A 22 YEAR RECORD OF DREDGED MATERIAL MONITORING: RESULTS FROM THE FIELD VERIFICATION PROGRAM (FVP) MOUND IN LONG ISLAND SOUND

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ABSTRACT

In the spring of 1983, 55,000 m^3 of contaminated sediment from Black Rock Harbor, CT was placed at the Field Verification Program (FVP) dredged material disposal mound in central Long Island Sound. Placement of the material was designed to support extensive field and laboratory experiments as well as biological, physical, and chemical testing protocols in order to develop a framework for monitoring the biological effects of dredged material disposal. The mound was left uncapped to serve as a 'negative control' to observe relative recolonization rates and long-term stability of the benthic community. While monitoring has occurred at regular intervals since the original disposal event, the most recent monitoring survey in June of 2005 was conducted to provide baseline information for future potential capping of this previously uncapped mound. A retrospective of the 22 years of data provides an unprecedented record of the active diagenetic and biological processes occurring at the surface of a dredged material deposit. Black Rock Harbor (BRH) sediment consisted of black, high water content, fine-grained sediment with elevated concentrations of metal and organic contaminants. Surface sediment samples collected immediately after disposal at the center of FVP revealed a mixture of gray sand and clay within a matrix of black organic silt. Sediment quality triad studies of BRH sediment showed extreme chronic and acute toxicity; sediments from near FVP collected in 2000, however, showed no sediment toxicity and no differences in benthic community structure relative to reference. Cores collected in June 2005 were sampled for assessment of sediment contaminants and physical properties. Concentrations of sediment contaminants in the surface sediments were similar to samples collected at the reference area, while samples collected below 10-15 cm in each core showed an increase in most measured contaminants, consistent with penetration into material mixed with BRH sediment. The highest concentrations measured were close to the lowest measured in the original BRH study. The deposit has been monitored frequently using a sediment-profile imaging (SPI) camera both to track the spread of dredged material and follow benthic recolonization of the mound. SPI surveys conducted since mound formation have consistently shown that the flanks of the mound have converged to near-reference conditions, with some variation in results in images collected from the center portion of the mound. SPI images collected in 2005 were consistent in demonstrating the return to a benthic community very similar to that of the reference images, especially on the flanks of the historical mound. The active diagenetic processes of bioturbation, diffusion, and ambient sedimentation have contributed to alteration of the surface sediments of FVP, although the lack of contaminants in the top of the cores suggests that active sedimentation is the most rapid process occurring at the sediment surface.

Keywords: Dredging, beneficial uses, slurry transport, dredged material disposal, contaminated sediment, natural recovery.

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INTRODUCTION

Background to the Field Verification Program

The Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Alternatives, known simply as the Field Verification Program or FVP, was conducted by the US EPA and Army Corps of Engineers in 1982-1986 (Peddicord 1988). The objective was to field-verify existing test methodologies for predicting the environmental consequences of disposal of highly contaminated dredged material under aquatic, wetland, and upland conditions. This cooperative research program was assigned to the US Army Waterways Experiment Station (WES), and the aquatic portion was carried out by the US EPA Environmental Research Laboratory in Narragansett, RI (Gentile *et al*. 1988).

The FVP disposal mound was created as part of the aquatic alternative study in the northwest corner of the Central Long Island Sound Disposal Site (CLDS; Figure 1). Disposal of approximately 55,000 m^3 of contaminated sediment from Black Rock Harbor, Connecticut was placed at the site to serve as the unconfined open-water disposal mound. The aquatic alternative included a host of biological, physical, and chemical testing procedures used to develop a framework for dredged material disposal monitoring of biological effects (Gentile *et al*. 1988). The mound was left uncapped to serve as a 'negative control' to observe relative recolonization rates and long-term stability of the benthic community.

Sediment dredged from Black Rock Harbor (BRH) consisted of black, high water content, fine-grained silts and clays with elevated concentrations of metal and organic contaminants (Table 1). Exposure to BRH sediment resulted in both chronic and acute effects in several test species, as well as PCB and PAH bioaccumulation (Gentile *et al*. 1988). If adverse effects were to be seen from placing material that would be considered unacceptable for open-water disposal, they should have occurred at FVP. While the mound was sampled quite frequently during the first five years after disposal as part of the FVP research program (Scott *et al*. 1987), concurrent and subsequent monitoring of this disposal mound came under the management of the Disposal Area Monitoring System (DAMOS) Program.

Periodic monitoring occurred throughout the 1980s and 1990s to look at ecosystem recovery and long-term trends in benthic recolonization on the mound (Table 2). The mound has shown a wide range of benthic community response, from an initial classic primary successional recovery following disturbance while monitored during the FVP research program (Scott *et al*. 1987), to episodes of retrograde succession following Hurricane Gloria (Parker and Revelas 1988) and hypoxic events in Long Island Sound (Morris 1997).

June 2005 Survey

A monitoring survey was conducted at the FVP dredged material disposal mound in June 2005 to provide baseline information for future capping of this previously uncapped mound. As part of the designation of the CLDS, the US EPA modified the site boundaries to encompass the FVP area, thereby providing an opportunity to cap the mound. Site condition data collected during this and previous monitoring surveys will be used to compare pre- and post-cap surface sediment conditions. Both sediment-profile imaging (SPI) photographs and sediment cores were collected. The survey was designed to evaluate current conditions at FVP at the center of the mound (within 50-75 meters of the mound center), as well as the flank (100-200 meters from the mound center), relative to reference conditions (Figure 2).

