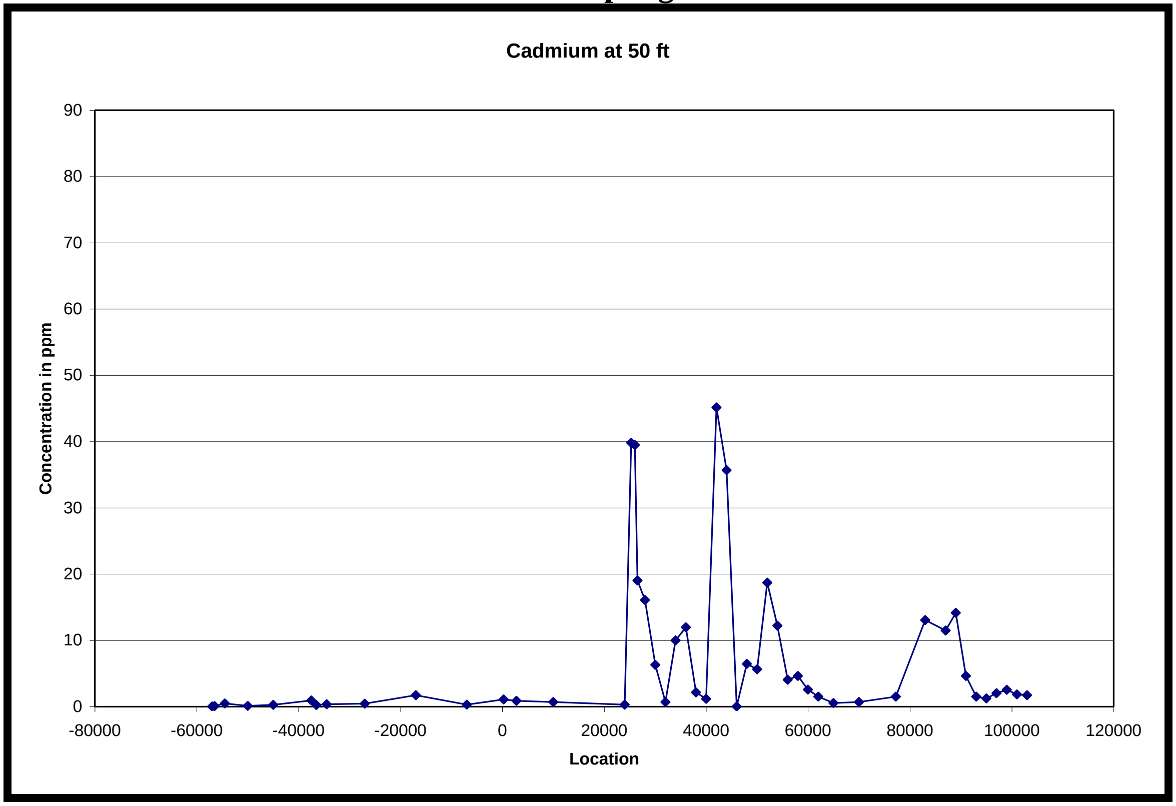

Figure 2. Cadmium distribution in the core segment from -48 to -50 feet MLW, 2005 sampling.

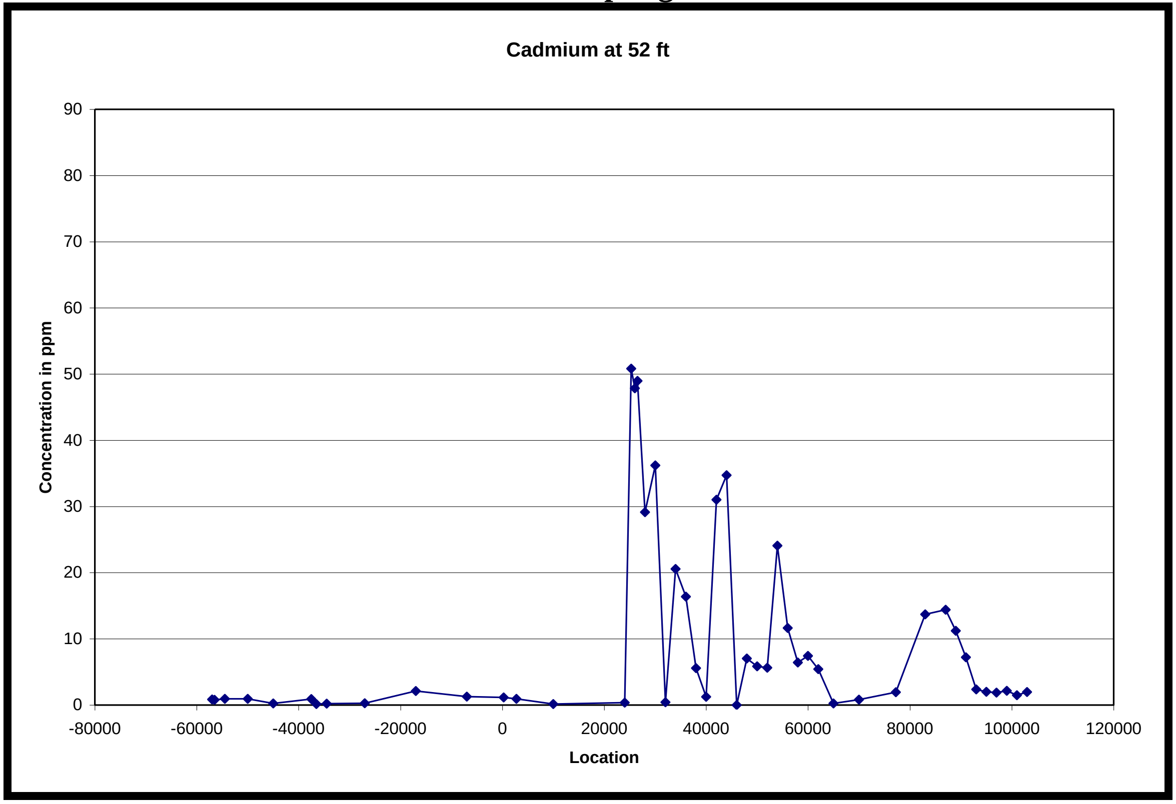

Figure 3. Cadmium distribution in the core segment from -50 to -52 feet MLW, 2005 sampling.

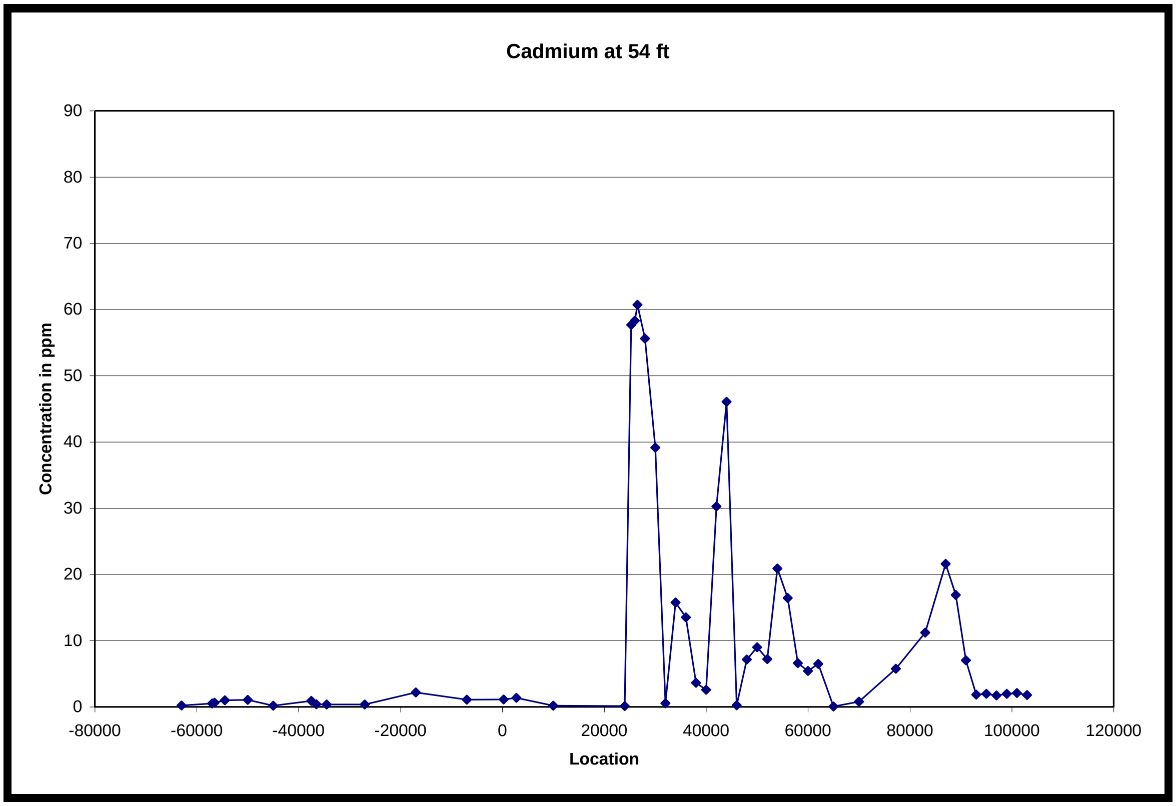

Figure 4. Cadmium distribution in the core segment from -52 to -54 feet MLW, 2005 sampling.

3.7 Expected Distribution of Miocene in the Channel Bottom Surface

Savannah District geologists examined several sources of information to determine where Miocene clays are currently exposed in the channel and where they are expected to be exposed after a 6-foot deepening (EN-G, 2006a). Within the inner harbor, most of the channel currently contains exposed Miocene, with gaps from Stations 0 to +25+000, and between Stations +65+000 and +85+000. Under Expansion, more of the channel would contain exposed Miocene, with a small gap at about Station +68+000, and another gap between Stations +5+000 and +15+000.

The 2005 core sampling was used to estimate the expected cadmium concentrations in surface Miocene clays forming the channel bottom sediments for both the existing condition and after SHEP (EN-G, 2006b). Expected changes in surface cadmium concentrations in the channel bottom sediments have also been identified. In general, cadmium concentrations in bottom sediments are expected to increase after Expansion, except in the reach from Stations +35+000 to +55+000, where some spots should increase and some decrease (EN-G, 2006b through e). Cadmium concentrations in the surface of river bottom sediments are discussed in the next section (3.8).

3.8 Expected Range in Cadmium Concentrations in the Surface Layer of Bottom Sediments by Reach

3.8.1 Use of Core Segment Data to Predict Ranges with Similar Channel Bottom Cadmium Concentrations

Table 18 shows the cadmium ranges expected in the parent material forming the bottom of the channel after SHEP. Ranges with the highest expected cadmium concentrations in bottom sediment are from Stations +94+000 to +80+000 and from Stations +45+000 to +16+000.

Table 18. Cadmium Concentrations of the Surface of Channel Bottom Sediments after SHEP Dredging, Station Ranges Selected According to Similarity of Sediment Cd Concentrations

Begin Station	End Station	Average Conc. (mg/kg)	Minimum-Maximum Core Segment Conc. (mg/kg)
103 + 000	94 + 000	1.9	1.8 – 2.0
94 + 000	80 + 000	13.3	9.2 – 20.1
80 + 000	45+000	7.4	ND-11.0
45 + 000	16 + 000	23.4	1.0 – 77.1
16 + 000	6 + 375	0.4	0.4
6 + 375	-63 + 000	0.9	ND – 2.4

3.8.2 Estimate of Reaches where Bottom Sediments are Exposed vs. Areas where Bottom Sediments Are Covered by Extensive O&M Sediments.

Using survey data from 2003 to 2006, District geologists identified areas of the channel experiencing scour and those areas experiencing fill (EN-G 2006f). In general, the upper end of the harbor down to about Station +79+000 experiences continual fill from deposition of O&M sediments. Scouring is the predominant characteristic from about Station +79+000 downstream to Station +49+000. From about Stations +49+000 downstream to Station +27+000, there are areas of scour and areas of fill. The reach from Stations +27+000 to +18+000 experiences predominantly scour. The area from Stations +18+000 to 0+000 experiences predominantly fill. According to the 2005 core data, areas expected to contain exposed bottom sediments with elevated cadmium levels occur from Stations +79+000 to +18+000. The data indicate that the area of major concern would be from Station +18+000 to Station +43+000 (this range includes all of the individual sample readings above 17 ppm Cd except for one 20.1 ppm reading at Station +87+000). A summary of these data is shown in Table 19.

Table 19. Cadmium Concentrations of the Surface of Channel Bottom Sediments after Expansion Dredging, Station Ranges Selected According to Expected Exposure of Bottom Sediments

Begin Station	End Station	Bottom Character	Average Conc. (mg/kg)	Minimum-Maximum Core Segment Conc. (mg/kg)
103 + 000	79 + 000	Covered with O&M Sediment	7.6	1.8 – 20.1
79 + 000	49 + 000	Scoured	7.9	4.1 – 11.0
49 + 000	27 + 000	mixed	17.9	ND- 77.1
027 + 000	18 + 000	scoured	29.4	12.9 – 57.9
18 + 000	0 + 000	Covered with O&M Sediment	1.1	0.4 – 1.6

3.9 Estimated Cadmium Concentrations of Sediments Proposed to be Dredged During SHEP

The 2005 core data show the distribution of cadmium within the proposed expansion sediments. These data are presented by elevation (2 foot lifts) in Figures 1-4, above. Average cadmium concentrations by station, based on data from each 1-2 foot lift within each core, are presented in Table 20. Table 21 shows the average cadmium concentration by reaches defined as containing similar levels of cadmium. There are no core data between Stations +10+000 and +24+000, hence the reach dividing point is listed as half-way between the two stations (Station +17+000). There are also no core data between Stations +2+750 and +10+000, hence the reach dividing point is again listed half-way between the two stations (Station SH00 +6+375). As discussed in the Phase 1 Evaluation (PD-E, 2006a), the 2005 sampling provided data by which reaches from Stations +103+000 to +94+000 and Stations +6+375 to -63+000B could be eliminated from further environmental concern due to low sediment cadmium concentrations within those reaches (PD-EC, 2006a).

Table 20. Average Sediment Cadmium Concentration (mg/kg) by Station

STATION	AVG CONC (mg/kg)	HIGHEST CONC (mg/kg)
+000 + 250	1.07	1.29
+002 + 750	1.03	1.65
+010 + 000	3.78	19.20
+24 + 000	16.85	63.48
+25 + 282	36.76	74.91
+26 + 000	39.37	72.94
+26 + 500	34.42	60.69
+28 + 000	27.15	55.61
+30 + 000	26.60	77.09
+32 + 000	0.58	1.02
+34 + 000	14.77	20.55
+36 + 000	15.69	20.07
+38 + 000	4.98	11.63
+40 + 000	7.10	26.16
+42 + 000	28.39	45.14
+44 + 000	23.57	40.06
+46 + 000	0.32	1.10
+48 + 000	6.76	9.66
+50 + 000	6.45	11.20
+52 + 000	9.25	18.71
+54 + 000	18.18	24.07
+56 + 000	8.42	16.43
+58 + 000	6.46	9.08
+60 + 000	6.44	9.02
+62 + 000	5.00	11.21
+65 + 000	2.94	10.09
+70 + 000	3.78	10.97
+77 + 250	2.99	5.46
+83 + 000	8.25	13.72
+87 + 000	11.91	21.58
+89 + 000	9.89	16.88
+91 + 000	5.02	10.64
+93 + 000	2.71	9.20
+95 + 000	1.77	2.00
+97 + 000	1.88	2.03
+99 + 000	2.16	2.55
+101 + 000	1.84	2.09
+103 + 000	1.57	1.98
-7+ 000	0.85	1.27
-17+ 000	1.95	2.36
-27+ 000	0.63	1.45
-34+ 500	0.38	0.53
-36+ 500	0.30	0.42
-37+ 500	0.84	1.04
-45+ 000	0.20	0.45
-50+ 000	0.63	1.07
-54+ 500	0.70	1.11
-56+ 500	0.40	1.31
-57+ 000	0.42	0.88
-63+ 000	0.21	<0.30

Table 21. Characterization of Cadmium Concentrations by Reaches as Initially Proposed*

BEGIN STATION	END STATION	AVERAGE CADMIUM CONC (MG/KG)	UCL 95% CHEBY-SHEV (MG/KG)	MINIMUM-MAXIMUM CORE SEGMENT CONC. (MG/KG)	APPROX 10^6 CU YDS (TOTAL)	ENVIRON-MENTAL CONCERN DUE TO CADMIUM?
+103 + 000	+94 + 000	1.83		1.12 – 2.52	2.4	No
+94 + 000	+45 + 000	6.67	10.5	0.04 – 24.07	8.9	No*
+45 + 000	+17 + 000	21.45	36.2	0.11 – 77.09	4.5	Yes*
+17 + 000	+6+ 375	3.78		0.15 – 19.20	1.0	No*
+6+ 375	-63+ 000	0.70		0.023 – 2.36	10.6	No

* Quantities include proposed advance maintenance from Stations +50+000 to +70+000 and passing lanes from Stations +55+000 to +58+000 and from +16+000 to +19+000. A bulking factor of 1.4 should be used to estimate required upland disposal area capacities.

These data indicate that 4.5 million cubic yards of SHEP sediments should average approximately 21.5 ppm cadmium and about 9 million cubic yards should average approximately 6.7 ppm cadmium.

An analysis of the latest sediment testing results indicates that a cadmium concentration of 14 mg/kg is the lowest concentration for which environmental impacts would be expected, see Sections 3.9 and 4.3.1.7. CESAS at first compared average cadmium concentrations by reach to this concentration of concern (Table 21). However, subsequent information became available on the deposition of clay-predominated sediments in DMCAs as clay balls. This information indicated that at least some of the clay sediments would not be expected to mix with other sediments but would tend to form clay balls. Therefore, determinations based on an assumption of sediments mixing to an average condition may not be appropriate where heavy clays are present. Because of the uncertainty surrounding how well clay balls will actually mix in the deposited materials, CESAS re-examined the individual lift data to determine if there are any areas not previously considered for management where the clay sediments could be expected to exhibit cadmium levels of 14 mg/kg or more. Sediments from the following stations (Table 21b) have certain depths where the cadmium occurs at a level of about 14 mg/kg or greater. Reaches with these stations (Stations 51+000 to 57+000 and 80+000 to 90+000) are now also proposed for management (covering) because of the potential for exposure of clay in an upland environment at levels of environmental concern.