Cores were collected from the FVP mound on June 28, 2005 for assessment of contaminants, TOC, and grain size in the top 20-40 cm of sediment. Two cores were collected at the CLDS reference site (CLIS-REF) and subjected to the same chemical analyses. Seven target core locations were occupied on both the central mound and flanks of the historical FVP mound (Figure 2). Immediately following collection, sub-samples were taken from five box cores at 5-cm intervals for geochemical analyses. In addition, two longer gravity cores were collected.

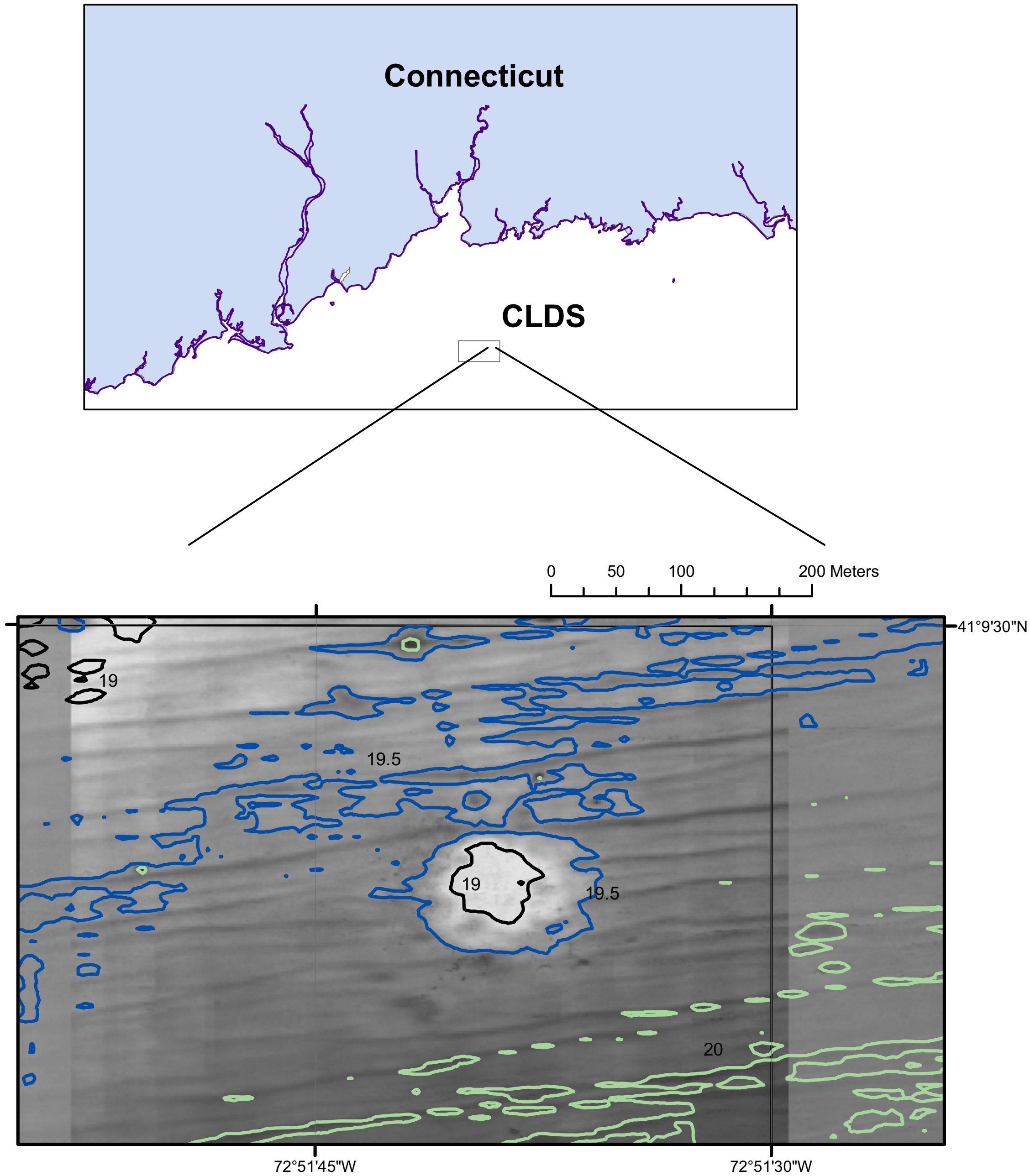


Figure 1. Top: Location of the Central Long Island Disposal Site (CLDS) off of Connecticut, Long Island Sound. Bottom (inset): Northwest corner of CLDS (border along longitude 72° 51' 31"), showing bathymetry contours (m) across the FVP mound (CLDS 2005 multibeam survey; ENSR in press) overlying shaded bathymetry and backscatter. Note presence of mud furrows surrounding mound.

Table 1. Concentrations of selected contaminants for Black Rock Harbor and the FVP mound (all dry weight).

Chemical Compound	Black Rock Harbor[1]	FVP[2]
Phenanthrene (ppb)	5,000 +/- 1,800 (15)	3,300 (C-01D)
Fluoranthene (ppb)	6,300 +/- 1,300 (15)	4,100 (C-01D)
Benzo(a)pyrene (ppb)	3,900 +/- 970 (15)	1,700 (C-01D)
Total PAHs (ppb)	142,000 +/- 30,000 (15)	25,645 (C-01D)
PCB as Aroclor 1254 (ppb)	6,400 +/- 840 (15)	
Total PCBs (ppb)		1,675 (B-03D)
Copper (ppm)	2,900 +/- 310 (18)	2,030 (C-01D)
Cadmium (ppm)	24 +/- 0.6 (18)	21.8 (C-01D)
Chromium (ppm)	1,480 +/- 83 (18)	804 (C-01D)
Iron (ppm)	31,000 +/- 2,800 (18)	27,700 (B-03A)
Water content (%)	63-150[3]	62-151

[1]All data from Gentile *et al*. 1988 except water content. Mean +/- one standard deviation reported (number of samples in parentheses).

[2]Maximum concentration reported from June 2005 cores collected for this survey. Sample identifier in parentheses.

[3]Range of water content (Morton *et al*. 1984) collected from surface of FVP mound.

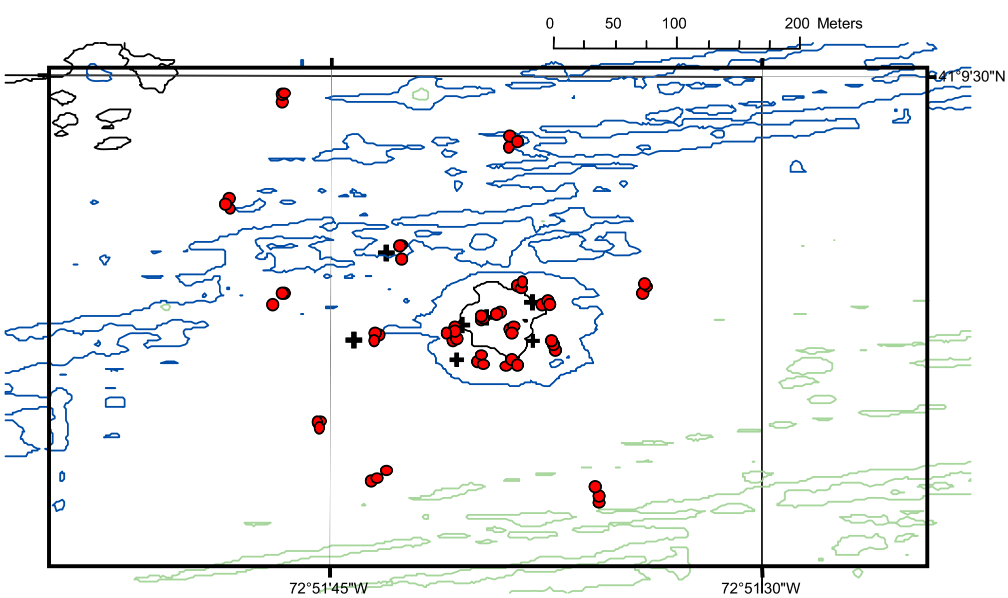


Figure 2. Location of SPI (small dots) and core (plus signs) stations from the June 2005 survey at CLDS. Bathymetry contours (m) are the same as in Figure 1. Stations located within the 19.5 m contour are mound stations; stations outside of this boundary are flank stations.

The primary objective of the SPI survey was to assess current benthic infaunal community conditions on the disposal mound. Ten stations were randomly placed on the bathymetrically-detectable mound, and ten stations were randomly placed on surrounding the mound on the historic extent of the original dredged material apron (Germano and Rhoads 1984; Figure 2). Five stations were also sampled at the historic CLIS REF station. The expected benthic assemblage was predicted to be a Stage 3 infaunal community based on the previous surveys over this mound in the last few years (Morris 1997; SAIC 2002).

Table 2. Summary of monitoring surveys at FVP, 1982-2005.

Monitoring Year	Description	Activity				Sources[1]	Comments
		Bathymetry	*Sidescan*	*Sediment Profile Imaging*	*Chemistry/Grain size*		
1982	Baseline - multiple surveys	☑	☑	☑	☑	1	Associated biological field and laboratory biological testing, diver obs
1983	Pre-, interim, and post-disposal	☑	☑	☑	☑	2	Diver obs, suspended sediment analyses, in situ geotechnical testing, cores
1984	Post-disposal monitoring	☐	☐	☑	☐	3	
1985	Pre- and post-storm monitoring	☑	☐	☑	☐	4	Hurricane Gloria studies
1986	Long-term monitoring	☐	☐	☑	☑	5	Chemistry from top/bottom of cores; analyses include benthic community and body burden analyses
1987	Long-term monitoring	☐	☐	☑	☑	6	Chemistry and body burden analyses for 1000E of FVP only; DO studies
1991	Long-term monitoring	☐	☐	☑	☐	7	Chemistry and grain size at reference sites only
1993	Long-term monitoring	☐	☐	☑	☐	8	
1995	Long-term monitoring	☐	☐	☑	☑	9	
1997	Regional survey	☑	☑	☐	☐	10	USGS sidescan survey - central Long Island Sound
1999-2000	Long-term monitoring	☑	☐	☑	☐	11	
2001	Long Island Sound EIS	☐	☐	☐	☑	12	
2001	Regional survey	☑	☑	☐	☐	13	USGS/NOAA bathymetry/sidescan survey
2005	Monitoring survey	☑	☐	☑	☑		

[1] **References**

1 Morton et al. 1982; also see 82-83 references
2 Morton 1983; also see 82-83 references
3 Germano et al. 1984; Morton et al. 1984
4 Morton et al. 1985; Parker and Revelas 1988
5 SAIC 1990a
6 SAIC 1990b
7 Wiley and Charles 1995
8 Morris Charles and Inglin 1996
9 Morris 1997

[1] **References**

10 Poppe et al. 2001
11 SAIC 2002
12 ENSR 2001
13 Poppe et al. 2004
14 ENSR in press; WEDA 2006

82-82 References (FVP Program)

Gentile et al. 1988
Peddicord 1988
Rogerson et al. 1985

RESULTS

Sediment Chemistry

Most of the chemicals evaluated showed a similar pattern at all stations. Concentrations at the reference areas and at the two stations on the farthest edges of the historical mound flanks (stations B-06 and B-07) showed low to undetected concentrations of all organic and metal contaminants measured. Copper was selected as an example chemical for this paper due to the presence of a historical record of copper data, and the fact that BRH material had highly elevated Cu concentrations (Table 1). Three of the box cores nearest the center of the mound (B-03, B-04, and B-05) showed an increase with depth in most measured contaminants, consistent with penetration into material mixed with BRH sediment (Figure 3). The mean Cu concentration of all of the reference samples (40.2 mg/kg ± 8.2%; all values reported are means ± one standard deviation as a percent of the mean) was slightly lower than the average of the upper box core samples (0-10 cm) at 76.3 mg/kg ± 23.2%. In comparison, the mean Cu concentration of the samples collected from 10-20 cm of the on-mound cores was 551 mg/kg ± 50%.