Table 21b. Additional Stations Identified for Management

Station	Sample	Depth Interval (feet below MLW)	Cadmium (mg/kg)
10+000	A+B	42 to 46	0.3
	C	46 to 48	19.2
	D	48 to 50	0.7
	E	50 to 52	0.3
	F	52 to 54	0.3
	G	54 to 56	0.4
52+000	D	48 to 50	18.7
	E	50 to 52	5.7
	F	52 to 54	7.2
	G	54 to 56	7.5
	H	56 to 57	5.1
54+000	D	48 to 50	12.2
	E	50 to 52	24.1
	F	52 to 54	20.9
	G	54 to 56	20.9
	H	56 to 57	7.4
56+000	C	46 to 48	1.8
	D	48 to 50	4.1
	E	50 to 52	11.6
	F	52 to 54	16.4
	G	54 to 56	9.3
	H	56 to 57	6.2
83+000	A+B	42 to 46	1.4
	C	46 to 48	1.1
	D	48 to 50	13.1
	E	50 to 52	13.7
	F	52 to 54	11.2
	G	54 to 56	9.8
87+000	A+B	42 to 46	2.7
	C	46 to 48	5.3
	D	48 to 50	11.5
	E	50 to 52	14.4
	F	52 to 54	21.6
	G	54 to 56	20.1
89+000	A+B	42 to 46	1.8
	C	46 to 48	1.9
	D	48 to 50	14.2
	E	50 to 52	11.2
	F	52 to 54	16.9
	G	54 to 56	16.7

Sediments from the reach defined by Stations +94+000 to +45+000 (originally not proposed for management) are predicted to average 6.67 mg/kg cadmium. With the reaches from Stations +51+000 to 57+000 and +80+000 to 90+000 (reach boundaries determined to be half-way between adjacent sampling points) removed, the remaining portion of the reach from Stations +94+000 to +45+000 averages about 4.6 mg/kg cadmium. The highest cadmium concentration in any lift within this interval is 11.0 mg/kg. Not only is the average concentration within this combination of reaches (Stations +94+000 to +90+000, +80+000 to +57+000, and +51+000 to +45+000) well below the 14 mg/kg cadmium level of concern, but so is any single lift value. No management of these reaches is warranted. Sediments from the reach enclosed by Stations +17+000 to +6+375 contain a layer with a cadmium concentration of 19.2 mg/kg. This reach would also require management.

Table 21c. Table 21 Revised. Characterization of Cadmium Concentrations by Reach*

Begin Station	End Station	Average Cadmium Conc (mg/kg)	Minimum-Maximum Core Segment Conc (mg/kg)	Approx 10^6 cu yds (total)	Environ-mental Concern Due to Cadmium?
+103+000	+90+000	2.42	1.12 – 10.64	4.980	No
+90+000	+80+125	10.02	1.09 – 21.58	1.555	Yes
+80+125	+57+000	4.62	0.30 – 11.21	5.020	No
+57+000	+51+000	11.95	1.78 – 24.07	2.007	Yes
+51+000	+45+000	4.56	0.04 – 10.57	1.894	No
+45+000	+6+375	19.11	0.11 – 77.09	7.368	Yes
+6+375	-85+000	0.73	0.02 – 2.36	15.855	No

* Quantities for the 48-ft project include proposed advance maintenance from Stations +50+000 to +70+000 and passing lanes from Stations +55+000 to +58+000 and from Stations +16+000 to +19+000. A bulking factor of 1.4 should be used to estimate required upland disposal area capacities.

3.10 Availability of Cadmium

3.10.1 Complete Digestion vs. Standard Digestion.

One aspect of the Savannah Harbor Expansion Phase 2 testing (sampling 2005) involved a comparison of digestion techniques for metals -- the complete digestion technique used by ATM (fluoric acid) vs. standard digestion (nitric/hydrochloric acid). The concern was that the complete digestion technique might detect cadmium that was tightly bound in sediment minerals and not available to organisms, thus overestimating potential availability and environmental impacts.

A total of 34 sediment samples were compared using both digestions, with sediment cadmium levels ranging from non-detect (<about 0.2 ppm) to 74.92 ppm. For sediments where cadmium levels for both extractions were greater than 1 ppm, the standard extraction technique produced cadmium results averaging 0.2 ppm higher than the total extraction (n=24). For sediments where cadmium levels were less than or equal to 1 ppm for at least 1 extraction, the standard extraction technique produced cadmium results averaging 0.2 ppm lower than the total extraction technique (n=10). For all extraction data, the mean difference is (-0.26)(19) + (-0.06)(5) + (0.17)(10) = -0.1 mg/kg. These results indicate that there was essentially no difference in measured sediment cadmium levels produced by these two extraction techniques. This implied that the cadmium found in the clays might not be tightly bound within the clay structure. This finding led to a decision to investigate in greater detail how tightly cadmium was bound within the sediments to further assess potential bioavailability.

Table 22. Comparison of Digestions Methods Where Sediment Concentrations are Greater than 2.5 ppm

SAMPLE ID	CADMIUM RESULT (PPM)	MDL	PREP METHOD	DIFFERENCE[1]
SH010 + 000 (C)	19.20	0.337	EPA 3052	
SH010 + 000 (C)	12.06	0.037	EPA 3050B	7.14
SH025 + 282 (G)	74.92	0.382	EPA 3052	
SH025 + 282 (G)	71.99	0.043	EPA 3050B	2.92
SH026 + 000 (C)	5.41	0.391	EPA 3052	
SH026 + 000 (C)	4.59	0.041	EPA 3050B	0.82
SH026 + 500 (D)	19.05	0.532	EPA 3052	
SH026 + 500 (D)	20.09	0.059	EPA 3050B	-1.05
SH028 + 000 (E)	29.13	0.427	EPA 3052	
SH028 + 000 (E)	40.18	0.047	EPA 3050B	-11.05
SH030 + 000 (C)	9.17	0.325	EPA 3052	
SH030 + 000 (C)	5.06	0.035	EPA 3050B	4.11
SH034 + 000 (D)	10.02	0.459	EPA 3052	
SH034 + 000 (D)	10.65	0.051	EPA 3050B	-0.63
SH034 + 000 (Z)	7.49	0.401	EPA 3052	
SH034 + 000 (Z)	9.81	0.043	EPA 3050B	-2.32
SH036 + 000 (D)	11.99	0.317	EPA 3052	
SH036 + 000 (D)	19.63	0.05	EPA 3050B	-7.64
SH042 + 000 (G)	8.29	0.576	EPA 3052	
SH042 + 000 (G)	8.66	0.064	EPA 3050B	-0.38
SH048 + 000 (D)	6.46	0.56	EPA 3052	
SH048 + 000 (D)	4.95	0.06	EPA 3050B	1.51
SH050 + 000 (H)	10.57	0.516	EPA 3052	
SH050 + 000 (H)	11.20	0.056	EPA 3050B	-0.63
SH052 + 000 (H)	5.11	0.355	EPA 3052	
SH052 + 000 (H)	4.63	0.04	EPA 3050B	0.49
SH054 + 000 (G)	20.94	0.378	EPA 3052	
SH054 + 000 (G)	20.23	0.04	EPA 3050B	0.71
SH058 + 000 (F)	6.62	0.466	EPA 3052	
SH058 + 000 (F)	5.83	0.05	EPA 3050B	0.79
SH062 + 000 (G)	7.41	0.409	EPA 3052	
SH062 + 000 (G)	7.44	0.046	EPA 3050B	-0.02
SH065 + 000 (G)	9.40	0.433	EPA 3052	
SH065 + 000 (G)	10.09	0.049	EPA 3050B	-0.69
SH087 + 000 (F)	21.58	0.382	EPA 3052	
SH087 + 000 (F)	21.03	0.043	EPA 3050B	0.55
SH091 + 000 (D)	4.63	0.362	EPA 3052	
SH091 + 000 (D)	4.25	0.041	EPA 3050B	0.37

[1] This column shows the difference between the complete extraction (EPA 3052) and the standard extraction (EPA 3050B)

SAMPLE ID	CADMIUM RESULT (PPM)	MDL	PREP METHOD	DIFFERENCE[1]
			sum of differences	-5.00
			Mean difference	-0.26

3.10.2 TCLP Test Results

Savannah District's February 2006 Dredged Material Evaluation (2005 sampling) discussed the potential availability of cadmium in project sediments and concluded there is reason to believe that cadmium could be released from these sediments. The TCLP test was later conducted on some archived sediments from the 2005 sampling to gain further insight into the possibility for release of cadmium under certain conditions.

The TCLP procedures are designed to provide information concerning the mobility of a constituent in material (soil or other waste) by simulating the leaching of the material by slightly acidic groundwater. In this procedure, a sample of the soil or other material is tumbled with the leaching solution (an acetic acid-Sodium acetate buffer solution of pH close to 4.93) for 18 hours. The solids are allowed to settle and the liquid is separated from the solids by filtering through a 0.6 micron glass fiber filter. Centrifugation is not employed to separate the solids from the leachate. The solids are discarded.

The pH of the liquid (TCLP leachate) is measured and the leachate is then acidified to pH <2 with nitric acid. A known volume (25-mL) of the acidified leachate is digested in the same manner as an aqueous sample (EPA SW Method 6010/6020 for metals), adjusted to a final volume of 50-mL, and then filtered using a 0.45 micron filter only if suspended matter is present. Generally, this filtration step is not necessary for most of the TCLP leachates, since they are already filtered using the 0.6 micron filter prior to digestion. This filtration step is used for the sole purpose of preventing the digestate from clogging up the sample inlet when the original aqueous sample contains suspended matter. The analytical results obtained are the concentrations of the metals (or other substances) in the decanted leachate. The results of the TCLIP analyses performed on three archived 2005 samples are shown below.

Table 23. Results of TCLIP Analyses Performed for Cadmium in April 2006 on Archived Samples

Sample Number	Sediment Cd Concentration (mg/kg)	TCLP Cd Result (ug/l)
SH030+000(H)	77.057	56.8
SH091+000(F)	7.026	35.7
SH087+000(F)	21.58	62.5

These data provide further indications that cadmium could be released to the environment under certain conditions. This evidence supported the decision that a more detailed analysis of cadmium was warranted, including determining how the cadmium would be expected to behave under proposed dredging and dredged sediment handling alternatives.

3.10.3 Cadmium Concentrations in the High and Low Composites Created by EA (2008)

The final round of sediment sampling and testing for the SHEP was conducted in 2007. The scope of work called for collection of samples for porewater extraction and creation of "high" and "low" cadmium composites that would be subjected to a number of laboratory studies, including sequential extraction, bioaccumulation, and plant uptake. Cadmium concentrations of the two composites as revealed by several different analyses are listed below in Table 24.

Table 24. Cadmium Concentrations (in ppm) in Composites (EA, 2008)

Test	Low Cadmium Composite	High Cadmium Composite
Average of Sediment Composite and Duplicate	**15.0**	**29.8**
Microwave Digestion (ave of two samples)	13.05	30.95
Plant test sediment	15.1	26.2
Plant test dried sediment	13.5	32
Plant test washed & dried sediment	**15.4**	**36.9**
SEP total dried soil	16.6	43.1
SEP total washed & dried soil	15.0	36.8

3.10.4 Calculation of the Ratio of Simultaneously Extracted Metals to Acid Volatile Sulfide (SEM/AVS Ratio)

In low oxygenated environments, metals may precipitate with sulfides, rendering them unavailable for uptake by aquatic organisms. Therefore a SEM/AVS ratio less than one is an indication that the metals are not available. No acid volatile sulfide was detected in either the low or high cadmium composites from the 2007 sampling, so calculation of a ratio could not be made by EA (2008). These results leave open the possibility that metals in the sediment could be available.

3.10.5 Sediment Sequential Extraction Procedures (SEP)

3.10.5.1 Availability of Cadmium in SHEP Sediment. Sequential extraction procedures (SEP) were conducted on both the high and low cadmium composites produced from the 2007 sampling to determine what proportion of the cadmium was loosely bound (available). This procedure would provide information on how easily organisms would be expected to accumulate cadmium from the sediments. Metals in the exchangeable fraction are freely soluble and likely to be bioavailable. Metals in the exchangeable and carbonate fractions are likely to be available with minor decreases in pH. Metals in the organic fraction may be available given moderate changes over time. Metals in the hydroxide and sulfide fractions are only available under extreme conditions (EA 2008, page 5-5). Results of the SEP investigation show that 76 to 78 percent of the cadmium in the Miocene clay sediment is relatively unavailable and no cadmium is freely available. Furthermore, because of the relatively large portion of cadmium in the organic fraction (20-22 percent), it appears that conditions that would degrade the organic fraction would be expected to increase availability of cadmium.

Table 25. Results of Sequential Extraction of Cadmium from Sediment

	Low Cd Comp	Low Cd Comp Dup	High Cd Comp	High Cd Comp Dup
Exchangeable	0%	0%	0%	0%
Carbonate	1.78%	2.02%	1.96%	1.56%
Organic	20.13%	21.94%	20.50%	20.64%
Hydroxide	74.18%	71.00%	73.52%	73.51%
Sulfide	3.91%	4.62%	3.51%	3.75%
Residual	0%	0.42%	0.50%	0.53%
Relatively Unavailable Hyroxide/Sufide/Residual	78.01%	76.04%	77.53%	77.79%
Total by Microwave Digestion (mg/kg)	13.1	13.0	29.7	32.2
Separate Sediment Analysis (mg/kg)	15.1	14.5	26.2	33.4

3.10.5.2 Availability of Other Metals. EA (2008) found arsenic, chromium, and nickel in the high and low cadmium composites above ERL levels, but not above ERM levels. Arsenic and chromium were not identified as contaminants of concern and are known to exhibit little bioaccumulation. Because of minimal environmental concern related to these two metals, they were not investigated further.

3.10.5.2.1 Nickel. The SEP results for nickel (Tables 26 and 27) show that about 58 to 64 percent of the nickel in the Miocene clays is relatively unavailable, while 7 to 9 percent is freely available. Furthermore, these data indicate nickel could become more available under conditions promoting the degradation of both carbonates and organics. Although nickel was not identified as a contaminant of concern, its potential for bioaccumulation led to the decision to investigate its availability under aquatic conditions in the bioaccumulation study performed by EA using *Macoma nasuta* and *Nereis virens*. Although nickel was found to bioaccumulate above reference, EA (2008) found tissue levels were below benchmarks, indicating no environmental concern (see Section 4.2.5 for further discussion).

Table 26. Results of Sequential Extraction of Nickel from Sediment (mg/kg dry wt)

	Low Cd Comp	Low Cd Comp Dup	High Cd Comp	High Cd Comp Dup
Exchangeable	2.5	2.3	1.9	2.4
Carbonate	2.5	2.6	2.2	1.9
Organic	7.4	7.5	6.7	5
Hydroxide	2.9	2.9	2.5	2.7
Sulfide	12.8	13.4	8.6	9.3
Residual	5.4	4.8	3.7	4.4
Relatively Unavailable Hyroxide/Sufide/Residual	21.1	21.1	14.8	16.4
Total by Microwave Digestion mg/kg	23.5	25.3	23.1	27
Separate Sediment Analysis mg/kg	21.6	20.5	17.4	19

Table 27. Results of Sequential Extraction of Nickel from Sediment, as Percent of Total Nickel

	Low Cd Comp	Low Cd Comp Dup	High Cd Comp	High Cd Comp Dup
Exchangeable	7.5	6.9	7.4	9.3
Carbonate	7.5	7.8	8.6	7.4
Organic	22.1	22.4	26.2	19.5
Hydroxide	8.7	8.7	9.8	10.5
Sulfide	38.2	40.0	33.6	36.2
Residual	16.1	14.3	14.5	17.1
Relatively Unavailable Hyroxide/Sufide/Residual	62.9%	62.9%	57.8%	63.8%

3.10.5.2.2 Zinc. Zinc was not identified as a contaminant of concern as a result of either the 1997 sampling or the 2005 sampling. However, because of its potential to bioaccumulate, it was investigated further by EA (2008) during the 2007 sampling and analyses. Zinc was found to become somewhat more available under dry oxidizing conditions (Section 2.1.5). Zinc uptake in the bioaccumulation tests (wet sediment) was found to be significantly different from reference only in the clam, and only in the low cadmium composite. The observed increase in uptake over reference (9.32 vs. 10.2 mg/kg wet weight) was less than 10 percent and should have no environmental significance. See further discussion at Section 4.2.5. Potential impacts under oxidizing conditions were assessed through the plant uptake test. Zinc uptake was significantly higher than reference for both the low and high cadmium composites, indicating zinc effects could add to potential cadmium effects identified for elevated cadmium sediments placed on the dikes. See further discussion at Section 4.3.1.6.

3.10.6 Sequential Extraction Procedures (SEP) for Cadmium on Washed and Dried Composites

Sequential extraction procedures (SEP) were conducted on washed and dried samples from both the high and low cadmium composites produced from the 2007 sampling to determine what proportion of the cadmium would be loosely bound after the sediments are oxidized.

As shown in the following two tables, SEP data from EA show there is a change in potential availability of cadmium between project wet sediment and dry "soil". Both composites show an increase in the carbonate fraction when dried. The low cadmium composite in addition showed a decrease in the hydroxide fraction. The high cadmium composite showed an increase in all fractions, making interpretation difficult. These changes do indicate cadmium should be more available in the dried soil than the wet sediment.

Table 28. Comparison of Wet and Washed/Dried Low Cadmium Composite SEP Results for Cadmium

	Wet Low Cd mg/kg	Wet Low Cd Dup mg/kg	Washed Dry Low CD mg/kg	Wet Low Cd %	Wet Low Cd Dup %	Washed Dry Low Cd %
Exchangeable	<0.105	<0.11	<0.11	0.60	0.63	0.63
Carbonate	0.31	0.35	2.5	1.77	2.01	14.26
Hydroxide	12.9	12.3	10.1	73.59	70.56	57.62
Organic	3.5	3.8	3.1	19.97	21.80	17.68
Sulfide	0.68	0.8	0.99	3.88	4.59	5.65
Residual	<0.0355	0.073	0.73	0.20	0.42	4.16
Total	17.5305	17.433	17.53	100.00	100.00	100.00

Table 29. Comparison of Wet and Washed/Dried High Cadmium Composite SEP Results for Cadmium

	Wet High Cd mg/kg	Wet High Cd Dup mg/kg	Washed Dry High Cd mg/kg	Wet High Cd %	Wet High Cd Dup %	Washed Dry High Cd %
Exchangeable	<0.095	<0.1	0.18	0.28	0.31	0.42
Carbonate	0.67	0.5	1.8	1.96	1.56	4.25
Hydroxide	25.1	23.5	28.2	73.32	73.28	66.54
Organic	7	6.6	8.9	20.45	20.58	21.00
Sulfide	1.2	1.2	2.9	3.51	3.74	6.84
Residual	0.17	0.17	0.4	0.50	0.53	0.94
Total	34.235	32.07	42.38	100.00	100.00	100.00

3.10.7 Sediment Porewater Analyses

Porewater measurements are often a better indication of potential risk in wet environments than total sediment concentration, as porewater concentrations are considered available to aquatic organisms. Porewater analyses were performed on intact sediment samples by the U.S. Geological Survey (USGS, 2007). The maximum detected cadmium porewater concentration was 0.12 mg/l (see Tables 30 and 31, below). This value is well below USEPA/SC chronic water quality criteria/standards of 9.3 mg/L (total) and 8.8 mg/L (dissolved). These results indicate there should be minimal concern related to potential environmental impacts associated with sediment cadmium in an aquatic environment.

Table 30. Core 8 Porewater Analysis, Station +26+000

Sample depth*1	Cadmium (ug/L)*2	Chloride (mg/L)	Mean Sediment Cd Concentration (mg/kg)
6”	0.06	14,523	31.8
18”	0.03	12,428	31.8
30”	0.02	10,689	49.0
42”	0.01	8,309	49.0
54”	0.00	7,042	53.5
66”	0.01	5,820	53.5

*1 Refers to location of pore-water sample, inches from top of core
*2 Refers to pore-water cadmium, dissolved, in micrograms per liter.