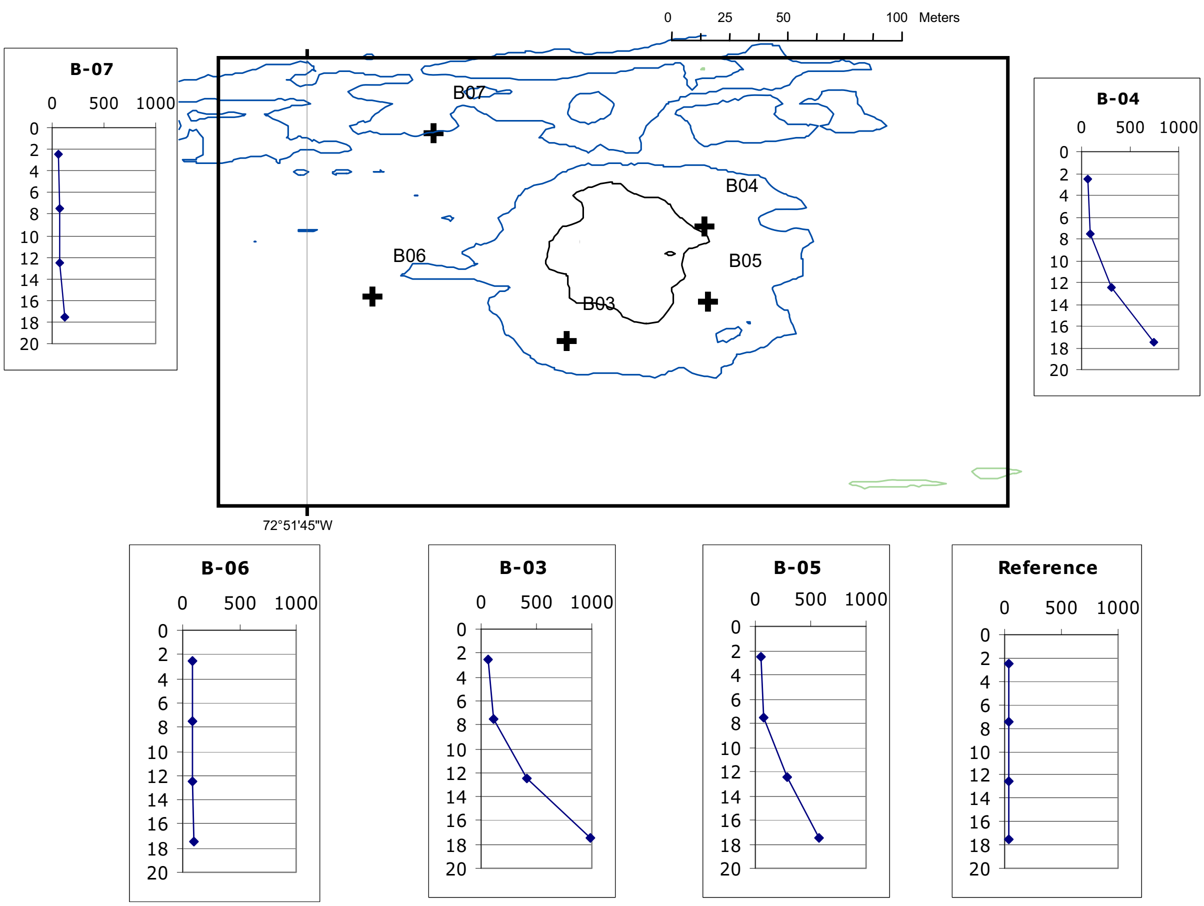


Figure 3. Copper concentrations (mg/kg) in box cores with depth (cm). Points represent center point of each sample, collected at 5 cm increments.

Metals associated with the natural sediment of Long Island Sound (aluminum, iron, selenium), as well as fine grain size, showed an inverse pattern, demonstrating that the surface sediment was associated with ambient deposition of native Long Island Sound sediments (Figure 4). There was no pattern (no change in depth, similar to reference) for arsenic, beryllium, and total organic carbon. Although the flank stations showed little variability of contaminants or conventional parameters with depth in the cores, there was a slight dredged material signal in these flank stations relative to reference (Figure 5). For example, the mean percentage of the fine-grained fraction was highest and least variable in the reference samples (87.7% ± 0.7%), followed by the upper box core samples (0-10 cm; 81.8% ±8.5%), and lowest among the 10-20 cm interval from the on-mound cores (44.88% ±21.9%).

The decrease of chemicals and increase in the fine-grained fraction in the surface sediments of the FVP mound suggest that active diagenesis is taking place, most rapidly in the flank stations where only thin layers of dredged material were originally present. Samples collected as far as 1000 meters from the mound center showed a chemical signal of the BRH material immediately after deposition (Figure 6). Active sedimentation, as seen in the increase in the percentage of fine-grained sediment at the surface (Figure 4), is likely the major source of sediment dilution of both chemicals and the sandier dredged material, but active biological mixing is also occurring at FVP, increasing the rate of "natural recovery" of the surface sediments of FVP.