Table 31. Core 3 Porewater Analysis, Station +26+500

Sample depth*1	Cadmium (ug/L)*2	Chloride (mg/L)	Mean Sediment Cd Concentration (mg/kg)
6”	0.12	14,146	42.9
18”	0.01	9,968	42.9
30”	0.01	10,122	46.2
42”	0.06	8,344	46.2
54”	0.01	5,980	64.1
66”	0.01	6,705	64.1

*1 Refers to location of porewater sample, inches from top of core
*2 Refers to pore-water cadmium, dissolved, in micrograms per liter.

3.10.8 Comparison of Surface Water Concentrations to Benchmarks

Two predictions of potential cadmium concentrations in water were made, one based on elutriate results, and the other based on cadmium concentrations measured in the bioaccumulation study tanks (EA 2008, Chapter 10.4.1.c). The elutriate studies found very high total cadmium concentrations, but only 1.5 ug/l dissolved cadmium in the high cadmium composite elutriates (see Tables 33 and 34 for the standard elutriate results). Since it is primarily dissolved cadmium that is believed to be available, this again indicates little environmental concern for cadmium in the aquatic environment. Furthermore, the elutriate test artificially ensured the test sediments were completely suspended prior to testing. The high TSS used in the elutriate tests may not accurately reflect what would happen during the dredging project, as the dredging process would not be expected to result in suspension of a large fraction of the clay particles (EA 2008, Chapter 10.4.1.c).

In the water quality monitoring associated with the bioaccumulation studies, the highest dissolved cadmium concentration was found to be 5.8 ug/L. Since this reading is also below chronic water quality criteria, this is further evidence there should be minimal concern related to potential environmental impacts associated with cadmium in an aquatic environment.

Table 32. Metal Concentrations in Dredging Water (Savannah River) and Receiving Water (Field's Cut) (ug/L), from EA, 2008, Table 6.3

	EPA/SC Acute Criteria	EPA/SC Chronic Criteria	Dredging Water Total	Dredging Water Dissolved	Receiving Water Total	Receiving Water Dissolved
Arsenic	69	36	7.5	20.8	11.7	16.5
Cadmium	40/43	8.8/9.3	<0.074	<0.074	<0.074	<0.074
Chromium	1,100	50	2.4	0.85	2.6	1.5
Copper	4.8/5.8	3.1/3.7	1.6	**7.5**	1.7	1.9
Lead	210/220	8.1/8.5	0.71	0.69	0.3	0.31
Manganese			15.9	2.2	36.2	26.6
Mercury	1.8/2.1	0.94/1.1	<0.048	<0.048	<0.048	0.053
Nickel	745/75	8.2/8.3	<0.2	4.1	0.66	1
Selenium	290	71	29.6	**93.6**	50.6	**75.4**
Silver	1.9/2.3		<0.31	<0.31	<0.31	<0.31
Thallium			0.26	<0.059	0.29	<0.059
Zinc	90/95	81/86	4.4	14.7	4	6.1

3.10.9 Conduct of Animal Bioaccumulation Studies

The sediment bioaccumulation studies conducted on the project high and low cadmium wet sediment composites found accumulation of cadmium and nickel above reference by a polychaete (*Nereis virens*) and accumulation of nickel and zinc above reference by a clam (*Macoma nasuta*). EA (2008) found tissue levels to be below benchmarks and risk analyses found no reason for concern. See paragraph 4.2.5 for further discussion.

3.10.10 Conduct of Plant Bioaccumulation Studies

A plant bioaccumulation study was conducted on project washed (to remove salinity) and dried high and low cadmium composites. Test plants were found to accumulate cadmium, nickel, and zinc significantly above reference for both the low and high cadmium composites. Plant growth was inversely related to cadmium concentrations, but other factors may have been operative (availability of nutrients). See further discussion at Section 4.3.1.5.

4.0 Proposed Action and Identification of Pathways of Concern

It is assumed that the majority of the SHEP dredging will be by hydraulic cutterhead dredge. Production rates make other forms of mechanical dredging impracticable. Hopper dredging is generally not suitable for the highly consolidated new work sediments. However, material from Stations +4+000 to -50+000B is being considered for both pipeline and hopper dredging. Material from Stations -50+000B to -98+000B is being considered for only hopper dredging.

The present plans are for the SHEP inner harbor dredged sediments to be placed by cutterhead hydraulic dredge in a DMCA adjacent to the channel. This should be the least expensive disposal method for sediments with minimal potential environmental impacts. Clamshell or other mechanical dredging equipment may also be used. For sediments requiring management due to concern over cadmium concentrations, ocean disposal is not deemed an option. Cadmium is one of the contaminants specifically prohibited by EPA regulations from ocean disposal at levels greater than trace. EPA regulations at 40 CFR 227.6(b) state "These constituents will be considered to be present as trace contaminants only when they are present in materials otherwise acceptable for ocean dumping in such forms and amounts in liquid, suspended particulate, and solid phases that the dumping of the materials will not cause significant undesirable effects, including the possibility of danger associated with their bioaccumulation in marine organisms." Furthermore, bioaccumulation studies demonstrated accumulation of cadmium above reference for the high cadmium sediment composite and no method has been identified for limiting exposure of these sediments after placement in the ocean.

For the SHEP sediments requiring management due to elevated levels of cadmium, there are three primary dredged material placement alternatives: (1) deposit the sediments in a DMCA, with subsequent management in the rotation plan; (2) deposit the sediments in a DMCA with capping/covering; and (3) deposit the sediments in a DMCA with capping/covering and lining. Management alternatives are discussed in detail at Chapter 6.0.

4.1 Identification of Pathways of Concern

The Upland Testing Manual provides guidance on evaluating the potential for contaminant-related impacts from deposition of dredged sediments within an upland DMCA. This guidance includes details on identifying the pathways by which a contaminant may be released from a DMCA and impact the surrounding environment. In addition, because the Navigation Project DMCAs are managed in a wet state to produce wetland habitat values as part of a wetland mitigation plan, guidance in the Inland Testing Manual is also relevant. This evaluation of potential sediment contaminant-related impacts uses guidance from the both the Upland Manual and Inland Manual (where appropriate).

The proposed work contains two separate actions through which cadmium could be released to the environment: dredging and dredged sediment placement. The potential pathways associated with each of these actions are listed below. Assessment of these pathways involves determining if a complete pathway exists (is there a potential for movement of a contaminant and is a receptor of concern present) and then determining the potential for affect to that receptor.

4.2 Potential Pathways through Dredging

4.2.1 Release of Sediment to the Water Column during the Dredging Activity

Discharges of sediment to the water column during hydraulic dredging, seen as increased turbidity in the water column, are normally considered *de minimis*. However, in this case the dredged sediment is expected to contain elevated levels of cadmium. The presence of sediments with elevated levels of cadmium raises the potential for environmental impact. However, the Miocene clays thought to contain elevated cadmium are expected to remain relatively intact during the dredging process and form clay balls that would be deposited in the DMCAs. Relatively minor amounts of clay would be expected to be released to the river water column. Furthermore, standard elutriate analyses on the sediment composites found the dissolved fraction of only three parameters (selenium, nickel, and ammonia) to be above water quality criteria (Table 34). Cadmium was not one of them.

EA (2008) ran the standard elutriate preparation on both the high and low cadmium composites and compared the results to EPA and SC water quality criteria. Total concentrations for several metals were high (EA, 2008, Table 6-5), but are not expected to reflect conditions in the field. This is because the elutriates were made by totally suspending all sediment in a sample, creating extremely concentrated suspended sediment mixtures that would not be expected under normal dredging conditions. This is because most of the clay sediment is expected to remain in large particles when dredged, mostly as clay balls, and not suspended in the water column. EA (2008) suggests the dissolved fraction should be a better estimate of metals that would actually be available to aquatic organisms in the river.

The selenium concentration in the dredging water was 93.6 ug/l (Table 32), making it highly unlikely that selenium in the dredged sediment contributed to the selenium criterion exceedence by the high cadmium composite elutriate (119 ug/L). This water was taken from the Savannah River and was not mixed with any cadmium-enriched sediment. The results for cadmium show there is little expectation for an exceedence of water quality criteria. In the cases of nickel and ammonia, ammonia would require the greatest dilution to meet chronic water quality criteria (factor of 8.7) and acute criteria

Table 33. Standard Elutriate Total Fraction Exceeding Criteria (from EA 2008, Table 6-5)

	USEPA/SC Acute Criteria	USEPA/SC Chronic Criteria	Low Cd Composite	High Cd Composite
Ammonia as N	9.14	1.37	15.5	6.1
Arsenic	69	36	944	1,200
Cadmium	40/43	8.8/9.3	1,790	3,740
Chromium	1,100	50	6,840	11,600
Copper	4.8/5.8	3.1/3.7	660	1,160
Lead	210/220	8.1/8.5	289	510
Mercury	1.8/2.1	0.94/1.1	3.2	6.7
Nickel	74/75	8.2/8.3	1,510	1,740
Selenium	290	71	249	342
Silver	1.9/2.3		21.3	78.2
Zinc	90/95	81/86	9,510	15,400

Table 34. Standard Elutriate Dissolved Fraction Showing Cadmium Results Plus Metals Exceeding Criteria (from EA 2008, Table 6-5)

	USEPA/SC Acute Criteria	USEPA/SC Chronic Criteria	Low Cd Composite	High Cd Composite
Ammonia, mg/L	9.14	1.37	**11.9**	**5.2**
Nickel, ug/L	74/75	8.2/8.3	**17.1**	**29.2**
Selenium, ug/L	290	71	**56**	**119**
Cadmium, ug/L	40/43	8.8/9.3	<0.37	1.5

(factor of 1.3). A dilution factor of 1.3 for acute exceedences means that almost immediate dilution with river water should reduce ammonia levels below acute criteria. Moreover, dilutions of greater than 8 to 1 would be expected far before the 4-day chronic exposure criteria are exceeded. Therefore, there should be little environmental concern related to river water metal concentrations exceeding criteria due to Expansion dredging.

4.2.2 Movement of Cadmium from Sediment in the Water Column to Aquatic Resources within the River

Measurements of pore water cadmium from high Cd sediments (Tables 30 and 31), dissolved cadmium in standard elutriates of both low and high cadmium sediment (Tables 33 and 34), and measurements of cadmium concentrations found in the overlying water for the bioaccumulation tests (Section 3.10.8) were all less than water quality criteria.

These data show there should be little concern for dissolved cadmium to be released to the water column during dredging.

4.2.3 Exposure of Cadmium Containing Sediment within the Channel Banks and Bottom to the Water Column, with Movement of Cadmium from the Sediment to the Water Column and then to Aquatic Resources within the River

In order for a complete pathway to exist from cadmium-containing Miocene sediments to the water column, the Miocene clays have to be exposed to the water column, and cadmium must move from the clays to the water column. To estimate the portions of the channel where channel bottom surface clays would be expected to remain exposed to the water column, several different investigations were conducted. Several of these assessments are discussed at Section 3.8.2. When annual dredging volumes are examined by channel reach, the data show where the majority of dredging takes place. In those reaches with large annual volumes of maintenance sediments, the channel bottom would be expected to be covered by O&M sediments for most of the year. In such areas, there would be little potential for environmental impacts, even if the underlying sediments contained elevated cadmium. Average annual dredging volumes by reach are show below in Table 35. A volume of about 18,500 cu yds represents an average cover of about 1 foot of maintenance material in a 1,000-foot section of the channel. These data show the reach from Stations +16+000 to +34+000 to be the primary location where channel bottom sediments with elevated cadmium concentrations might be expected to be exposed for any period of time.

Table 35. Annual Volume Dredged by Station 1970 thru 1975, 1981 thru 1985, and 1997 thru 2004 (from *Sedimentation Analysis*, CESAW (Mike Wutkowski, 22 Feb 06)

Station	Annual Volume 1970 - 1975	Annual Volume 1981 - 1985	Annual Volume 1997 - 2004	Cadmium at Bottom Surface after SHEP (mg/kg)
0+000	11,001	8,797	9,683	1.16
1+000	11,001	15,079	9,683	
2+000	11,001	18,823	11,380	1.65
3+000	11,001	19,272	10,010	
4+000	11,001	19,272	21,153	
5+000	8,447	19,272	21,153	
6+000	8,447	19,272	21,367	
7+000	18,585	12,459	837	
8+000	22,019	22,587	1,995	
9+000	22,019	22,587	6,803	
10+000	22,019	22,587	6,659	0.42
11+000	22,019	12,459	4,355	
12+000	21,611	10,694	5,533	
13+000	13,036	10,694	5,621	
14+000	13,036	19,881	9,411	
15+000	13,036	16,709	12,069	
16+000	8,497	16,709	14,940	
17+000	8,497	16,709	15,306	
18+000	20,191	29,664	15,312	
19+000	20,606	22,080	12,786	
20+000	20,606	17,662	12,392	
21+000	8,912	14,832	7,948	
22+000	8,912	14,832	2,053	
23+000	8,912	14,832	1,516	
24+000	8,912	16,425	4,915	57.85
25+000	8,912	32,183	3,731	31.26
26+000	10,520	32,183	19,921	15.50
27+000	18,108	32,183	16,190	12.92
28+000	18,108	509	13,100	7.72
29+000	10,520	509	13,482	
30+000	45,568	9,155	10,411	77.09
31+000	45,568	9,155	10,738	
32+000	45,568	9,155	10,738	1.02
33+000	45,568	3,615	8,577	
34+000	28,481	3,084	5,382	16.86
35+000	14,103	57,629	34,378	

36+000	29,818	57,629	40,242	15.60
37+000	38,433	57,629	28,060	
38+000	40,495	46,069	19,905	6.53
39+000	33,758	46,069	20,292	
40+000	76,149	66,182	12,368	26.12
41+000	116,413	66,182	17,180	
42+000	124,529	66,182	26,794	26.05
43+000	128,368	54,853	34,487	
44+000	142,068	53,224	13,999	9.76
45+000	135,979	43,934	20,683	
46+000	106,296	53,275	16,493	0.06
47+000	133,497	39,085	20,828	
48+000	146,264	45,191	20,529	9.66
49+000	163,380	61,778	21,759	
50+000	141,880	61,778	18,002	10.57
51+000	174,377	71,137	20,598	
52+000	188,639	92,452	20,598	5.11
53+000	193,596	93,785	8,704	
54+000	190,299	115,300	9,277	7.38
55+000	161,113	76,769	5,096	
56+000	160,300	55,987	4,693	6.23
57+000	122,867	52,886	5,454	
58+000	109,962	49,485	4,906	9.08
59+000	133,168	57,258	37,995	
60+000	131,148	45,450	49,241	9.02
61+000	110,486	45,450	61,092	
62+000	106,426	45,551	39,164	10.47
63+000	89,087	53,840	30,262	
64+000	100,260	35,414	15,444	
65+000	101,008	25,862	15,243	5.96
66+000	106,589	16,393	34,283	
67+000	274,687	88,310	69,954	
68+000	266,254	118,417	81,214	
69+000	275,892	117,415	81,214	
70+000	48,582	8,586	74,633	10.97
71+000	48,582	8,586	77,856	
72+000	48,582	2,414	71,549	
73+000	37,644	2,414	8,005	
74+000	0	13,229	12,072	
75+000	0	16,478	17,602	
76+000	18,037	16,120	19,442	
77+000	18,037	17,767	15,030	4.07
78+000	18,037	1,647	15,030	
79+000	19,574	0	3,057	
80+000	20,826	6,988	2,415	

81+000	24,844	6,988	2,415	
82+000	28,076	143	8,156	
83+000	29,352	1,866	11,103	9.81
84+000	32,851	143	1,294	
85+000	27,249	143	1,294	
86+000	25,973	143	13,693	
87+000	22,059	0	30,111	20.14
88+000	36,358	357	51,888	
89+000	145,865	3,547	58,976	16.68
90+000	152,442	3,414	70,584	
91+000	177,433	3,414	74,601	10.64
92+000	32,716	534	44,419	
93+000	32,276	534	1,673	9.20
94+000	9,929	534	1,673	
95+000	9,929	0	1,673	1.93
96+000	23,753	0	1,381	
97+000	82,606	26,268	116,226	2.01
98+000	455,992	63,995	189,772	
99+000	459,867	63,995	399,576	1.76
100+000	434,603	100,592	308,948	
101+000	56,211	64,377	239,898	1.96
102+000	68,420	37,007	49,172	
103+000	90,052	29,667	41,306	1.80
104+000	76,625	9,392	42,106	
105+000	59,900	6,954	32,687	
106+000	16,264	776	2,191	
107+000	16,264	776	2,191	
108+000	16,264	1,256	2,191	
109+000	27,795	3,339	10,857	
110+000	62,488	17,082	17,411	
111+000	62,488	17,082	17,411	
112+000	51,033	17,082	18,226	
113+000	23,238	0	0	

EA (2008) used both sediment profile imaging (SPI) and side scan sonar imaging to assess how much of the channel bottom surface is currently exposed to the water column and how much is covered by O&M sediments. With these techniques, they were able to determine the distribution and proportion of exposed clays relative to other bottom habitat types. While small areas of exposed Miocene clays were identified in some specific portions of the target areas, these regions were isolated and discontinuous throughout the channel bottom (EA 2008, page ES-2).

Side scan sonar was used by EA to document the bottom characteristics between Stations +16+500 and +62+000. They found 28 percent of the channel bottom was comprised of compact clays, course sands and gravels. In addition, more intense side scan sonar investigations in the region between Stations +24+000 and +30+000 found active sand wave migration occurring on the order of 4 to 6 feet per tide cycle. The results of the SPI and side scan sonar investigations indicate that only a small portion of the channel bottom currently contains exposed Miocene clay and that the majority of the channel is covered by shifting bottom sediments. Because the District predicts little change in channel sedimentation patterns due to Expansion, this condition is expected to be characteristic of the channel bottom after Expansion dredging is completed. Therefore, between Stations +16+000 and +62+000, Expansion dredging is expected to result in a channel bottom where only a small portion of the bottom would consist of exposed Miocene clays. The channel bottom above Station +60+000 is not expected to contain any exposed Miocene, since high siltation rates are expected to result in a channel bottom covered with silts. In conclusion, the post-project condition is expected to include a channel bottom in which only a small area of Miocene clay would be exposed at any one time. Therefore, the potential for cadmium-related impacts to the water column due to exposed cadmium containing clays is expected to be minimal.

As further support for this expectation, the findings of both the porewater study (Section 3.10.7) and the bioaccumulation monitoring (Section 3.10.8) show cadmium-containing sediments release cadmium at levels below water quality criteria, indicating that if the high cadmium sediments were exposed to the river water column, release of cadmium would be expected to be minimal.

4.2.4 Colonization of Exposed Cadmium-containing Sediments by Benthic Organisms, with Movement of Cadmium through Benthics to the Aquatic Food Chain

Several factors could influence the degree to which cadmium might move from channel bottom sediment to benthics to the aquatic food chain: (1) Would clay sediment with elevated cadmium be exposed so that benthics growing in the clay could support an aquatic food chain? (2) Can Miocene clays support benthic organisms? (3) Would cadmium in the bottom sediments be available to benthic organisms such that the organisms would accumulate cadmium and pass it through the food chain?