Further evidence in support of the recovery of the flank sediments of FVP was published in the recently completed Environmental Impact Statement (EIS) for dredged material disposal in Long Island Sound (ENSR 2001). Surface sediment samples were collected approximately 100m west of the center of the mound. Bioassay tests showed no sediment toxicity, and there was no difference in benthic community structure relative to reference, despite concentrations of metal and organic contaminants above selected sediment quality guidelines. The EIS results suggest that the surface sediment at FVP, especially at the flank areas, is currently not toxic due to the digenetic processes of bioturbation and ambient sedimentation.

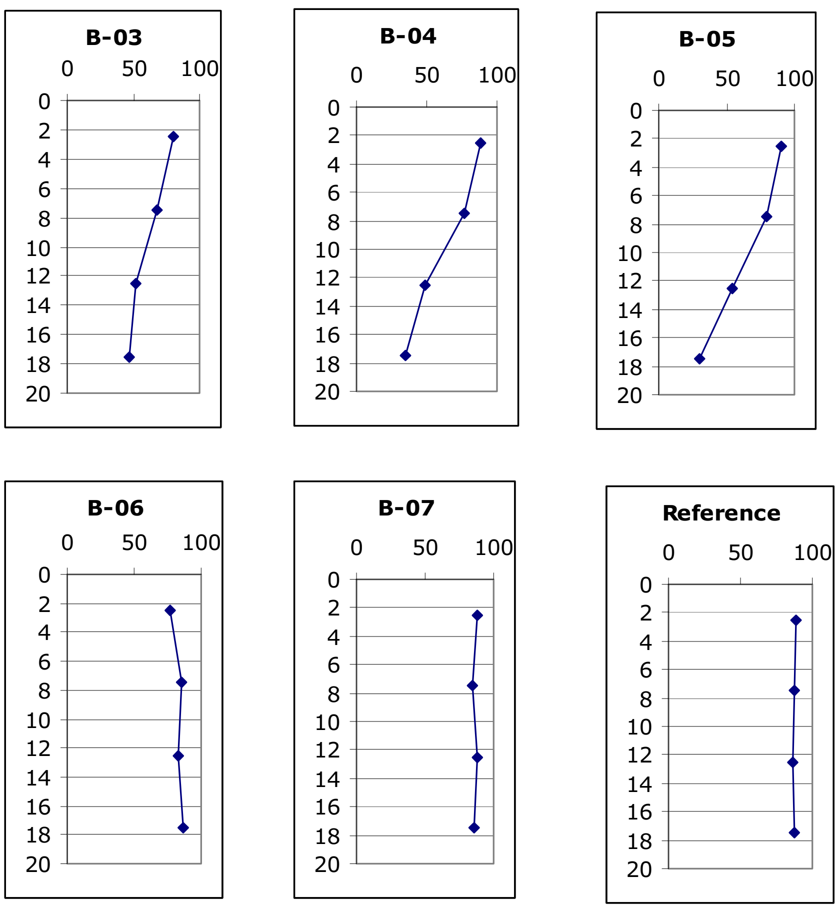


Figure 4. Results for percent fines (%) in cores from mound (B-03, B-04, B-05), flank (B-06, B-07) stations, and reference.

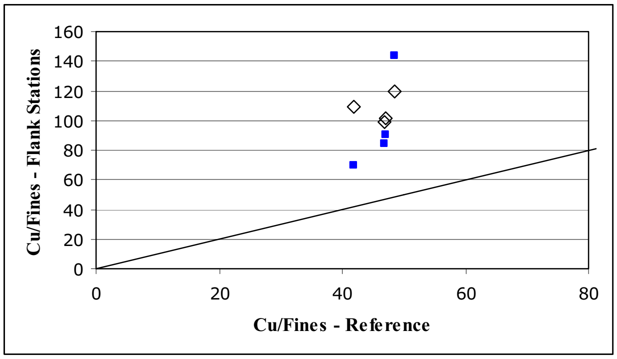
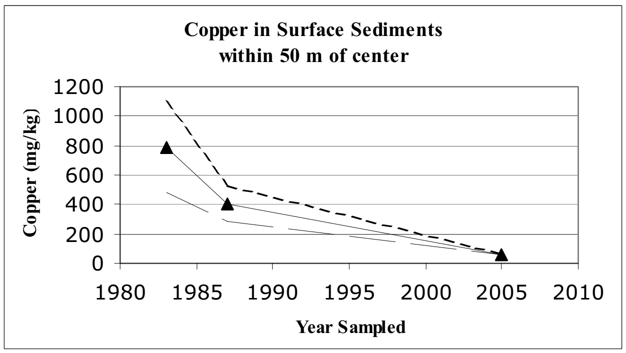
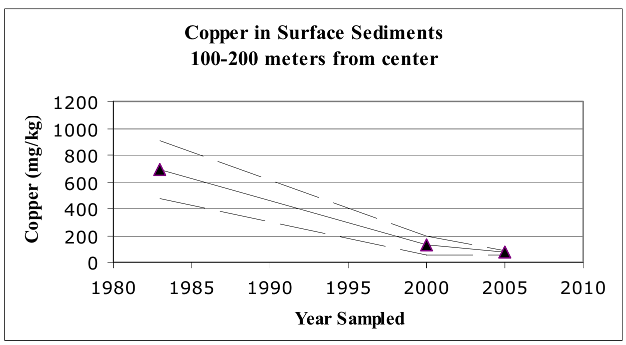


Figure 5. Copper as a function of percent fines for flank stations relative to similar depths in reference core (diamonds: B-06; squares: B-07; line represents 1:1 ratio).