EA (2008) conducted a benthic community assessment of the river bottom both inside and outside the channel. They found a substantial benthic community within the channel bottom. In addition, they found that the course sand/gravel/clay substrate was used by benthic organisms, although they were unable to determine to what extent benthic organisms might burrow into the clay. They found that the substantial presence of benthic organisms within the channel maintenance sediments indicates that the impact of maintenance dredging is temporary. However, the limited availability of exposed high cadmium sediments within the navigation channel, as discussed above, precludes more than minimal potential for clay dwelling benthic input to the riverine ecosystem. EA found that the clay substrate does support benthic organisms, but this substrate should be exposed only between Stations +16+000 and +60+000 and should comprise less than 28 percent of the channel bottom between those stations. This finding indicates that benthic organisms residing in exposed Miocene clays should present a relatively small fraction of the benthic organisms within the channel ecosystem. Because of the predicted small fraction of available habitat, potential impacts through bioaccumulation of cadmium by benthic organisms within the Miocene clays appear to be minor, but not zero. To be conservative, the potential for bioaccumulation of cadmium by benthic organisms is addressed in the next section. The bioaccumulation studies discussed below show bioaccumulation in high cadmium sediments to be well below potential levels of effect. Therefore, potential environmental impacts through bioaccumulation of cadmium by benthic organisms is expected to be minimal.

4.2.5 28-day Bioaccumulation Studies Using Miocene Clay Composites

Aquatic Bioaccumulation Studies were performed by EA (EA 2008, Chapter 8). These studies were performed in accordance with EPA protocols for evaluation of dredged sediment proposed for placement in the ocean. The studies used sand worms (*Nereis virens*) and the blunt-nosed clam (*Macoma nasuta*) grown in both the low cadmium and high cadmium wet composites and reference sediment. Although the only contaminant of concern had at that time already been identified to be cadmium, a set of metals detected in the project sediments and deemed most likely to bioaccumulate were evaluated (cadmium, copper, lead, mercury, nickel, zinc) to address any potential concerns that might be raised by others. The results of that study are discussed below. The detailed results of that study are shown in EA, 2008, Table 8-7.

Tissue results significantly different from reference values are shown in Tables 36 and 37, below. The bioaccumulation study found that cadmium and nickel concentrations in the worm tissues statistically exceeded concentrations in reference site tissues for both the high cadmium and low cadmium wet sediment composites. Copper, lead, mercury and zinc tissue concentrations showed no significant difference from reference. The clam tissues showed no differences from reference for cadmium, but did find significant differences for nickel, using both composites. Zinc uptake in the clam was inconclusive, with the low cadmium composite tissues showing a significant but only slightly higher tissue zinc concentration when compared to reference, but the high cadmium composite tissues showing no difference. Given that the low cadmium composite contained 96 ppm zinc compared to 164 ppm zinc in the high cadmium composite, the observed significant difference from reference for zinc in the low cadmium composite is probably due to chance variation and should have no environmental significance. When compared to the clam results, higher uptake levels for cadmium and nickel were shown by the worm (Table 36) and those results (Table 37) are discussed here as the worst case scenario.

Table 36. Mean Tissue Metal Concentrations (mg/kg wet wt) from Bioaccumulation Study (EA 2008, Table 8-7), Showing Results Significantly Different from Reference (in Bold)

	Reference	Low Cd Composite	High Cd Composite
Worm Tissue Cd Conc	0.0164	**0.113**	**0.198**
Sediment Cd Conc	0.15	15	30
BCF	0.11	0.0075	0.0066
Worm Tissue Ni Conc	0.248	**0.678**	**0.694**
Sediment Ni Conc	4.6	21	18
BCF	0.054	0.032	0.039
Clam Tissue Ni Conc	0.368	**0.54**	**0.484**
Sediment Ni Conc	4.6	21	18
BCF	0.08	0.026	0.027
Clam Tissue Zn Conc	9.32	**10.2**	9.38
Sediment Zn Conc	25.8	96	147
BCF	0.36	0.11	0.064

Table 37. Worm Tissue Results from Bioaccumulation Study (EA 2008, Table 8-7), mg/kg wet wt.

	Reference	Low Cd Composite	High Cd Composite	NOAEL (ERED)
Cadmium	0.0164	0.113	0.198	1.12 [*1]
Nickel	0.248	0.678	0.694	2.0 [*2]

* 1 Lowest Cadmium NOAEL in ERED database for *Neanthes arenaceodentata*; NOAELs for other polychaetes (*Laeonereis acuta*) range from 0.14 to 0.48 mg/kg.
* 2 Rainbow Trout (lowest NOED/NOAEL for nickel in ERED database, except for a frog).

The sequential extraction and bioaccumulation results provide an expectation that, given the opportunity, some aquatic organisms would be expected to bioaccumulate cadmium and nickel. However, worm tissue levels observed in the bioaccumulation study for both cadmium and nickel were at or below most NOAELs published in the ERED database. The database does contain starfish LOEDs of 0.03 mg/kg Cd(gonad) in males and 0.14 mg/kg Cd(gonad) in females. Starfish are known from bioassay studies to be very sensitive organisms. These data, therefore, show the potential for borderline effects in very sensitive benthic organisms. Overall, these data show there should be minimal environmental concerns for benthic aquatic organisms exposed to the cadmium-containing sediments within the river.

To predict fish tissue levels, an overly conservative assumption that the BAcF=1 would predict fish tissue levels would be the same as worm tissue. This assumes the fish would feed entirely on worms living in the cadmium-containing sediments. The ERED database shows a cadmium NOAEL of 0.3 mg/kg-wet wt. and an LOED of 0.9 mg/kg Cd for developmental impacts to the sheepshead minnow (*Cyprinodon variegates).* Since the cadmium worm tissue concentration in the high cadmium composite was found to be about 0.2 mg/kg wet wt., there should be no environmental concerns related to fish living and feeding in the river.

For predicting potential effects to higher trophic level organisms, a wildlife ingestion model was used by EA (EA 2008, Section 10.2.1) to develop dose-based exposure estimates. The cadmium tissue uptake results were evaluated in a risk assessment by EA (EA 2008, Chapter 10) using winter flounder as a surrogate for short-nosed sturgeon, great blue heron, spotted sandpiper, osprey, river otter, and Canada goose and muskrat as surrogates for wetland herbivores. These estimates were compared to NOAELs and LOAELs. NOAELs were calculated as the geometric mean of NOAELs for growth and reproduction. For birds, the NOAEL endpoints ranged from 0.125 to 12.5 mg/kg-bw day and the geometric mean was 1.47 mg/kg-bw day. For bird LOAELs for growth and reproduction, the data range from 2.37 to 37.6 mg/kg-bw day, with a geometric mean of 5.88 mg/kg-bw day. The lowest bounded LOAEL, 2.37 mg/kg-bw day was selected as an unbiased estimate of the 95 percent LPL (Lower Prediction Limit, EA 2008, 10.3.3.a). Exposure estimates were generated for great blue heron, spotted sandpiper, osprey, and river otter for both low and high cadmium sediments as shown in the table below (from EA 2008, Table 10-13).

Table 38. Cadmium Exposure Estimates for Wet Sediments (from EA, 2008, Table 10-13, and Response to Comments, an Appendix to this Report), (mg/kg bw-day)

	Low Cd Composite	High Cd Composite
Great blue heron	0.212	0.418
Osprey	0.037	0.067
Spotted sandpiper	0.81	1.63
River otter	0.091	0.175

These data show the spotted sandpiper at 1.63 mg/kg bw day (high cadmium composite), slightly above the NOAEL of 1.47, but below the LOAEL of 2.37 mg/kg bw-day. Because of the conservative assumptions built into the consumption estimates, including the high improbability of any bird feeding on benthic organisms in contact with the high cadmium Miocene clays in the channel bottom, the District's overall assessment is that there would be no environmental concerns related to higher trophic level wildlife feeding along the Savannah River.

4.3 Potential Contaminant Pathways Associated with Dredged Sediment Placement in a DMCA

The Upland Manual contains Corps of Engineers guidelines for assessing the pathways by which a contaminant placed in an upland DMCA may impact the environment. These pathways are listed in the Upland Manual as effluent, surface runoff, leachate, volatiles, plant uptake, and animal uptake (USACE, 2003, page 2-3).

If there is a potential for the presence of a COC in the dredged sediment and an evaluation of pathways is deemed appropriate, the next step in the evaluation process is to identify the relevant pathways of concern (Upland Manual, sections 3.1 and 3.2). Exposure of workers is also a standard item of concern. Corps of Engineers experts in dredged sediment evaluation from ERDC and experts in risk assessment from the Hazardous, Toxic, and Radioactive Waste Center of Expertise (CENWO-HX-S) were consulted to perform screening level assessments of these pathways. Where insufficient evidence was available to make a determination of potential effect, Tier III assessment procedures were followed.

Under the District's rotation management plan, DMCAs are held in a wet state for 3 years and then dried for 3 years. While a DMCA is in a wet state, sediments are expected to remain essentially saturated and for the most part anoxic. In the dry state, sediments will be dry and oxidized. Contaminants can be expected to behave differently under these two sets of conditions. Therefore, contaminant pathways have been examined for both conditions.

The current management strategy for the DMCAs is to hold water in the areas while dredging is being conducted and after dredging is complete. The intent is to maintain the DMCAs in an aquatic state to generate wildlife habitats (as part of the LTMS wetland mitigation plan). After functioning in an aquatic state for a number of years (usually 3), the DMCAs are drained and ditched to dry the sediments. After one to two years of drying, sediments are excavated from the areas and used to raise the dikes. During the drying phase and subsequent placement on the dikes, the sediments oxidize and take on characteristics of soils. Because the availability of sediment cadmium may change as sediment dries and is oxidized, the potential movement of cadmium to the environment from a DMCA is addressed separately for the aquatic state and for the dry condition.

A Tier I assessment of environmental effects within a DMCA involves development of a conceptual model (Section 8.2.2 of the Upland Manual). Paragraph 8.2.3 states the following: "If a reasonable complete exposure route to a ROC population outside the DMCA exists, there is generally no risk of an effect unless there is potential for a sufficient number of individual organisms to be affected in a manner severe enough to threaten the long-term sustainability of viable local populations of the ROC outside the CDF." A conceptual model for the rotational use of the DMCAs is described in PD-EC, 2006. It includes effects within the DMCAs, because the DMCAs are managed to produce wetland habitat and the DMCAs attract large numbers of migratory birds. For any alternatives involving capping/covering of enriched sediments, the bioaccumulation potential within the DMCAs would be minimal. However, this model clearly shows that with inclusion of enriched sediments in the rotation of the DMCAs, there are complete pathways for several ROCs that could potentially affect the long-term sustainability of local populations. The following sections discuss potential pathways for both the dry and wet scenarios, identify complete pathways of concern, and discuss potential risk to local populations of organisms.

4.3.1 Potential Cadmium Pathways for Drying and Dry Sediments within a DMCA

For drying sediments within a DMCA, the potential pathways by which cadmium could enter the environment outside the DMCA are as follows: volatilization, effluent, surface runoff, leachate, plant uptake (with movement to species that leave the DMCA), animal uptake (Upland Manual, page 2-3), and worker exposure.

4.3.1.1 Volatilization. There is little concern for volatilization of cadmium compounds at levels of potential environmental effect, since cadmium and the compounds in which it would occur in sediments are not volatile (see CENWO, 2006a). No further evaluation of this pathway is warranted.

4.3.1.2 Effluent. Appendix C of the Inland Testing Manual provides guidance on mixing zone evaluations and models to predict compliance with State Water Quality Criteria. The following information includes the available data on cadmium concentrations in waters associated with the Savannah Harbor project.

On September 12, 1997, a Savannah River background water sample was taken at Station -9+800 and found to contain cadmium at an estimated 0.544 ug/L (J flagged). A background water sample was taken at Station +36+200 on September 13, 1997 and found to contain cadmium at an estimated 0.652 ug/L (total fraction, J flagged)(111 mg/L TSS). An elutriate of the Area 1 (Station 36+200) composite (about 4.38 mg/kg Cd) was found to show 0.220 ug/L Cd (total fraction) and <0.208 ug/L Cd (dissolved fraction) (GEL, Dec. 1997, Advance Maintenance Sediment Testing Report).

Two samples of river water (taken from -35 feet MLW Oct-Nov 1997) at Stations +90+000 and +55+000 showed non-detect with a PQL of 0.001 ug/L (dissolved fraction)(Savannah Harbor Deepening, ATM 1998).

Savannah River water metals data were taken during the Agitation Dredging Study in Mar 2001. River samples (surface, mid-level, and bottom) unaffected by the agitation dredging plumes were all found to be non-detect for cadmium (about 55 samples) with a DL of 0.251 ug/L, except for one upcurrent sample that showed an estimated level of 0.45 ug/L (J flagged). About 9 samples downcurrent from the agitation dredging events showed estimated (J flagged) cadmium values ranging from 0.280 to 0.902 ug/L. These are thought to have been taken within the dredge plume. All of the samples were taken from about Stations +71+000 to +92+000 on March 7, 8 and 14, 2001 (ATM, 2002).

The Nov 2004 ENSR Savannah Harbor O&M Sediment Evaluation performed modified elutriate studies on 5 composites of inner harbor O&M sediments. These composites showed the following cadmium concentrations. These concentrations reflect expected cadmium concentrations in water standing in the DMCAs immediately following an O&M dredging event.

Table 39. Predicted Cadmium Concentrations in DMCA Water after an O&M Disposal

Station Composite	Sediment Cd Concentration (mg/kg dry wt)	Dissolved Cadmium (ug/L)	Total Cadmium (ug/L)
Kings Island TB	0.3 U	0.05 U	0.05
60+000 to 90+000	1	0.05 U	0.11
30+000 to 50+000	0.69	0.07	0.06
5+000 to 25+000	0.29 U	0.06	0.08
Sediment Basin	0.34	0.05 U	0.07

ERDC used existing data (including a bulk sediment cadmium concentration of 21 mg/kg) to conservatively estimate a DMCA effluent cadmium concentration for the SHEP of no more than 2.2 ug/L. The marine chronic water quality criterion for cadmium is 8.8 ug/L. The predicted effluent concentration is not likely to violate marine chronic water quality criteria, with no mixing zone required. They found it is not likely that DMCA effluent cadmium concentrations would cause environmental impacts and recommended no further evaluation of this pathway (ERDC, July 06).

To confirm this recommendation, EA conducted the effluent elutriate test on both the low cadmium and high cadmium sediment composites. The effluent elutriate test is designed to estimate contaminant concentrations that may occur within a DMCA and its effluent. The results of their analyses are shown in Table 40.

Table 40. Effluent Elutriate Dissolved Fraction (from EA 2008, Table 6-5)

	USEPA/SC Acute Criteria	USEPA/SC Chronic Criteria	Low Cd Composite	High Cd Composite
Ammonia	9.14 mg/L	1.37 mg/L	**9.7 mg/L**	**4.9 mg/L**
Nickel	74/75 ug/L	8.2/8.3 ug/L	**15.5 ug/L**	**21.7 ug/L**
Selenium	290 ug/L	71 ug/L	78.6 ug/L	**96.6 ug/L**
Cadmium	40/43 ug/L	8.8/9.3 ug/L	<0.37 ug/L	0.82 ug/L

As was the case for the standard elutriate results, ammonia estimates exceed both the acute (factor of 1.06) and chronic (factor of 7.1) water quality criteria. As discussed under the standard elutriate results, dissolved cadmium concentrations do not exceed criteria, and selenium exceedences are due to concentrations in the dredging water (see Section 4.1.1). Nickel concentrations exceed the chronic criteria by a factor of 2.6. These dilution factors indicate dilution of effluent in receiving waters should result in no exceedences of water quality criteria well before the 4-day chronic exposure time is met. Therefore, there should be little concern for environmental impacts due to effluent discharge.

Potential impacts associated with organisms living and feeding in ponded water within a DMCA are addressed under the ponded scenario (Section 4.3.2), below.

4.3.1.3. Surface Runoff. There is a run-off water quality screen at paragraph 5.3.1 in the Upland Manual. Using that screen, ERDC conservatively predicted the runoff cadmium concentration to be 26 ug/L, which is less than the Federal marine acute water quality criterion of 40 ug/l. They expected that this concentration would decrease over time as cadmium leaches from the soil, and would be expected to drop below the marine chronic criterion of 8.8 ug/l in a short time (ERDC, July 2006, page 18, par. 4). They concluded it is not likely that DMCA effluent cadmium concentrations would cause environmental impacts and no further evaluation of this pathway was necessary. EA (2008), conducted the SLRP test on both the low and high dried sediment composites to verify the ERDC conclusion. These data show violation of only the SC total criteria, and only for the highly unlikely event of runoff containing 5,000 mg/L TSS (see Table 41, below). Since that TSS level greatly exceeds the 500 mg/L standard that Savannah District uses for discharges from the DMCAs, violation of that criterion is not expected. Taking into consideration that the high cadmium sediment composite contained a much higher cadmium concentration (37.1 mg/kg) than the expected average cadmium concentration from the high cadmium reach from Stations +6+375 to +45+000 (19.1 mg/kg), these data confirm the prediction that runoff from dried sediment should not have an adverse effect on the environment.

Table 41. Results of SLRP (Simulated Runoff Procedure) on Dried High Cadmium Sediment Composite (from EA, 2008, Table 10-7)

	Units	EPA Criterion Acute/ Chronic	SC WQ Standard Acute/ Chronic	Low Suspended Solids	Moderate Suspended Solids	High Suspended Solids
TSS	mg/L			50	500	5000
Total Cadmium	ug/L		43/9.3	0.893	7.77	67.5
Dissolved Cadmium	ug/L	40/8.8		0.367	1.37	8.43

4.3.1.4 Leachate. A Leachate Water Quality Screen is described in paragraph 6.3.1 of the Upland Manual. Cadmium would be expected to leach from both unoxidized and oxidized sediment, but at different rates. Freshly dredged sediment and sediment maintained in a wet state would be expected to remain essentially unoxidized. ERDC conservatively estimated the pore water concentration of cadmium in unoxidized/reduced sediment to be 2.4 ug/L. Actual porewater measurements by USGS found porewater cadmium concentrations of no more than 0.12 ug/L (Section 3.10.7). The drinking water standard is 5 ug/L. Therefore, no environmental impacts should be expected due to leachate from unoxidized/reduced sediment.