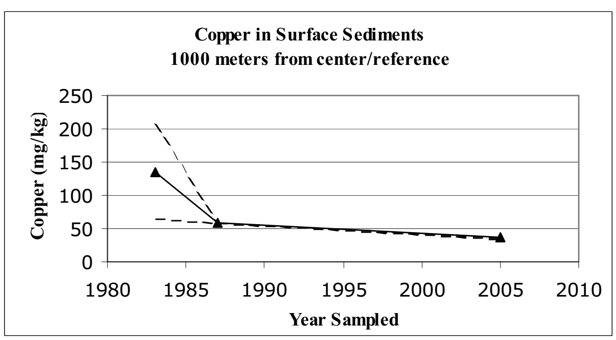


Figure 6. Historical trend of mean copper (solid line; ppm) in surface sediments on the mound (top), near-center flank (middle), and outer flank (bottom). Reference data from 2005 are plotted on the bottom graph. Top and bottom lines define one standard deviation from the mean of all samples within each zone.

Sediment Profile Imaging

SPI parameters were grouped by the location of the station, with descriptive statistics calculated for reference, flank, and mound stations (Table 3). Most parameters measured were consistent within each group classification; mound stations generally had the widest range of measured parameters. Sediments throughout the site and at the reference station were primarily fine-grained silt/clays (major mode $\geq$ 4 Φ; Table 3). Four stations on the mound and one station on the mound apron had evidence of very fine to fine sand layers at the sediment surface and at depth, consistent with the measured presence of sand in on-mound box cores.

Table 3. Summary of SPI parameters measured in June 2005 survey.

Station	Station Average Penetration	Grain Size Major Mode	Station Average Boundary Roughness (cm)	Station Average aRPD	Station Average Max Void Depth	Highest Successional Stage Present	Methane Present?
REFERENCE Stations							
R-01	14.43	>4	0.39	4.02	12.93	Stage 1 on 3	NO
R-02	14.63	>4	0.99	3.92	12.13	Stage 1 on 3	NO
R-03	15.72	>4	0.86	4.22	14.48	Stage 1 on 3	NO
R-04	14.27	>4	0.79	4.26	12.46	Stage 1 on 3	NO
R-05	14.06	>4	0.94	4.03	10.87	Stage 1 on 3	NO
Average	14.62		0.79	4.09	12.58		
Minimum	14.06		0.39	3.92	10.87		
Maximum	15.72		0.99	4.26	14.48		
"FLANK" Stations							
SOF-01	15.91	>4	0.66	3.11	15.00	Stage 1 on 3	NO
SOF-02	14.60	>4	0.82	2.74	12.42	Stage 1 on 3	NO
SOF-03	17.28	>4	0.45	2.56	16.06	Stage 1 on 3	NO
SOF-04	14.82	>4	0.80	3.00	12.00	Stage 1 on 3	NO
SOF-05	15.37	>4	0.38	2.61	12.38	Stage 1 on 3	NO
SOF-06	14.81	>4	0.38	2.85	12.78	Stage 1 on 3	NO
SOF-07	15.70	3-2/>4	0.78	2.59	13.98	Stage 1 on 3	NO
SOF-08	15.78	>4	1.09	2.05	13.96	Stage 1 on 3	NO
SOF-09	15.67	>4	0.50	3.17	14.26	Stage 1 on 3	NO
SOF-10	17.04	>4	0.66	2.42	13.52	Stage 1 on 3	NO
Average	15.70		0.65	2.71	13.63		
Minimum	14.60		0.38	2.05	12.00		
Maximum	17.28		1.09	3.17	16.06		
"ON MOUND" Stations							
SON-01	13.82	>4	0.60	2.02	6.94	Stage 1 on 3	NO
SON-02	11.21	4-3	0.80	2.68	10.31	Stage 1 on 3	NO
SON-03	15.09	4-3/>4/4-3	0.62	1.75	9.07	Stage 1 on 3	NO
SON-04	15.48	4-3	0.66	1.97	10.80	Stage 1 on 3	NO
SON-05	15.45	>4	0.90	2.23	9.85	Stage 1 on 3	NO
SON-06	14.28	>4/4-3	0.76	2.23	9.56	Stage 1 on 3	NO
SON-07	15.53	>4	0.55	2.70	9.35	Stage 1 on 3	NO
SON-08	14.39	>4	0.49	2.30	9.14	Stage 1 on 3	NO
SON-09	15.05	>4	0.63	2.04	11.24	Stage 1 on 3	NO
SON-10	16.09	>4	0.80	2.21	14.80	Stage 1 on 3	NO
Average	14.64		0.68	2.21	10.11		
Minimum	11.21		0.49	1.75	6.94		
Maximum	16.09		0.90	2.70	14.80		

Mean apparent redox potential discontinuity (aRPD) values at the stations on the disposal mound ranged from 1.8 - 2.7 cm, with an overall mound average of 2.2 cm; values on the historic apron ranged from 2.1 – 3.2 cm, with an overall average of 2.7 cm, and those at the reference site ranged from 3.9 - 4.3 cm, with an overall average of 4.1 cm (Table 3). In order to determine what a reasonable variance in mean aRPD values should be on the ambient seafloor, reference station data from the CLDS collected in 2004 and 2005 were examined. Variation in mean aRPD depths on the ambient seafloor ranged from 0.3 to 2.3 cm at this location in the last 2 years, and from 2.0 - 3.5 cm the other reference stations in this area. The boxplot of mean aRPD depths shows that there is an apparent difference among the locations (Figure 7). A subsequent interval test confirmed that the mean aRPD depths from the mound stations are not equivalent with those found on the ambient seafloor.