If the cadmium-enriched sediments deposited within a DMCA were subsequently used to construct dikes, the cadmium would be expected to oxidize. ERDC conservatively estimated pore water cadmium concentration in oxidized sediments used directly to construct dikes (with no interim period of time where leaching would occur) to be 152 ug/L. Surficial seepage from sediment placed on the dike in that manner and maintained in an oxidized geochemical environment may impact ground water because its pore water concentration in oxidized material is conservatively estimated to be 152 µg/L. Seepage from the DMCAs would interact with foundation soils in the vadose zone and disperse in the surficial aquifer under the DMCA. With the sediment under oxidized conditions, it appears there is a potential for elevated concentrations of cadmium to enter the surficial aquifer in the distant future. However, the surficial aquifer is not used as a drinking water source. ERDC concluded that "No significant breakthrough of cadmium would be expected in thousands of years" (ERDC, July 2006, page 18, par. 2). ERDC evaluated sediments with cadmium levels of 28.4 to 60 mg/kg, although their conclusions are based on a sediment cadmium level of 21 mg/kg. Since they saw no reason for concern from this pathway using a cadmium level of 21 mg/kg, we assume that there would be no leachate concerns related to sediments containing less cadmium (including the reaches averaging about 4.6 mg/kg).

Savannah District geologists assessed the possibility of ground-water impacts from placing the cadmium-bearing soils in the proposed DMCA (EN-GG, 2006). A records search indicated that there are no historical data that show cadmium-bearing soils have impacted ground-water quality in the coastal Georgia region. According to the City of Savannah and the USGS, wells in the Savannah area and the coastal region, whether screened in the confined aquifer or surficial aquifer system, generally do not indicate presence of cadmium in ground water. The assessment also indicated that the physical characteristics and thickness of confining material underlying the DMCA would most likely severely inhibit any potential interactions with the underlying confined aquifer and that the volume of water associated with the cadmium-bearing soils was insignificant when compared with the daily yield of the confined aquifer. This indicates that even if ERDC's estimate of a porewater cadmium concentration of 152 ug/L under oxidized conditions is correct, the volume of water carrying this concentration is so small that there should be no cadmium-related environmental impacts, including no expectation of violation of the cadmium drinking water standard.

4.3.1.5 Plant Uptake in Dry DMCAs. Plant bioaccumulation in a dry soil environment is a pathway of concern with the rotational use of the DMCAs, since the conceptual model (PD-EC, 2006b) shows several species of birds that have plants found within the dry DMCAs as comprising a substantial part of their diet or supporting their food chain. A Tier II Plant Bioaccumulation Screen has been developed by the Corps of Engineers Waterways Experiment Station (same organization as ERDC). This is a procedure to extract metals from sediment using diethylenetriamine-pentaacetic acid (DTPA), with the data requiring analysis with the PUP model (Upland Manual, Appendix H, H.2). This procedure has been used to predict plant bioaccumulation from dredged sediments placed in terrestrial (wetland and upland) environments (Upland Manual, Section 9.3.2). An assessment would then be made of whether birds feeding on these plants or their herbivores are likely to be impacted through bioaccumulation of cadmium.

ERDC conducted the DTPA procedure on archived samples from the 2005 sampling. The results indicate some unusual responses in pH and redox potential, which are key controllers of cadmium availability. As such, the PUP estimates they calculated are considered unreliable for determining cadmium bioavailability through the plant pathway. The highest predicted plant concentration (8.77 mg/kg) which ERDC calculated exceeds the limitations in leafy vegetables and animal feeds set by the World Health Organization and the European Community ranging from 0.1 mg kg^{-1} (fresh weight) to 1.0 mg kg^{-1} (dry weight) (ERDC, 2006). Without further information, cadmium bioavailability through the plant pathway could not be ruled out as potentially resulting in impacts to birds feeding on plants within a DMCA. Plant bioassays were subsequently conducted by EA (2008) to provide more reliable quantitative information on which to judge the environmental effects of unrestricted placement of cadmium enriched sediments within a DMCA.

Capping/covering enriched sediments could negate the need for plant bioassays, if cadmium levels in the covering materials themselves are sufficiently low. Based on the plant tissue concentrations predicted by PUP (Table 4), and measured sediment concentrations, ERDC calculated allowable sediment concentrations (yielding a plant tissue concentration of 1 mg/kg dry weight). These data were found to be quite variable, and ERDC’s analysis indicated that sediment cadmium concentrations for sediment which could be used as covering material range from 2.39 mg/kg to 77 mg/kg (depending on which data were used for the prediction). More definitive resolution of covering material criteria was not possible with the earlier data. Therefore, plant bioassays were chosen to address potential impacts for all dry sediments averaging over 2 ppm cadmium.

Potential pathways of concern for plant uptake in an upland environment include: (1) plant contact with soil; and (2) plant contact with water. These pathways lead to two pathways by which plant uptake can play a significant role in potential environment impact. These are (1) direct uptake by plants and animals living on dried dredged sediment, and (2) subsequent cycling through food webs both inside and outside the DMCAs. These latter two pathways were selected for evaluation of the dry soil upland placement scenario (EA 2008, Section 10.1.3). The endpoints selected by EA to assess these two pathways were as follows: 1) protection of plants from adverse impact due to cadmium exposure from water and soil; 2) protection of wildlife (birds and mammals) from adverse impacts due to cadmium exposure from ingestion of water, sediment, and food resources. The results of the assessment of these two endpoints are discussed in the next two sections: Plant Uptake Test, and Animal Uptake in a Dry DMCA.

4.3.1.6 Plant Uptake Test.

As shown in the table below, SEP data from EA show there is a change in potential availability of cadmium between project wet sediment and dry "soil". In the dry "soil" condition, both composites show primarily a decrease in the hydroxide fraction, and an increase in the carbonate and exchangeable fractions. This change indicates cadmium should be more available in the dried soil than the wet sediment. This result confirms the appropriateness of the decision to conduct a plant uptake test on dried soil.

Table 42a. Percent Cd in each SEP Fraction of the Low Cadmium Composite (0 used for non-detects, from Tables 9-8 and 9-9, EA, 2008)

	Low Cd Comp "Wet"	Low Cd Comp Dup "Wet"	Low Cd Dried	Low Cd Dried Washed / Dried
Exchangeable	0.00	0.00	2.18	0.65
Carbonate	1.78	2.02	14.10	14.82
Hydroxide	74.18	71.00	59.60	59.86
Organic	20.13	21.94	19.23	18.37
Sulfide	3.91	4.62	4.42	5.87
Residual	0.00	0.42	0.47	0.43
Total Cd mg/kg	15.1	14.5	16.6	15

Table 42b. Percent Cd in each SEP fraction of the High Cadmium Composite (0 used for non-detects, from Tables 9-8 and 9-9, EA, 2008)

	High Cd Comp "Wet"	High Cd Comp Dup "Wet"	High Cd Dried	High Cd Dup Dried	High Cd Dried Washed Dried	High Cd Dup Dried Washed Dried
Exchangeable	0.00	0.00	1.32	1.34	0.42	0.37
Carbonate	1.96	1.56	4.60	5.23	4.25	4.35
Hydroxide	73.52	73.51	66.54	64.04	66.54	63.94
Organic	20.50	20.64	20.72	22.19	21.00	22.62
Sulfide	3.51	3.75	5.86	6.28	6.84	7.61
Residual	0.50	0.53	0.96	0.92	0.94	1.11
Total Cd mg/kg	26.2	33.4	43.1	NA	36.8	NA

The plant uptake test was conducted in accordance with the Upland Testing Manual (UTM) (USACE 2003) using *Cyperus esculentus*. Sediments were dried for 3 weeks before plants were introduced. Seven days after starting the test, the study was suspended because of low growth and begun again with a higher moisture regime. This second attempt was also stopped after 7 days because of low growth. Salinities ranging from about 25 to 28 ppt were determined to be the issue. After failure of the UTM wash procedure because of failure of the sediment to settle out, a wash procedure using centrifugation was used. After the washing process reduced the salinity to approximately 4 ppt, there was an additional 3 week period of grinding and drying before the test was begun. Tables 42 a and b, above, provide a comparison of the results of SEP procedures on the dried and washed/dried soils, showing the washing had minimal impact on soil cadmium levels. However, the table shows that the test soils did experience a small drop in cadmium when washed. The SEP analyses show this drop was primarily in the exchangeable fraction. In the low cadmium composite, the loss in the exchangeable fraction appears to have been approximately 10 percent of the total cadmium, although the loss did not show up in the total cadmium figures. The loss in the exchangeable fraction through washing is understandable since that fraction would be expected to dissolve in water. This loss does indicate that predictions based on the washed sediment results may not account for all cadmium originally present in the sediments. The washing also tended to affect nutrient levels, but not in a consistent pattern (EA, 2008, Chapter 9.2). This potential loss was taken into account during the final risk assessment for the dry "soil" condition (see discussion at Section 4.3.1.7).

The plant uptake test involved control sediment (potting soil), reference sediment (sediment exposed on the back of the DMCA 12B dike for several years), and the washed and dried low and high cadmium composites.

Cadmium, copper, lead, nickel, and zinc were evaluated in the plant bioaccumulation study due to their potential to bioaccumulate. Other metals were eliminated from further assessment because they do not readily bioaccumulate and were not found in the sediments at levels of potential concern. Tissue concentrations from plants grown in the washed and dried low and high cadmium composites were compared to tissue concentrations in plants grown in the control (potting soil), and the reference soils to determine the potential of project soils to support bioaccumulation of contaminants. The low and high cadmium composites generally produced tissue metal concentrations less than or equal to reference (copper and lead), or 2 to 5 times reference (nickel and zinc) The exception to those general relationships was cadmium (18 to 27 times higher than reference). These metal concentrations are shown in the table below. Mean plant tissue concentrations of cadmium, nickel, and zinc exposed to washed/dried soils statistically exceeded concentrations in tissues from plants grown in the reference soil for both the low and high cadmium composites. This indicates uptake of these three metals. A finding of plant uptake greater than reference, such as found for these three metals, requires assessment of the potential environmental impact on both plant growth and potential impacts to animals feeding on the plants. Animal uptake is addressed in the next section.

Table 43. Mean Plant Tissue Metal Uptake Compared to Reference (mg/kg dry wt). (EA 2008, Table 9-14)*

Analyte	Upland Reference	Low Cd Composite	High Cd Composite
Cadmium	0.383	**6.93**	**10.2**
Copper	1.48	0.790	1.10
Lead	0.0172	0.0169	0.0165
Nickel	0.0573	**0.120**	**0.223**
Zinc	14	**52.9**	**73.3**

* Bold indicates tissue sample concentration significantly greater than reference.

Table 44. Sediment Metal Levels in Composites in mg/kg (from EA 2008, Tables 5-6, and 8-8)

Analyte	High Cadmium Composite Average	Low Cadmium Composite Average	High Cadmium Composite Washed and Dried	Low Cadmium Composite Washed and Dried
Aluminum	14,600	16,000	17,600	17,000
Arsenic	12	11	12.5	12.6
Cadmium	30	15	36.9	15.4
Chromium	104	111	133	122
Copper	13	13	15.2	14.2
Lead	6	4.9	5.9	5.6
Manganese	198	177	207	185
Mercury	0.052	0.032	0.052	0.025
Nickel	18	21	21.7	24.4
Zinc	147	96	171	93.1

According to standard UTM guidance, environmental effects are only a concern if they extend outside the DMCA. Therefore, plant growth within a DMCA may not ordinarily be considered very important. However, the Savannah DMCAs are part of a wetland mitigation plan in which they are managed for shorebird and waterfowl habitat while they are in use. Therefore, potential impact to plant growth is an important consideration in this evaluation.

The high cadmium composite washed/dried soil contained 69 percent silt and clay, whereas the low cadmium composite contained 91 percent silt and clay. Except for cadmium and zinc, metal concentrations were generally similar in the two composites (see Table 43). The low cadmium composite washed/dried soil contained 15.4 ppm cadmium and 93.1 ppm zinc, whereas the high cadmium composite washed dried soil contained 36.9 ppm cadmium and 171 ppm zinc (EA 2008, Table 9-8). At the end of the growth period, laboratory controls showed the heaviest mean tissue wet weight (210.0 g), followed by the reference (43.0 g), the low cadmium composite (30.0 g) and finally the high cadmium composite (10.9 g)(EA 2008, Table 9-5). The low growth in the high cadmium and low cadmium composites cannot be directly attributed to the high cadmium concentrations, but cadmium cannot be ruled out as the causative agent of the low growth.

The observed cadmium tissue concentrations can be compared to benchmarks to predict potential effects on plant growth. EA (EA 2008, Section 10.3.2) cites a USEPA Ecological Soil Screen Level for cadmium plant NOAELs and LOAELs of 32 mg/kg and a 10^{th} percentile of plant LOAEL values for dissolved cadmium in water by Oak Ridge National Labs of 100 ug/L. EA also cites an 8 mg/kg cadmium NOAEL and 11.4 mg/kg cadmium LOAEL for water hyacinth (wet weight) as appropriate tissue benchmarks for plants. These were converted to cadmium dry weight benchmarks (assuming a plant moisture content of 75%) of 32 mg/kg dry-wt. (NOAEL) and 45.6 mg/kg dry-wt. (LOAEL). The observed high composite cadmium tissue level (10.2 mg/kg dry wt) is substantially below the LOAEL for water hyacinth (45.6 mg/kg). This indicates that the observed tissue cadmium levels may not inhibit plant growth. A comparison between the high and low cadmium composites of BCFs for several metals shown in Table 44 indicates potential inhibition of uptake for some metals (Cd, Zn), but not others (especially Cu, and Ni). These results are not conclusive as to the potential for the high cadmium soil to inhibit plant growth. However, it is unlikely that cadmium concentration was the cause of the low growth. Additional information is provided in the Response to Comments section (responses to USFWS comments 11, 30, and 36) where other studies on cadmium toxicity to plants found no effect at cadmium sediment levels similar to those studied here.

Table 45. BCF Soil to Plant Tissue Cadmium Concentrations (Total washed/dried soil, dry wt. basis, Tissues Dry wt.mg/kg)(from EA 2008, Tables E-11, and 9-13)

Analyte	Control	Reference	Low Cd	High Cd
Cadmium	0.115	0.395	0.45	0.276
Copper	0.0506	0.221	0.0556	0.0724
Lead	0.00372	0.00239	0.00302	0.00280
Nickel	0.00546	0.0122	0.00492	0.0103
Zinc	0.548	0.534	0.568	0.429

When EA (2008) conducted the Simulated Effluent Runoff procedure on the high cadmium composite, the test predicted 8.43 ug/L dissolved cadmium in the runoff. EA (2008, Table 10-17) found potential dissolved cadmium in runoff to be well below the 100 ug/L plant benchmark. This in an indication that runoff would not be expected to inhibit plant growth.

In conclusion, the test plant species experienced less growth in the high cadmium composite soil than other tested media. However, predicted soil and water cadmium concentrations indicate there should be little concern that plant growth would be affected by cadmium levels present in the high cadmium soils.

4.3.1.7 Animal Uptake in a Dry DMCA. A conceptual model was developed by District biologists predicting the pathways by which cadmium could enter the environment through the animal uptake pathway during the drying phase (PD-EC, 2006b). Past observations within the DMCAs have identified only a few reptiles within the DMCAs during the drying phase, primarily a few anoles, fence lizards, snakes (including diamond-backed rattlesnake), alligators and very few amphibians (primarily southern toads, green tree frogs and leopard frogs). A number of mammals inhabit the drier portions of the DMCAs, including deer, hogs, raccoons, opossums, rabbits, armadillos, bobcats, various rodents, and an occasional coyote. There are also a few reports of large cats. However, the primary vertebrates on the site are various species of birds. Birds occur in much higher numbers than mammals and are much more likely to leave the DMCAs and move out into the surrounding environment.

The District model identified the primary classes of birds that dominate the drying DMCAs to be wintering sparrows and insectivores. Primary wintering birds within the dry DMCAs are sparrows. There are lesser numbers of frugivores and insectivores, including mimic thrushes, wrens, and yellow-rumped warblers. A small number of other warblers and vireos are also present. Because the drying sediments do not have time to develop into a structured soil, soil-based prey do not appear to play a significant role in the food chains of the dried areas. For example, birds are rarely seen probing into the soils for food items. Because winter sparrows are by far the most abundant wintering birds within the DMCA dry habitats, those species were judged to be a significant pathway that should be evaluated. Migratory and summering species within the DMCA dry habitats appear to be mostly foliage gleaning insectivores, of which migratory warblers and vireos form the largest segment. Summer insectivores include mostly species that are partial insectivores such as red-winged blackbirds and boat-tailed grackles, mimic thrushes, cardinals, towhees, Carolina wrens, painted buntings, and indigo buntings. No toxicity / bioaccumulation tests are available to directly assess these pathways. Since the pathways all appear to be plant based, the plant uptake test was used to predict plant uptake of cadmium and a consumption model was used to predict the subsequent movement of cadmium through herbivores (primarily insects) to insectivores such as warblers. The consumption model results were compared to tissue benchmarks to predict potential environmental impact.

EA (EA 2008, Section 10.1.4.c) developed a conceptual model in which they selected the Song Sparrow, meadow vole, Marsh Wren, short-tailed shrew, red-tailed hawk, and red fox as representative/or surrogate species for evaluation. They considered the following modes by which animals could uptake cadmium in developing their consumption / exposure model.

- Wildlife dermal contact with soil (normally considered insignificant, EA 2008)
- Wildlife ingestion of soil
- Wildlife inhalation of soil (normally considered insignificant, EA 2008)
- Wildlife dermal contact with water (normally considered insignificant, EA 2008)
- Wildlife ingestion of water
- Wildlife ingestion of plant material
- Wildlife ingestion of herbivores

Exposures were calculated by including estimates for consumption of water, soil, and food. They used estimates of soil ingestion, water ingestion, and food ingestion to calculate exposure. The formula EA (2008) used is shown starting at their Figure 10-2. These estimated exposures were then compared to benchmarks to assess potential environmental effect (EA 2008, Section 10.2.1). EA (2008) selected two benchmark end points for cadmium bird exposure rates using the EPA EcoSSL database -- the geometric mean of NOAELs (1.47 mg/kg-bw day), and the lowest bounded LOAEL (2.37 mg/kg-bw-day, EA 2008, 10.3.3.a).

Exposure estimates are detailed in EA (2008), Figures 10-8 through 10-13, and Tables 10-20 through 10-26. For the high cadmium composite, exposure estimates for the song sparrow (2.94/2.97 mg/kg-day) and marsh wren (3.72/3.75 mg/kg-day) under exposures to both effluent and runoff waters exceed the bird LOAEL benchmark. In addition, the exposure estimate for the meadow vole (1.01 mg/kg-day) exceeded the mammal NOAEL of 0.770 mg/kg-day and the exposure estimate for the shrew (2.29/2.262 mg/kg-day) exceeded the mammal LOAEL benchmark of 2.06. These estimates are based on a soil cadmium concentration of 36.9 mg/kg (washed dried soil), derived from the high cadmium sediment with a 29.8 mg/kg cadmium concentration. These estimates are shown below in Table 46 for the runoff exposure estimate (slightly larger than the effluent exposure estimate). These results indicate an expectation of impact to both birds and mammals feeding within dried portions of a DMCA containing sediments similar to the high cadmium sediment composite.

The CENWO-HX-S (CENWO, 2006A) risk assessment found the cadmium sediment data to be non-parametric and advised that the 95% Chebyshev (Mean, Sd) UCL be used in evaluating each reach. The reach with the highest average cadmium concentration (21.5 mg/kg) was found to have a 95% Chebyshev UCL of 36.2 mg/kg cadmium concentration. This value was used for their risk assessment. Their selection of 36.2 mg/kg cadmium as an appropriate value for the risk assessment for the high cadmium sediments shows that the use of 36.9 mg/kg by EA for the washed sediment exposure assessment is appropriate for the risk estimate for the high cadmium reach. This is further indication that adverse impacts to both birds and mammals could be expected should the high cadmium sediments enter the DMCA's rotation management plan.

Table 46. Dose Predictions for the High Cadmium Composite Under Dry DMCA Conditions, mg/kg bw-day

	Effluent Exposure	Runoff Exposure	NOAEL mg/kg bw-day	LOAEL mg/kg bw-day
Song sparrow	2.97	2.94	1.47	2.37
Meadow vole	1.01	0.990	0.770	2.06
Marsh wren	3.75	3.72	1.47	2.37
Shrew	2.29	2.263	0.770	2.06
Red-tailed Hawk	.000061	.000061	1.47	2.37
Red Fox	0.169	0.160	0.770	2.06

EA also calculated exposure estimates for the low cadmium composite under both effluent and runoff water exposures. These exposures are shown in Table 47, below, for the potential effluent water exposure route and runoff exposure route and compared to benchmarks.

Table 47. Dose Predictions for the Low Cadmium Composite Under Dry DMCA Conditions, mg/kg bw-day

	Effluent Exposure	Runoff Exposure	NOAEL mg/kg bw-day	LOAEL mg/kg bw-day
Song sparrow	1.93	1.784	1.47	2.37
Meadow vole	0.797	0.639	0.770	2.06
Marsh wren	2.48	2.27	1.47	2.37
Shrew	1.52	1.354	0.770	2.06
Red-tailed Hawk	.000048	.000048	1.47	2.37
Red Fox	0.131	0.066	0.770	2.06

These estimates are based on a sediment cadmium total of 15.4 mg/kg and a calculated bioavailable cadmium total of 14.6 mg/kg, a water concentration based on the cadmium effluent total for the low cadmium composite (761 ug/L), 45% uptake by plants from soil based on results of the low cadmium composite plant uptake test, and 110% uptake by invertebrates from plants based on literature review. Only the marsh wren is shown to exceed the LOAEL, and only by 5%. Using the relationship between the 15.4 mg/kg total cadmium sediment level and predicted exposure level for the Marsh Wren of 2.48 mg/kg bw-day, the sediment level associated with the LOAEL of 2.37 mg/kg bw-day should be 14.7 mg/kg cadmium. However, when taking into consideration that the washing procedure may have removed the exchangeable fraction of cadmium (up to 10% of total cadmium), potential additive effects from nickel and zinc, and variability in the measured amount of cadmium in the test sediment, the lowest effect level should be applicable to sediments containing about 14 mg/kg cadmium. One can also use the cadmium bioavailable level (14.6 mg/kg cadmium) to estimate a bioavailable sediment level associated with the 2.37 mg/kg bw-day LOAEL to be 14.0 mg/kg cadmium. Those estimates led to the selection of 14 mg/kg as the lowest sediment cadmium level expected to have environmental impacts when associated with drying dredged sediments.

4.3.1.8 Worker Exposure. There is a potential risk to workers handling and working in potentially-contaminated dredged sediments. The CENWO-HX-S conducted a Human Health Risk Assessment (CENWO, 2006b). Their assessment assumed exposure to an occupational worker for 10 hrs per day, for 300 days per year, over a 15-year period. It concluded "the calculated non-cancer hazards and cancer risks indicate that exposure to the cadmium-enriched dredged material does not pose a concern for adverse non-carcinogenic or carcinogenic health effects for the occupational worker scenario, and therefore, does not present a risk to human health." Therefore, this pathway was not evaluated further.

4.3.2 Potential Aquatic Effects From Placement of Cadmium Sediments in a DMCA Where Water is Ponded

There are two major pathways by which cadmium could affect the aquatic ecosystem through placement of cadmium containing sediments within a DMCA: (1) cadmium toxicity to invertebrates feeding within the containment areas; (2) bioaccumulation of cadmium by shorebirds and waterfowl feeding within the containment areas.

4.3.2.1 Cadmium Toxicity to Invertebrates Feeding within the Containment Areas. This pathway is of little concern since it will for the most part not be complete. Should organisms within a DMCA not be able to survive due to cadmium toxicity, they would not serve as food for birds and waterfowl feeding within the DMCA. Since no organisms associated with this pathway would leave the site, there would be no impact on the outside environment.

4.3.2.2 Bioaccumulation of Cadmium by Shorebirds and Waterfowl Feeding within the Containment Areas. This pathway is of concern since large numbers of shorebirds and waterfowl feed in the wet areas within the containment areas (see Conceptual Model, PD-EC, 2006b). No Tier II evaluation techniques are available for heavy metals, but may become available in the future (Upland Manual Sections 8.2.3 and 8.3.1). Therefore, the Corps' Hazardous and Toxic Waste Center of Expertise (shown as CENWO-HX-S) was enlisted to conduct a screening level risk assessment for the bioaccumulation pathway within a DMCA (see CENWO, 2006a). The purpose of the risk assessment was to identify the pathways that contain more than minimal risk of adverse effects. Additional Tier III assessments of the bioaccumulation potential would be required for any pathways that remain of concern.

There are other vertebrates on the site that were not evaluated for potential cadmium impacts since they are thought to occur in only small numbers or are not expected to move off site . These include amphibians (primarily tree frogs), reptiles (anoles, various snakes, including the diamond-backed rattlesnake, fence lizards, turtles, and alligator), and various fish (mosquito fish, striped mullet, sheepshead minnow, and killifish). Based on Planning Division's conceptual model identifying birds as the primary receptors of concern, CENWO-HX-S was asked to evaluate potential effects on birds.

4.3.2.3 Ecological Risk Assessment by CENWO-HX-S. In evaluating the high cadmium reach, CENWO-HX-S (CENWO, 2006a) found that aquatic nesting birds were most likely to be impacted by cadmium, should the dredged sediments be held in an aquatic state where nesting shorebirds would feed. They estimated a daily dose (DI) of cadmium would be about 6.5 mg/kg-body wt/day. This value was compared to a toxicity reference (TRV) value of 1.45 mg/kg-body wt/day (a level found to produce reproductive effects in captive mallard ducks). The ratio of these two values (DI/TRV) is defined as an ecological quotient (EQ). Where conservative assumptions are made, "EQs between 1 and 10 have some small potential for adverse effects" (CENWO, 2006a). They calculated an EQ for the high cadmium sediment to be 4.5. Because they believed their assumptions in calculating the dose value were conservative, they concluded "it is not of significant project-wide concern". There are several indications that this estimate may be closer to a reasonable expectation than a conservative estimate. For example, ERDC felt that the estimate was not conservative (ERDC, 2006). Other evidence that the estimate is not conservative is discussed below.

4.3.2.4 Discussion of Conservative Assumptions in the CENWO-HX-S EQ Estimate.

The CENWO-HX-S (CENWO, 2006a) listed four factors that "were maximized to maintain the conservative nature of this evaluation." These are discussed below, to ascertain the true "conservative" extent of the EQ estimate.

a. Area Use factor. Assumed to be 100% within the contaminated area. For nesting black-necked stilts, this is not particularly conservative, since adults appear to spend most of their time within the containment areas, and young flightless birds spend all of their time there (see the conceptual model, PD-EC, 2006b). For the 3-5 month nesting and rearing season, black-necked stilts could easily spend all of their time within the DMCAs. Black-necked stilts have been observed flying from one DMCA to another to feed. Since the project would most likely deposit the enriched sediments in only one DMCA and should have other DMCAs flooded at the same time, we expect flying stilts would conduct some of their feeding in areas in which the enriched sediments have not been placed.

b. Bioavailability. Assumed to be 100%. Food was considered to have the same concentration as the sediment. A bioaccumulation factor (BAF) is defined as the ratio of the concentration of the contaminant in the tissues of the organism to the sediment concentration to which the organism is exposed. These appear to be somewhat variable, depending on the species. ERDC found that "When considering the bioaccumulation of cadmium in both freshwater and estuarine invertebrates, a BAF of 1.0 appears reasonable for invertebrate species in both freshwater and estuarine portions of Savannah Harbor" (see ERDC, July 2006). Therefore, this assumption should be considered reasonable (not conservative) for invertebrates within the DMCAs.

c. Estimates of Body Weight and Food Ingestion. Estimates of body weight and food ingestion rates of the ROCs were made conservatively to maximize the dose (i.e., the intake of cadmium-enriched dredged sediment). CENWO-HX-S used published average consumption rates (based on Spotted Sandpiper data) and body weights in estimating doses. This estimate should also be considered reasonable (and not conservative). A conservative assumption would be use of consumption rates beyond normal expectations.

d. Dietary Composition. "Assumed 100% of diet consists entirely of the most contaminated dietary component (i.e., food and dredged material)." Lacking specific data, it is reasonable to assume that the food and dredged sediment would have the same concentration of cadmium. The CENWO-HX-S (CENWO, 2006a) calculated a 95 percentile distribution UCL for the reach with the highest concentration to be 36.2 mg/kg cadmium and used this value in their assumptions, rather than an average value of about 21.5 mg/kg. This is a conservative procedure. However, the food consumption rate (for the Spotted Sandpiper) does not appear to include incidental soil ingestion. Furthermore, the calculated dose does not include ingestion of water. Lack of inclusion of these elements in the dose calculation brings uncertainty into the conservative extent of the dietary composition assumptions.

e. Other Factors. There are other factors that indicate there may be additional uncertainty in the ingestion rate assumption and EQ estimate. For example, feeding rates for the EQ calculation are based on published estimates for the Spotted Sandpiper, derived from a published regression equation for all birds. The Spotted sandpiper has about ¼ the body weight of the species of concern (Black-necked Stilt). Although the estimated Black-necked Stilt rate is adjusted for body weight, it is not clear that the two species would have the same body weight adjusted feeding rate. Furthermore, the stilt uses an entirely different foraging method (feeds mostly wading), whereas the sandpiper feeds mostly by gleaning food from the surface of damp substrates. This hints that the food composition of the two species is likely to be entirely different. Finally, the toxicity reference value used is based on effects on a much larger and unrelated species (the Mallard Duck). This may be the best available toxicity reference value, but it is uncertain how conservative is the use of such a toxicity reference value. An analysis may be conservative for one species, but we have no information concerning how other species may compare in their feeding rates, body weights, etc., so we may not be able to say it is conservative for all species that use the DMCAs.

4.3.2.5 Decision to Proceed with Additional Risk Assessment. Risk assessments were performed by CENWO-HX-S (CENWO, 2006a) for birds feeding in sediments containing two different levels of cadmium (10.5 mg/kg and 36.2 mg/kg). These levels were the 95 percentile of the cadmium levels for two different reaches (averaging 6.67 mg/kg and 21.45 mg/kg). Daily doses were calculated and compared to a reference toxicity value, and the resulting ratio defined as an EQ (ecological quotient). The EQ calculated by the CENWO-HX-S for the 10.5 mg/kg cadmium reach was 1.3, and the EQ for the 36.2 mg/kg cadmium reach was 4.5. As mentioned earlier, CENWO considers EQs between 1 and 10 to have some small potential for adverse effects. Because the calculated EQ for the reach averaging 6.67 mg/kg cadmium was found to be only slightly above 1 (at 1.3) based on the 95 percentile UCL, they found there is at most only a small potential for adverse effects from birds feeding on these sediments. Therefore, they found that placement of these sediments (reach averaging 6.67 mg/kg cadmium) within a DMCA would be expected to have minimal and acceptable environmental impacts.

In contrast, since the calculated EQ (4.5) for the reach averaging 21.45 mg/kg (based on a 95 percentile concentration of 36.2 mg/kg) is 4.5 times the toxicity reference value of 1.45 mg/kg-bw day, and this value appears to be based mostly on expected average or standard conditions, sediments from this reach have a much greater potential for adverse effects than the other reaches. As discussed above, it was concluded by the District that these potential effects could not be discounted.

It was determined by the District that additional toxicity and bioaccumulation testing would be necessary before it could be concluded that there would be minimal risk to birds feeding within a DMCA where sediments average 21.45 mg/kg cadmium. Since the calculated daily cadmium dose for Black-necked Stilts feeding within the disposal area was found to be 4.5 times a published toxicity value, it appeared that there was a reasonable potential for adverse effects should the higher cadmium sediments be exposed in an aquatic state within the DMCAs. This prediction was part of the basis for the decision to conduct further assessment using Tier III Bioaccumulation procedures.

Tier III Bioaccumulation assessment using ocean disposal protocols was deemed appropriate to assess potential wet phase impacts from placement of high cadmium sediments within the DMCAs, since most of the water in the DMCAs is expected to be brackish water pumped into the areas during the dredged sediment placement operations. This analysis selected *Nereis* and *Macoma* as test organisms because they thrive in brackish conditions. Results of the bioaccumulation study are discussed at Section 4.2.5.

4.3.2.6 Risk Assessment by EA (2008). EA (2008) conducted the additional sampling and analyses and used their data to conduct a risk assessment of direct uptake by animals living in the river in high cadmium exposed clay within the channel. That assessment found minimal risk associated with the aquatic pathway. The analyses applied to the situation that would occur within the channel after Expansion deepening would also apply to wet sediments held within a DMCA, with the exception that at least some shorebirds could be expected to feed almost entirely on prey organisms within the wet sediments. EA also conducted a risk assessment of direct uptake by plants and animals living on sediment held in a wet condition within the containment areas. These assessments are discussed below along with the assessment by CENWO-HX-S.

The first risk assessment was conducted by CENWO-HX-S. They began by analyzing the sediment cadmium data to determine appropriate concentrations to use in their predictions. They found the sediment cadmium data to be non-parametric and advised that the 95% Chebyshev (Mean, Sd) UCL be used in evaluating each reach. The reach with the highest average cadmium concentration (21.5 mg/kg) was found to have a 95% Chebyshev UCL of 36.2 mg/kg cadmium concentration. This value was used for their risk assessment of the high cadmium sediments. The reach with an average cadmium concentration of 6.67 mg/kg cadmium was found to have a 95% Chebyshev UCL of 10.5 mg/kg cadmium. This value was used in their risk assessment for that reach. The results of their assessment are discussed at Sections 4.3.2.3 through 4.3.2.5.

EA conducted their risk assessments based on the results of the bioaccumulation testing of the low and high cadmium composites. The 29.8 mg/kg cadmium total for the high cadmium composite is slightly less than the 36.2 mg/kg cadmium average CENWO-HX-S found to be appropriate for assessment of the high cadmium sediments. Decisions based on the high cadmium composite concentration could therefore slightly underestimate overall potential impacts.

EA conducted high cadmium (29.8 mg/kg) sediment exposure estimates including food, sediment, and effluent water exposure for great blue heron, osprey, spotted sandpiper, Canada goose, river otter, and muskrat. The predicted consumption exposure of 1.63 mg/kg-bw day for the spotted sandpiper is above the mean NOAEL cited by EA (1.47 mg/kg bw day) but below the LOAEL of 2.37 mg/kg bw-day. Estimates for the other species were below NOAELs. These results are shown in Tables 10-15 to 10-19 in EA, 2008. It should be recognized that the assumptions leading to this estimate reflect more the expected state, rather than being conservative, especially for young birds feeding within the DMCAs. For example, in the case of young black-necked stilts raised within the DMCAs, they would be expected to spend 100 percent of their time feeding on prey that are in continual contact with cadmium-containing sediments. If the bird LOAEL cited by CENWO-HX-S (1.45 mg/kg bw-day) is used as a benchmark, then the sandpiper estimate slightly exceeds the LOAEL benchmark.

4.3.2.7 Conclusion Regarding Birds Feeding Within a DMCA in an Aquatic State. The cadmium exposure prediction by EA (2008) for birds feeding 100 percent of the time in high cadmium sediments within the DMCAs is 1.63 mg/kg bw-day for spotted sandpiper. This is less than the original prediction by CENWO-HX-S (CENWO, 2006a) of 6.5 mg/kg bw-day, which did not include ingestion of water in the estimate. EA included ingestion of water in its estimate, but the exposure from water was found to be small. EA used a food ingestion rate (0.294) expressed as kg food (wet wt.) per kg body wt. per day. CENWO-HX-S used a food intake rate (0.0077) expressed as kg food per day. Using the spotted sandpiper body weight of 0.0425 kg cited by CENWO-HX-S, the feeding rate described in their assessment for the spotted sandpiper converts to 0.273 kg wet wt. per kg body weight-day. This indicates both groups used similar feeding rates in their calculations. The difference in exposure estimates can be explained by how the food and sediment ingestion exposures were estimated. The CENWO-HX-S calculation is overly conservative in that it assumes food and sediment would have the same concentration of cadmium (36.2 mg/kg). EA (2008, Chapter 10) used the bioaccumulation results for *Nereis* grown in the high cadmium composite to predict benthos in the spotted sandpiper diet would have a cadmium concentration that was 0.664 percent of the cadmium present in the sediment. In other words, EA used site-specific information to conclude that a lower cadmium intake should be expected for the spotted sandpiper.

A difference in evaluation criteria led to different conclusions by CENWO-HX-S and EA. CENWO-HX-S used the lowest published bird LOAEL value of 1.45 mg/kg bw-day as a benchmark. EA used the lowest "bounded" LOAEL of 2.37 mg/kg bw-day and the geometric mean of the NOAEL data (1.47 mg/kg bw-day) in the ERED database as benchmarks. However, the major difference in evaluation criteria was the calculation of an ecological quotient "EQ", in accordance with Interim EPA superfund guidance (CENWO, 2006a). The next paragraph provides an explanation of the use of the "EQ" from CENWO-HX-S.

"Ecological risk should be interpreted based on the severity of the effect reported and the magnitude of the calculated EQ (EPA, 1997). For example, EQs between one and 10 have 'some small potential' for adverse effects, EQs between 10 and 100 have 'significant potential' for adverse effects, and EQs greater than 100 indicate 'expected' adverse effects (Menzie et al., 1992). The EQs associated with the risk of cadmium for this project in both cadmium reaches are greater than one, but less than 10, for both ROCs, and therefore, it is not of significant project-wide concern."

It is our conclusion that the exposure estimate (1.63 mg/kg bw-day) for shorebirds feeding within the ponded area of a DMCA containing sediment cadmium levels similar to those in the high cadmium composite shows a level slightly above the lowest published LOAEL for birds (1.45 mg/kg bw-day). Because the DMCAs are managed to produce wildlife habitat for birds, impacts to feeding birds would be unacceptable. Since this exposure estimate is based on birds feeding within a DMCA 100 percent of the time, this estimate would apply only to birds feeding within the DMCAs 100 percent of the time (nesting black-necked stilts and their young). Using the high cadmium sediment composite level of 30 mg/kg cadmium as equating to an exposure level of 1.63 mg/kg bw-day, a 1.45 mg/kg bw-day exposure level would equate to a 27 mg/kg wet sediment cadmium level as the lowest wet sediment level of potential concern within a DMCA.