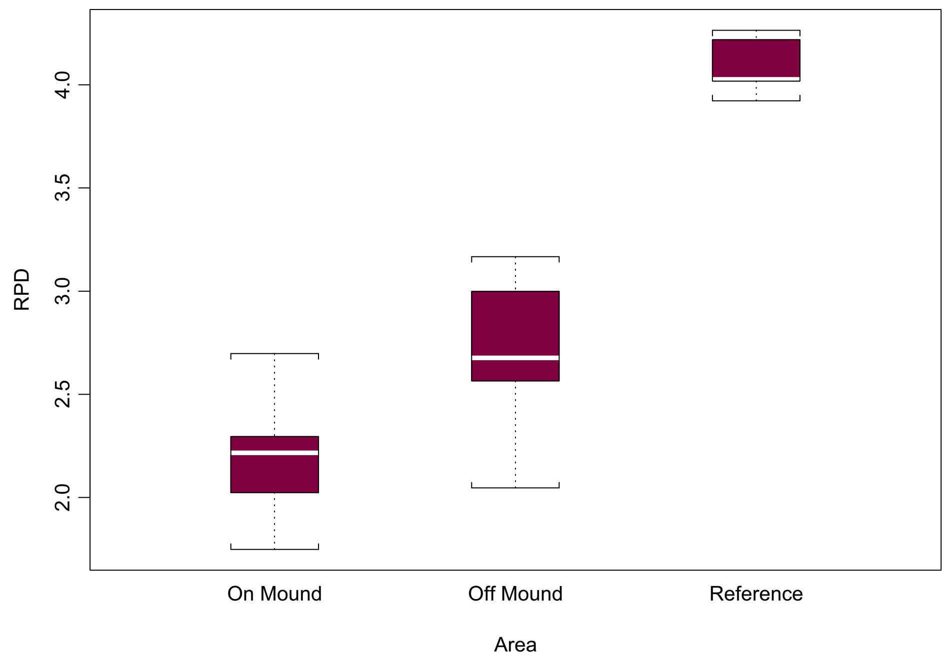


Figure 7. Variation of mean apparent RPD (aRPD) in mound, flank ("off-mound"), and reference stations for June 2005 survey.

Evidence of mature, Stage 3 fauna was found at every station surveyed, confirming earlier findings of a biological community recovery on the mound (Scott *et al*. 1987). Subsurface feeding voids, burrows, and evidence of particle transport by "conveyor belt" taxa (*sensu* Rhoads 1974) were apparent in at least one or more replicate images from stations on the mound, on the historic apron, and at the reference station. The maximum depth in the sediment profile at which feeding voids or burrows were found was quite similar in all areas surveyed.

DISCUSSION

Long-term Impact of Dredged Material Disposal

Bathymetric surveys conducted right after creation of the FVP mound showed the formation of a small deposit approximately 200m by 100m, with the major axis in the east-west direction; the maximum height was 1.8m (Morton *et al*. 1984). The spatial extent of the dredged material apron was mapped using diver observations and SPI images, showing that the apron extended to 400-500 meters in the EW direction, and 300-400 meters in the NS direction (Germano *et al*. 1984). Cores collected in July 1983 recovered 86 cm of material at the center of the mound, with thicknesses ranging from 8-28 cm at cores collected 100 meters from the center of the mound (Morton *et al*. 1984).

Neither the mound footprint, nor the apparent area of disturbance to the seafloor from disposal, has changed significantly in the 22 years since disposal (Figure 1). The baseline texture of the seafloor in the area of the FVP consists of fine-grained silt with the common appearance of mud furrows and pits (Poppe *et al*. 2001; 2004). Figure 1 shows that the FVP mound overlies these features and continues to show high acoustic reflection in both multibeam backscatter records as well as sidescan surveys (Table 2). Despite the presence of a new fine-grained sediment recovered in core samples, the acoustic signature of FVP material remains. This is likely due to both the distinct topography of FVP against the background sediment, as well as the difference in texture (grain size and water content) of the historical dredged material. The intensity of the reflections, however, have most likely dissipated, considering the lack of many bright “disposal trails” visible in sidescan data from immediate post-disposal surveys (Morton *et al*. 1984).

The USGS has conducted extensive research into sediment texture and transport processes in Long Island Sound. The presence of mud furrows in the FVP area suggests sediment transportation related to the tidal regime (Poppe *et al*. 2001). Although indicative of sediment movement, the sedimentary environment of the CLDS seafloor does not experience true erosion; resuspension is the major mechanism of bottom sediment transport (Signell *et al*. 2000). The furrows are likely relic features that do not continue to migrate significantly in the FVP area, rather sediment is resuspended and deposited over short spatial and temporal scales.

Core data suggest that sedimentation is taking place at the surface of the sediments at FVP. Published example sedimentation rates for Long Island include 0.78 cm/year (Moore *et al*. 2002) to 0.82 cm/year (Varekamp *et al*. 2003). At an average rate of 0.8 cm/year since disposal in 1983, an additional 17.6 cm of sediment would have been deposited at FVP since disposal. The box core data suggest that this is a reasonable estimate, assuming that the 10-15 cm interval represents mixing of the upper ambient sediment and lower BRH material. It is likely, however, that the sedimentation rate at the top of the FVP mound is lower, as it is most susceptible to periodic disturbance.