4.3.2.8 Worker Exposure During Dredging. Although the risk assessment conducted previously CENWO-HX-S concluded that occupational workers' exposure to the cadmium-enriched dredged material would not pose a concern for adverse non-carcinogenic or carcinogenic health effects, the District conducted an additional assessment to confirm those findings.

Workers associated with the dredging and sediment placement operations could experience some exposure as the new work sediments are removed from the channel and deposited within the DMCA. The duration of this potential exposure is not certain, but would extend only during the period of construction. Large dredges expected to be used for this construction could be expected to move along the channel at a rate of about 50 feet per day. At that rate, it should take a dredge 560 days to deepen the 28,000-foot length of channel enriched with cadmium at levels averaging 21 mg/kg. Workers at the DMCAs may experience exposure for a longer period, as the Contractor is typically responsible to decant the DMCA, a process which often takes 30 days. For those workers, the total exposure time would lengthen to 590 days (560 + 30 days).

A dredge can be expected to operate for 24-hours per day, so two 12-hour shifts would perform the work. The work time for a given worker could be as much as 6,720 hours (560 days X 12 hours/day). The exposure for occupational workers on a dredge would be for a much shorter period of time than the exposure found by CENWO-HX-S to have no effect (6,720 hours rather than 45,000 hours). Similarly, for the Contractor's workers at the DMCAs, the total exposure time would be 7,080 hours. This is also much shorter than what CENWO-HX-S concluded would have no effect.

Therefore, the conclusion for workers during the dredging and sediment placement operations would be the same: exposure to the cadmium-enriched dredged sediment does not pose a concern for adverse non-carcinogenic or carcinogenic health effects.

5.0 Conclusions.

5.1 Potential Contaminants of Concern

Cadmium has been identified as the only contaminant of concern for the Savannah Harbor Expansion Project. Cadmium concentrations within new work sediments have been found to be elevated above levels normally encountered in sediments and soils. An assessment of potential availability of cadmium and associated risk has identified scenarios with little environmental concern and others where environmental concerns dictate management to minimize risk.

5.2 Project Extent

Cadmium sediment concentrations within the channel were investigated from Station +103+000 to the end of the project in deep water in the Atlantic Ocean at Station -63+000B. Extension of the proposed work to Station -98+600B is believed to have no additional sediment contaminant-related impacts since the tested bar channel sediments were found acceptable and the additional length would extend further into the ocean and away from possible sources of contaminants.

5.3 Cadmium Concentrations

As discussed in Section 4.2.5, the lowest cadmium level of potential concern in wet sediments within the DMCAs is approximately 27 mg/kg (dry wt).

As discussed above (Sections 3.9 and 4.3.1.7), a sediment cadmium concentration of 14 mg/kg has been identified as the lowest concentration warranting environmental concern when sediments are placed in a dry environment. This level was used in determining which reaches contained sediments require management. The highest observed cadmium concentration is 77.1 mg/kg in the -56 to -58 foot (MLW) layer at Station +30+000. The Station with the highest sediment cadmium average (39.4 mg/kg) is Station +26+000. The reaches where potential contaminant-related environmental impacts have been identified and sediment management is required include inner harbor Stations +90+000 to +80+125, +57+000 to +51+000, and +45+000 to +6+375. Average cadmium concentrations associated with each of these reaches is shown in Table 21c.

In response to concerns raised by the USFWS, the District agreed that a cadmium "trigger" level should be identified for this project below which there should be no contaminant concerns associated with a proposed cover/cap. In deriving this "trigger" level, the District used the dose (exposure) prediction procedure discussed at 4.3.1.7, data from the low cadmium composite, and very conservative assumptions to predict an exposure estimate for the Marsh Wren (the most sensitive target species investigated by EA). Those assumptions included: all sediment cadmium would be bioavailable (15.4 mg/kg cadmium dry wt), cadmium concentration in water would be the total effluent concentration from the low cadmium elutriate study (761 ug/L), a sediment to plant transfer factor of 1, and a plant to invertebrate transfer factor of 1.1. The Marsh Wren cadmium exposure under these conditions was estimated to be 4.81 mg/kg bw-day. By relating this exposure level to the total cadmium sediment level of 15.4 mg/kg, the predicted cadmium sediment level associated with the lowest published effect level of 1.45 mg/kg bw-day would be 4.64 mg/kg dry wt. sediment cadmium. Acknowledging there is some degree of uncertainty associated with this prediction, the District determined the dry sediment level associated with no effect on birds could be considered with a high degree of certainty to be no more than 4.0 mg/kg cadmium. Therefore, 4.0 mg/kg dry wt. cadmium was selected as the cover criterion below which environmental concerns should be minimal.

5.3 Contaminant Concerns Related to Water Quality

Potential adverse contaminant impacts on water quality related to the required dredging were found to be minimal.

5.4 Potential Contaminant Impacts within the Savannah River

Potential contaminant impacts associated with exposed high cadmium sediments within a deepened channel have been found to be minimal, primarily because sediment cadmium was found to be unavailable and bioaccumulation tests found cadmium uptake below levels of concern. The essentially anoxic state of the channel sediments should preclude significant movement of cadmium to the environment. Furthermore, it is expected that exposure of the riverine environment to high cadmium clays would be restricted since the majority of the exposed clays are expected to be covered by O&M sediments

5.5 Potential Contaminant Impacts associated with Dredged Sediment Placement

Potential contaminant impacts related to sediments held in a wet state within a DMCA were found to exist only for birds that feed within a DMCA 100 percent of the time. This would refer primarily to nesting black-necked stilts and their young. To minimize environmental risk, high cadmium sediments should be managed in a way that excludes exposure to nesting black-necked stilts.

5.6 Other DMCA Pathways

Potential impacts associated with other pathways by which a contaminant might leave a DMCA (leachate to groundwater, runoff, effluent, volatilization) were found to be minimal.

5.7 Potential Impacts Associated with the DMCA Rotation Management Plan

The DMCA rotation management plan involves keeping a DMCA flooded for 3 years and then maintaining the DMCA in a dry state for the next 3-years. During the "dry" cycle, sediments within a DMCA dry for 2 years, and then the dried sediments are relocated to the dikes in the third year. Studies found that drying the sediment changed the behavior of cadmium in the sediment. Sequential extraction procedures on washed and dried sediment showed that cadmium becomes more available in the dried sediment and a plant uptake study found that plants can accumulate cadmium from dried sediments. Exposure models found that both bird and mammals exposed to the dry high cadmium sediments are likely to accumulate cadmium at levels shown to cause impacts. To minimize potential contaminant risk, high cadmium sediments within the DMCAs should not be allowed to be dried and exposed to a degree that allows plant growth and feeding by birds and mammals. In addition, the high cadmium sediments should not be placed so that they would be exposed on the surface of the containment area dikes.

5.8 Nearshore Placement of Bar Channel Sediments

No contaminants of concern were found to exist for new work sediments oceanward of Station +6+375. Therefore, there should be no contaminant-related environmental concerns associated with proposed placement of new work entrance channel sediments in the ODMDS, nearshore submerged berms, or nearshore feeder berms. The placement of dredged material into the nearshore sites has been removed from the project.

6.0 Placement Alternatives for High Cadmium Sediments

6.1 Project Dredged Sediment DMCA Placement Alternatives

There are four primary dredged sediment placement alternatives for the Expansion Project sediments containing elevated levels of cadmium: (1) Deposit the sediments in a DMCA, with subsequent management in the rotation plan; (2) Deposit the sediments in a DMCA, with isolation of the sediment through capping/covering; (3) Deposit the sediments in a DMCA, with isolation through capping/covering and lining; and (4) Deposit the sediments in the Sediment Basin or other open water site.

6.2 Deposit the Sediments in a DMCA, with Subsequent Management in the Rotation Plan

This alternative is unacceptable because of the potential environmental impacts associated with accumulation of cadmium by birds and mammals feeding within the DMCA.

6.3 Deposit the Sediments in a DMCA, with Isolation within One or More DMCAs with Capping/Covering

This alternative is acceptable from an environmental perspective since it would preclude movement of cadmium from sediments to populations of concern outside the DMCAs, including birds and mammals.

6.4 Deposit the Sediments in a DMCA, with Isolation within One or More DMCAs with Capping/Covering and Lining

This alternative is acceptable but appears to be unnecessary. A liner would be appropriate to prevent cadmium movement to groundwater as leachate, should the leachate contain cadmium at levels of concern. Studies discussed in this assessment found cadmium to be tightly bound within wet sediments and clay porewater concentrations were found to be very low. Therefore, movement of cadmium through leachate is expected to be minor and of minimal environmental concern.

6.5 Deposit the Sediments in a Sediment Basin or Other Open Water Site

Under our current level of understanding, elevated cadmium sediments placed in an anoxic open water site would be expected to release minimal cadmium to the environment. However, placement of these sediments in the high current Back River Sediment Basin with a pipeline dredge could not guarantee the sediments would be localized in one area and remain anoxic. Movement of these sediments throughout the estuary could result in future unforeseen impacts. Potential environmental impacts make this alternative unacceptable with pipeline dredging. Clamshell dredging with bulk placement of the sediments would reduce sediment resuspension and subsequent offsite spread of those sediments. This could render this option acceptable, but further consideration of potential impacts would be necessary before confirming that determination.

7.0 Recommendations

7.1 Isolate High Cadmium Sediments

New work sediments from Stations +90+000 to +80+125, +57+000 to 51+000, and +45+000 to +6+375 should be isolated within a DMCA and capped/covered with sediment from another reach. More than one DMCA may be needed to store the volume of new work sediments resulting from some channel depth alternatives. The high cadmium sediments should not be disturbed further and should not be allowed to be later excavated and placed in any exposed upland area.

7.2 Potential Method of Isolation

Once a DMCA is selected to receive the sediment, the high cadmium sediments should be pumped into the area first. Once placement of sediments from this reach is completed, markers should be placed on the surface of the sediment to allow easy determination of when the proper cap/cover depth has been attained. At least 2 feet of additional sediment from another reach (the cover material) should then be placed in the area as soon as practicable, but as part of the SH Expansion Project, to ensure minimal environmental impacts from birds feeding within the DMCA. Once the sediments have consolidated, a covering of crushed limestone, coal or similar marking material should then be placed on the surface of the area to ensure that the surface of the cover can be located in the future and the cover left undisturbed.

7.3 Monitoring and Contingency Plan

7.3.1 Placement of Dredged Material

An hydraulic dredge will be used to place material averaging approximately 14 ppm cadmium or greater into Dredged Material Containment Areas (DMCAs) 14A and/or 14B. Material placed in the DMCAs will remain in a "ponded" state (inundated) until the material is covered/capped by placing an approximately 2-foot layer (i.e., cap) of dredged material averaging ≤ 4.0 ppm cadmium. It should be noted that the dredged material containing 14 ppm cadmium will not be allowed to dewater and/or desiccate to the point that it would come into contact with the atmosphere. Cadmium-laden sediments would not be diluted with other sediments to reduce concentration during dredging nor allowed to mix substantially with cap/cover material when the cap/cover sediments are placed.

To ensure even distribution of dredged material throughout the disposal area, a floating discharge with a spreader may be required to allow the head section to be relocated as necessary using a system of wenches and cables as heavier material will fall out and tend to accumulate close to the head section. Bulldozers adapted to aqueous work would be required to keep dredged material submerged to minimize contact with the atmosphere and ensure a level surface. After a period of 3-6 months, the cap material would be placed using the same approach as the cadmium material was placed. Prior to deposition of the cover/cap material, light-weight settlement plates or other appropriate settlement measuring devices will be distributed across the disposal area in a grid and marked so that the contractor will able to tell when 2 feet of covering sediment has been deposited.

Another approach for actual placement of material is also under review. This approach would use a float hose with a y-valve and an operator at the end of the line, which could control the discharge by directional pumping. This method would require first depositing material closest to the weirs and piping off to move the head section to the front of the disposal area. Discharge would begin near the front of DMCA 14A near the weirs and then shift away to allow suitably clear water to be discharged. Deposition would progress toward the rear of the disposal area, around the finger dike, and back to the front of the disposal area. Assuming a 47' project, the remainder of the cadmium material to be managed would most likely be placed in DMCA 14B using the same approach as identified with DMCA 14A. With respect to this alternative approach, a 2-foot covering layer would still be used.

7.3.2 Monitoring Sediments During Placement in DMCA

The goal of this analysis is to characterize the cadmium concentrations that are actually deposited in the confined disposal area. Samples of the sediment slurry would be collected from the head section discharge pipe on a weekly basis and analyzed for total cadmium. Total solids would be reported on a g/L basis and cadmium concentration would be reported on a dry-weight basis (mg/kg). If clay balls are being discharged, a typical clay ball would be collected on a weekly basis at the same time the slurry sample is collected and the total cadmium concentration reported for both the slurry and clay ball on a dry-weight basis (mg/kg).

7.3.3 Sampling of Effluent During Placement of Sediment in DMCA

The goal of this analysis is to ensure effluent from the DMCA satisfies TSS limits and cadmium water quality standards. At the beginning of the deposition of new work sediments in the DMCA, the contractor would construct a 500mg/L TSS standard and determine turbidity (in NTU's) associated with the standard. The contractor would then visually compare effluent turbidity at each of the discharging weirs to the standard on a daily basis. The contractor would measure turbidity on a weekly basis at each outfall pipe with a discharge. Measurements would include dissolved oxygen, salinity, conductivity, temperature, and turbidity. Measurements would be made with a Hydrolab or similar instrument. At the same time the turbidity measurement is made, every two weeks the contractor would collect a water sample for chemical analysis. Sample would be obtained from the outfall pipe. Analyses would include NTUs, total suspended solids (TSS) in mg/L and cadmium concentration in ug/L (dissolved). Should the effluent dissolved cadmium concentration be found to be higher than the State standard (i.e., 8.8 ug/L for South Carolina), sampling would be repeated within two days and would include both the outfall pipe sample and a receiving water sample taken approximately 100 feet down-current of the point at which the effluent enters the receiving water. Should the receiving water sample be found to violate the State standards, corrective action would be undertaken to eliminate the violation. Any violations of the turbidity or TSS standards would be immediately addressed by corrective action to eliminate the violation. Corrective action may include boarding up the weir to reduce or eliminate effluent discharge, or reducing sediment discharge rate into the disposal area.

7.3.4 Sampling of Cadmium-Laden Sediments

Once placement of cadmium-laden sediments has been completed in a DMCA, grab samples would be collected to characterize the cadmium levels of the surficial sediments. This would occur prior to placement of the sediment cover/cap. Approximately 86 grab samples would be collected from the top 15 cm of the surface of each disposal area used to deposit sediments containing $\geq$14 ppm cadmium. It is expected that this sampling will require use of a water craft, since the area must remain inundated until the high cadmium material is covered by cap/cover material. Samples would be evenly spaced across the DMCA. A sampling depth of 15 cm would be used for these saturated sediments as cadmium transfer to the water column or other organisms should be minimal below this depth. These samples would also be analyzed for cadmium concentration on a dry-weight basis (mg/kg).

7.3.5 Sampling of Capping/Covering Layer

Eighty-six grab samples would be collected after the cover has been placed on the DMCA in order to characterize the cadmium levels of the exposed, surficial “capping” sediments. The same procedure for sample collection would be used as previously described. Approximately 86 samples would be collected from the top 30 cm of the cover/cap for each disposal area used to deposit sediments containing an average of ≥14 ppm cadmium. These samples would be evenly spaced across the DMCA and the location of these sites recorded using a GPS system. These samples would be analyzed for cadmium concentration on a dry-weight basis (mg/kg). If the distribution of sediments with cadmium concentration ≥ 4 ppm extends over a cumulative area of 25 acres or greater, then O&M sediments will be placed over the cap/cover, at the earliest possible time. Once the layer of O&M material has been placed in the DMCA, the surface sediments (to a depth of 30 cm) will be sampled (86 grab samples) and analyzed for cadmium. The process of placing O&M material in the DMCA and testing for cadmium would be repeated until the cadmium concentration in the surface sediments is less than 4 ppm.

7.3.6 Wildlife Use of the DMCAs

The District would perform monthly wildlife use surveys of the DMCAs used for placement of cadmium-laden sediments. These one-day surveys would record all birds and other major vertebrates seen within each of the appropriate DMCAs. Weekly monitoring of target species to determine arrival dates and ensure capture within two weeks of arrival will be conducted, most likely in April and September. Monitoring would be performed during placement of sediment (including any required cover) and for 3 years after any required placement is complete. If there is a concern about the number of birds or other animals or a particular species using the DMCA, some type of hazing may be appropriate. Any hazing decisions would be coordinated with the USFWS.

7.3.7 Vegetation Sampling

Should analyses of the cap/cover material show that concentrations of cadmium are equal to or exceed 4 ppm in a cumulative area of 25 acres or more, vegetation sampling will be required. This vegetation sampling would be conducted on a quarterly basis. Sampling of vegetation would be initiated in defined “hot spots” to determine cadmium uptake by plants. Samples collected from the DMCA of interest would be compared to control samples derived from other, cadmium-free environments found in adjacent DMCAs. Where at all possible, vegetation comparisons to reference will be by species and sampling will include all dominant species growing on the cover/cap (where dominant species are determined by the specie exhibiting the highest stem count or percent cover plus all other species equaling at least 20 percent of the total). If vegetation samples have significantly elevated cadmium concentrations, then efforts would be initiated to eradicate vegetation and/or place additional, low-cadmium sediments over the original covering layer. These contingency measures would eliminate wildlife exposure should vectors for cadmium uptake be identified. Once an additional layer of material has been placed on the covering layer, then soil/sediment sampling would resume. When sampling confirms that all the amended covering layer contains sustained cadmium concentrations of <4 ppm, the vegetation monitoring requirements would be complete. Specific details on the vegetation monitoring are described below at Section 7.4.3.1.4.

7.3.8 Tissue Monitoring

The District does not expect to encounter large numbers of birds feeding in elevated cadmium sediments during the dredged material disposal operations. This is because the proposed disposal design calls for sediments to be placed in an area where water is being held above the level of the placed sediments. Avian access to these inundated sediments is expected to be limited to birds that feed by swimming and diving. The species expected to be encountered in the highest numbers in the inundated areas include American Coot, Common Moorhen, Mottled Duck, feral Mallard Duck, Double-crested Cormorant, and in winter only, Northern Shoveler, Green-winged Teal, Ruddy Duck and Pied-billed Grebe.

Tissue monitoring would be conducted during placement of cadmium-laden sediments and the cap/cover and for 3 years after the placement is complete. Since the DMCAs will reenter the rotation program after the covering sediments are placed, the DMCAs may be dry or wet, depending on the year. Their hydrologic condition would drastically alter their bird use, as different species use the DMCAs in those two conditions. The season also drastically affects bird use of the DMCAs.

If/when the DMCAs are dry, individuals from two species would be sampled at the beginning and end of the nesting season (April and August) chosen from the following nesting species: Red-winged Blackbird, Mourning Dove, Eastern Towhee (white or yellow-eyed), Brown Thrasher, and Northern Mockingbird. Similarly, if/when the DMCAs are dry, individuals from two species would be sampled at the beginning and end of the wintering season (October/November and March/April) chosen from the following wintering species: Eastern Towhee (white or yellow-eyed), Brown Thrasher, Northern Mockingbird, House Wren, Song Sparrow, and Savannah Sparrow.

If/when the DMCAs are wet, migratory birds predominate at the sites. Sampling would be timed to correspond when the majority of each species arrives and is about to depart, which corresponds to approximately April and September. Sampling in April should maximize exposure time for wintering species (September through April), while sampling in about September should maximize exposure time for summer nesting species (April through September). Individuals of two species would be sampled in April and September. The proposed species to be sampled under wet conditions are the following: Northern Shoveler (open-water winter species), Avocet (edge-feeding winter species), Mottled Duck (open-water summer species), and Black-necked Stilt (edge-feeding summer species). The proposed species to be sampled under dry conditions are the following: Red-winged Blackbird (summer nester), Mourning Dove (summer nester), Savannah Sparrow (winter), and House Wren (winter). Other species listed above in the first paragraph may be substituted for one of these species upon mutual agreement between the District and the USFWS.

One of two types of tissue monitoring may be used. Liver and other tissue may be collected from three individuals of each target species. Blood/feather monitoring is currently deemed to be the appropriate method as it will allow collection of higher numbers of tissue samples. Specific details of the blood/feather monitoring are provided at Section 7.4.3.1.2.

7.3.9 River Bottom Sampling of Cadmium: Post-Construction Mapping

At the end of construction, sediment samples would be taken from the exposed channel bottom sediment surface and analyzed for grain size and metals (aluminum, iron, arsenic, beryllium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, and zinc). Samples would be cores taken to a depth of 15 cm. Where both O&M and new work sediments appear in the core, each would be analyzed separately. Samples would be taken within the channel every 2,000 feet from Stations +100+000 to 0+000 (26 samples) randomly selecting either the center line of the green side or red side. Five stations would be randomly selected to have two adjacent samples collected, from both the red and green side (10 samples). These last samples would be used to define the variability in bottom sediment metal concentrations across the channel. In addition, 5 samples would be run in duplicate (lab duplicates). Analysis of the river bottom would provide an assessment of anticipated cadmium concentrations in sediment at the sediment water interface.

7.4 Summary of Cadmium Management and Monitoring

7.4.1 Placement of Cadmium-laden Sediments

All cadmium-laden sediments would be placed in DMCAs 14A and/or 14B. Material would be placed so that it remains covered with water until after placement of the cover is completed. This material would not be allowed to dewater and/or desiccate to the point that it would come in contact with the atmosphere until placement is complete.

7.4.2 Placement of Cover/Cap

The covering material should come from reaches averaging less than 4 ppm cadmium. A capping layer of at least 2 feet of sediment should be placed above the cadmium-laden sediments. Once the cover has been determined to be sufficient, a marking layer (limestone, coal, etc.) would be placed on the surface. These sediments are not to be exposed in the future.

7.4.3 Required Cadmium Monitoring

7.4.3.1 Biological Monitoring

The District would perform monthly wildlife and avian/abundance surveys and avian blood tissue monitoring at the DMCAs used for placement of cadmium-laden sediments. Avian liver tissue monitoring and vegetation monitoring would take place only if results from the proposed blood/feather monitoring and or sediment cap monitoring indicate specific criteria are exceeded.

7.4.3.1.1 Wildlife and Avian Abundance Surveys

The District proposes to conduct these surveys monthly to monitor avian and terrestrial wildlife (large mammals) use of the DMCAs. This monitoring would be conducted independent of cadmium concentrations in the deposited sediments (in the two DMCAs that will receive the cadmium-laden sediments). Weekly monitoring of target species to determine arrival dates and ensure capture within two weeks of arrival will be conducted, most likely in April and September. The monitoring would be conducted during SHEP construction and would continue for at least 3 years after sediment placement is complete. Wildlife and avian monitoring will be extended as necessary until results from cadmium monitoring of sediment, vegetation, avian tissue and effluent indicate that cadmium concentrations are below levels of concern for 3 years post-construction. Cadmium levels of concern are considered to be 4.0 mg/kg sediment dry wt., chronic water quality criteria and standards within a DMCA or receiving water after mixing, 5.0 mg/kg plant tissue dry weight, avian blood tissue concentrations significantly greater than reference, and 45 ug/g wet liver tissue weight.

7.4.3.1.2 Avian Blood Tissue Monitoring

This monitoring will also be conducted independent of the concentrations of cadmium in the cover/cap and will be conducted both during and for 3 years after construction. It would be extended as necessary to ensure monitoring results are below levels of concern for 3 years post-construction.

The District believes that the overall purpose of the cadmium tissue monitoring is to ensure that the proposed sediment placement does not impact biota within the DMCAs, with concern focused on birds since they are thought to be the most important class of vertebrates that lives both inside and on the periphery of the DMCAs. This class is also important because most species move into and out of the areas at least during migrations. The District proposes that this monitoring be conducted primarily by analysis of blood collected from target species. A baseline data set would be collected, with a target of 30 blood samples from two target species from each season (approximately 120 blood samples) prior to commencement of dredging in the inner harbor in DMCAs 14A and 14B. The Corps may also collect additional baseline data upon the migratory arrival of the species in a given year. The actual number of baseline and project blood samples may vary depending on the ease with which each species can be captured, but should not be less than 10 per species. The baseline data set would provide information on ambient or background blood tissue cadmium levels. Project sampling events would be performed each year on the target species at mid-season in the DMCA (at least 10 samples) and the resulting data compared to the baseline data set for identification of any potential effects from their use of the DMCAs. This sampling procedure would be repeated during each year of construction and for 3 years following construction. Should the project samples show a significant difference from the baseline data (95% confidence interval) for any species, liver tissue sampling would be performed on that species. Target species must be collected prior to their departure from the DMCA. This procedure would be repeated for any species and any season where significant differences in cadmium blood levels are observed.

Of prime importance for this monitoring is the establishment of baseline blood tissue data for comparison to levels observed prior to a species leaving the DMCAs each year. There appears to be two potential methods for establishing these data: (1) collect the baseline data prior to construction, or (2) collect the baseline data upon arrival of species in the DMCAs. There are advantages and disadvantages for each as outlined below:

Collect baseline data prior to construction

Advantages: Ensures collection of adequate data prior to construction. The ease with which collection of bird blood samples can be accomplished at the sites is currently unknown. Sampling before construction occurs would allow refinement of collection techniques without the time restraints associated with collection at the arrival of the target species. This method would still require a small number of confirmatory samples (at least 3 to 5) at the beginning of the arrival of each species in the areas. This yearly confirmatory sampling should remove uncertainty in whether target species have been influenced by site cadmium levels prior to their yearly arrival to the DMCA.s If the confirmatory samples differ from the baseline data (at 95% C.I.), then additional baseline data would be obtained. This eventuality is not considered likely and is not included in Appendix D.

Disadvantages: Adds uncertainty to the results due to potential yearly variation in cadmium concentrations within target species when they arrive at the DMCAs. There is the potential for selected target species to not return to the DMCAs in a given year during construction in sufficient numbers, thus requiring selection of an alternate species.

Collect baseline data upon arrival of species

Advantages: Accounts for potential yearly variation in cadmium concentrations within species. Ensures target species are actually present at the construction site during construction.

Disadvantages: Requires adequate data be collected in a short period of time (soon after arrival at the DMCAs each year). Failure to collect adequate data in a given year could result in collection of inadequate baseline monitoring data. Since arrival dates for target species can only be estimated, target species could begin arrival prior to detection and begin uptake of cadmium prior to their capture. This potential adds uncertainty to whether baseline data collected in this manner are actually baseline.

The selected method of baseline data collection for the bird blood tissue monitoring is a combination of the two methods described above. A baseline data set will be collected the year before start of the inner harbor dredging. This will include all target wet and dry species. In addition, at least 3-4 samples of target species will be collected within two weeks of their arrival within the DMCAs. For resident dry species targeted for sampling (Red-winged Blackbird and Mourning Dove), augmenting baseline samples could only be taken the first year. These samples will be compared to the baseline dataset. Should the new samples fall outside the original dataset (95%CI), that would be considered an indication of population changes in tissue cadmium levels occurring outside the influence of the DMCAs. Should the results indicate such changes are occurring, a new baseline dataset would have to be established in consultation with the USFWS.

7.4.3.1.3 Potential Avian Liver Tissue Monitoring

Should data for cadmium blood levels for any bird species be shown to be significantly different from the baseline data (95% confidence level), six liver tissue samples would be collected for that species and cadmium concentrations compared to lowest published avian liver cadmium toxicity levels (screening level). These levels are currently thought to range from 45 to 70 ug Cd/g wet weight liver tissue (Cadmium in Birds, Mark Wayland and Anton M. Scheuhammer, in Environmental Contaminants in Biota, Jekker Frederick Warne &Co.). Liver values significantly above these screening values would trigger additional management options. The District may also choose to collect baseline liver tissue data to which project liver tissue data would be compared. Project liver tissue data would have to significantly exceed baseline data and the threshold value to trigger additional management options.

Blood tissue monitoring would continue until 3 years have passed where either no blood tissue samples are found statistically significantly above the baseline or no liver samples have been found statistically significantly above both baseline and screening values.

The District concurs with the USFWS recommendation that 45 ug Cd/g wet weight liver be the threshold concentration that would trigger additional management options. While the citation listed above provides a threshold toxicity range, that range includes values that indicate potential toxicity to other organs such as kidneys or testes. Eisler (1985) has stated that cadmium residues in vertebrate kidney or liver that exceeds 10 ppm fresh weight should be viewed as evidence of probable Cd contamination. Also, Furness (1996) suggested that 40 ppm in the liver should be viewed as a tentative threshold tissue concentration above which cadmium poisoning in birds might be expected. The District believes that the combined evidence of elevated Cd blood concentrations and Cd liver concentrations at or above published toxicity threshold concentrations (using 45 ug Cd/g as the most recently published lower threshold concentration) should warrant management action.

7.4.3.1.4 Potential Vegetation Tissue Monitoring

Vegetation sampling would be conducted on a quarterly basis should areas of elevated cadmium be found in the covering sediment. This monitoring is not included in Appendix D because it is not certain that it will be required. Should sampling of the cover show areas with cadmium concentrations greater than or equal to 4.0 mg/kg dry wt. and representing a total cumulative area of 25 acres or greater of the covering layer (not necessarily contiguous), such areas would be considered "hot spots". Vegetation sampling would be conducted at each sampling point within a "hot spot" where the cover sediment cadmium concentration is equal to or greater than 4.0 mg/kg dry wt. Vegetation sampling would be conducted in these defined "hot spots" to determine the potential for cadmium uptake by plants.

A plant tissue threshold can be derived from avian uptake benchmarks. Since the primary movement of cadmium into birds is expected to occur through seed eaters (winter sparrows including the Song Sparrow) or insectivores (Marsh Wren) consuming insects feeding on plants, either the Song Sparrow or Marsh Wren could be considered appropriate species to model.

The values and calculations for determining the plant tissue threshold are the same as those used for the Savannah Harbor Expansion Project Phase II Risk Assessment and are based on using the cadmium washed/dried sediment composite and effluent' scenario. For a total cadmium uptake dose to not exceed the No Observable Adverse Effect Level (NOAEL) benchmark of 1.47 mg/kg body wt/day (using the same assumptions regarding food, water, and incidental soil ingestion rates, cadmium bioavailability, and soil-to-plant bioaccumulation of cadmium), the cadmium concentration in plant material (e.g., seeds) for the Song Sparrow would have to be ≤5 mg/kg dry wt (assuming the same cadmium uptake from water at a concentration of 0.1517 mg/kg body wt/day based on the low cadmium composite effluent).

Using the Marsh Wren, a plant tissue concentration of 4 mg Cd/kg dry weight as a threshold for further action can be derived from comparing the predicted exposure to a Marsh Wren of 3.75 mg/kg bw-day from a high cadmium sediment concentration of 10.2 mg/kg to the NOAEL exposure of 1.47 mg/kg bw-day (a no effect level). To be conservative, we have chosen the Marsh Wren exposure to establish the plant tissue concentration threshold as 4 mg Cd/kg dry weight plant tissue.

Samples collected from DMCAs 14A and/or 14 B (or any other area receiving cadmium laden sediments) would be compared to control samples from other, cadmium-free environments found in adjacent DMCAs, and to the cadmium plant tissue threshold level of 5 mg/kg (dry wt.). If vegetation samples have significantly elevated cadmium concentrations with respect to both control and the plant tissue threshold level, efforts would be initiated to eradicate vegetation, and/or place an additional covering sediment layer in the DMCA, and or conduct hazing of species inhabiting the "hot spots".

Proposed Vegetation Tissue Monitoring Plan.

1. Vegetation sampling will only occur if sediment sampling of the cover/cap layer finds a "hot spot".
2. A "hot spot" is a cumulative area of 25 or more acres, not necessarily contiguous, in which the cadmium sediment concentration is equal to or greater than 4.0 mg/kg dry wt. as determined by 30 cm core samples, each representing approximately 9 acres.
3. Vegetation to be monitored includes higher plants that could for the basis of movement of cadmium to species of concern (birds), either through support of potential herbivore prey or seed production.
4. Monitoring would occur at each sampling point determined to be within a "hot spot" where the sediment cadmium concentration is equal to or greater than 4.0 mg/kg dry wt.
5. Sampling of vegetation would occur within a radius of approximately 350 feet of the sampling point.
6. Dominant higher plant species would be determined by stems in contact with randomly placed straight lines through the site or by either areal coverage or stem counts within randomly placed 1 meter squares. Enough lines or squares would be used until the dominant species are evident. All dominant species (the most dominant species and any additional species comprising at least 20% of the samples) would be collected.
7. For each dominant species, above ground tissues will be collected, dried, and homogenized into one sample for each species. Sufficient tissue would be collected to perform all required tests.
8. This pattern would be completed for each identified "hot spot sampling point".
9. Cadmium vegetation tissue concentrations (in both wet wt. and dry wt.) would be determined for all dominant higher plant species (as defined in Par. 1). Analytical standards would be in accord with EPA Region IV/COE Southeast Regional Implementation Manual for Section 103 Evaluations (SERIM).
10. Control samples of the same species (at least 5 samples) would be collected from other areas with low cadmium content found in adjacent DMCAs.
11. Data from all sampling points within a "hot spot" would be assembled by species and the average of each species compared to the control samples and the 5 mg/kg dry wt. plant tissue threshold. Should species-specific tissue data from a "hot spot" be significantly higher at the 95% confidence level than both the control samples and the plant tissue threshold, additional management action by the District would be required.

7.4.3.2 DMCA Sediment Sampling During Placement

Samples would be taken weekly from the inflow during placement operations and analyzed for cadmium. Sampling could include a slurry sample and clay ball sample (if clay balls are being discharged).

7.4.3.3 DMCA Sediment Sampling Following Placement of Cadmium-Laden Sediments

Following placement of cadmium-laden sediments within a DMCA (and before placement of the cap), eighty-six (86) grab samples would be collected from a depth of 15 cm to characterize the cadmium levels of surface sediments. Samples would be evenly spaced across the DMCA, and they would be analyzed for cadmium concentration on a dry weight basis.

7.4.3.4 Cover/Cap Sampling

A cover/cap of sediments obtained from areas of the channel where concentrations of cadmium are believed to be 4 mg/kg or less would be placed on the cadmium-laden sediments in DMCAs 14A and/or 14 B. Following placement of the cover, eighty-six (86) grab samples would be taken from a depth of 30 cm and analyzed for cadmium.

In summary, the District would sample the deposited cadmium-laden sediments when the DMCAs are still inundated. These grab samples would be collected to a depth of 15 cm. To speed the collection of the next round of sampling (after placement of the covering sediments), the District would also likely sample the completed cover when the DMCAs are still inundated. These grab samples would be collected to a depth of 30 cm. If the DMCA is drained and the sediments are allowed to dry, the cover sampling would still be taken to a depth of 30 cm.

7.4.3.4.1

If the analysis of the sediment samples taken from the cover indicates that concentrations of cadmium are less than 4 mg/kg, monitoring of the cover is complete.

7.4.3.4.2

If the analysis of the sediment samples taken from the cover indicate that concentrations of cadmium are equal to or exceed 4 mg/kg in a cumulative area of 25 acres (not necessarily contiguous) or more of the covering layer, then three actions would be required irrespective of when any additional cover is placed. In addition, if there is a concern about the number of birds or other animals or a particular species using the DMCA, then some type of hazing may be appropriate. Hazing techniques would require the approval of the USFWS prior to implementation. The three required actions are as follows:

1. The DMCA would be kept flooded to keep the sediments wet/moist.
2. The DMCA would receive a cover of O&M material at the earliest possible time. Once the layer of O&M material has been placed in the DMCA, the surface sediments (to a depth of 30 cm) will be sampled (86 grab samples) and analyzed for cadmium. The process of placing O&M material into the DMCA and testing for cadmium would be repeated until cadmium concentrations in the surface sediments are less than 4 mg/kg.
3. Vegetative monitoring would begin.

7.4.3.5 Water Quality Monitoring Requirements for Cadmium-Laden Sediments

The effluent from all DMCAs would be monitored during dredging operations. The effluent from DMCAs 14A and/or 14B would be specifically monitored for cadmium levels. All DMCA 14A weirs discharge to the Savannah River. The main weir for DMCA 14B discharges to Fields Cut. It is possible that minor discharges to Wright River could occur from the other weirs in DMCA 14B. Cadmium concentrations in the effluents from DMCAs 14A and/or 14B from all weirs discharging at 0.1 cfs or greater would be monitored weekly. Should one of the constituents exceed State water quality standards, the additional sampling procedure outlined in the DEIS for sampling effluent during placement of sediment in DMCAs (Appendix M, 7.3.3) would be followed.

The District would perform a quarterly metals scan (including ammonia) on the cadmium-laden DMCA effluent at each outfall pipe discharging at 0.1 cfs or greater. This monitoring would cease one year after installation of the final cover unless a metal constituent is found to exceed chronic water quality criteria or standards. In that case, monitoring for metals would occur on a quarterly basis until no chronic criteria are violated at the outfall pipe for one year.

A copy of all sampling results will be provided to the USFWS.

Monitoring of the effluent from DMCAs 14A and/or 14B would continue as long as a discharge is present and until all sediments have been covered, dewatered, and stabilized. Following the installation of a clean cover, cadmium would be monitored in the effluent on a monthly basis for one year.

7.4.3.6 Other Monitoring Requirements

7.4.3.6.1

At the end of construction, sediment samples would be taken to 15 cm from the exposed river channel bottom sediment surface and analyzed for grain size and metals (including cadmium). This would provide an assessment of cadmium concentrations in sediment at the sediment-water interface that are exposed at the end of deepening, before normal sedimentation occurs.

7.4.3.6.2

As requested by Georgia DNR-EPD, sediment analysis would be required prior to maintenance dredging in channel reaches with cadmium–laden sediments. Samples are to be taken and analyzed for cadmium from two locations for at least two maintenance dredging cycles and furnished to Georgia DNR-EPD at least 45 days prior to dredging.

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29 September 2008
Revised 20 October 2009
Revised 29 June 2010
Revised 22 June 2011
Revised 12 December 2011
Revised 26 January 2012, 7 March 2012
<u>Revised 30 May 2012</u>

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