Historical aRPD data have shown that surface sediments of the mound, especially those at the top of the mound, are susceptible to resuspension of the upper few centimeters of oxygenated sediment. For example, survey results after Hurricane Gloria (Parker and Revelas 1988) showed a dramatic decrease in aRPD depth at that time (Figure 8), corresponding to a loss of the upper 2-3 cm of sediment from the surface of the mound (Figure 9). Over the long-term, however, recovery of the surface sediments, especially at flanks of the mound, has resulted in increased thickness of bioturbated, oxygenated sediment over the historical BRH material (Figure 10).

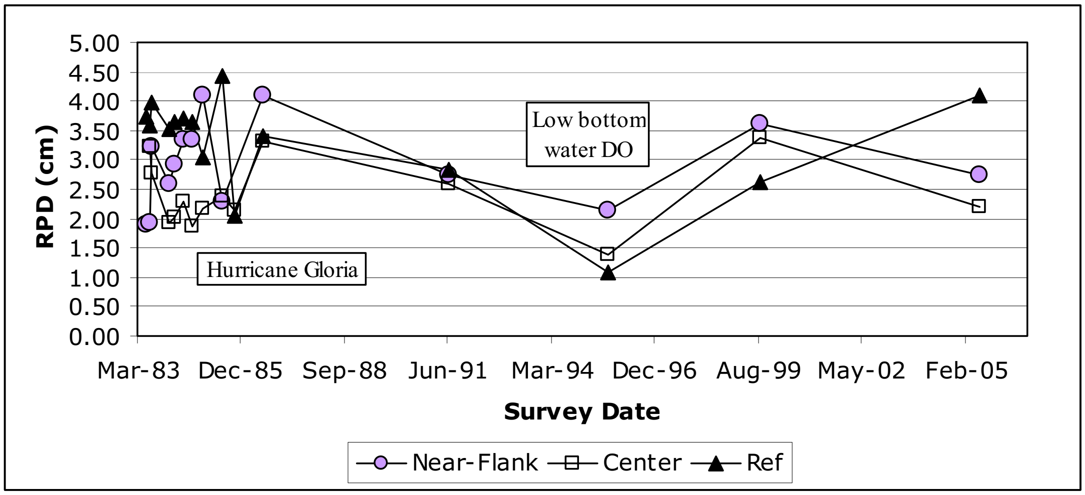


Figure 8. Historical trend of mean apparent RPD (cm) of near-flank, mound center, and reference stations. Samples within 75 meters were averaged for Center (mound) stations; stations within 100-200 meters of center were averaged for Near-Flank stations.

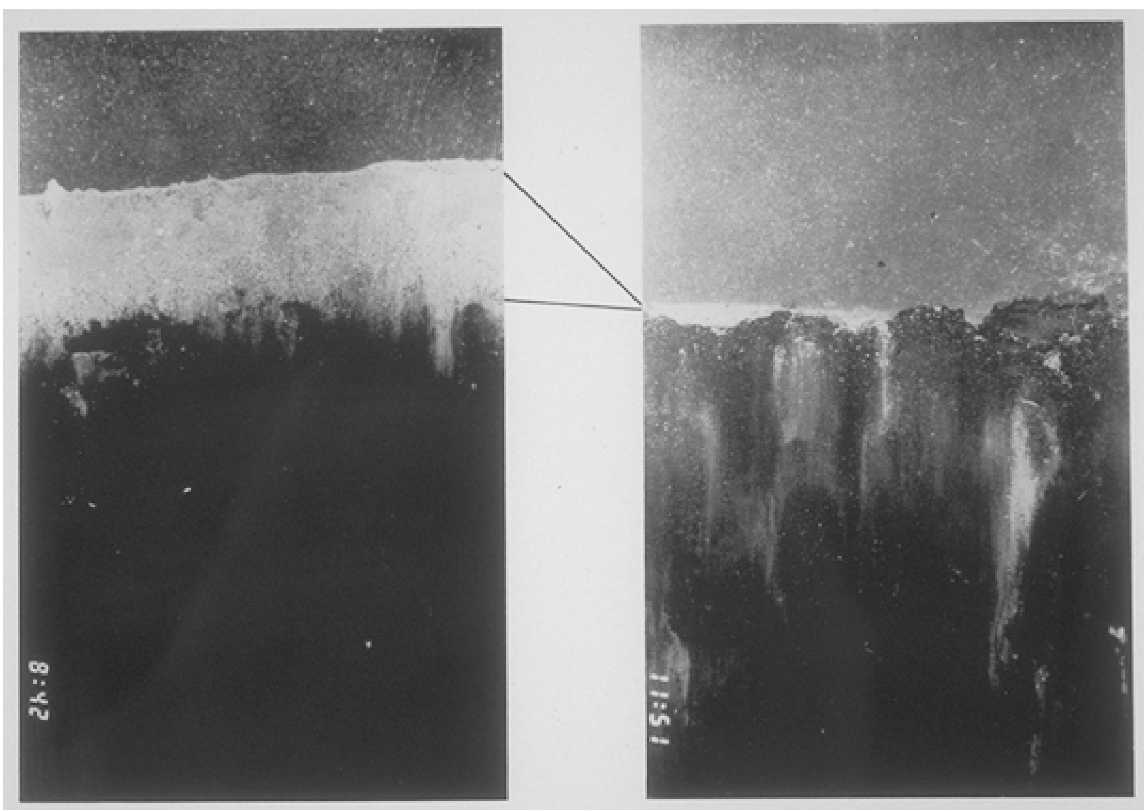


Figure 9: Sediment profile images from the center of the FVP mound immediately before (left) and immediately after (right) passage of Hurricane Gloria; note the loss of the reworked, oxidized layer of surface sediments.

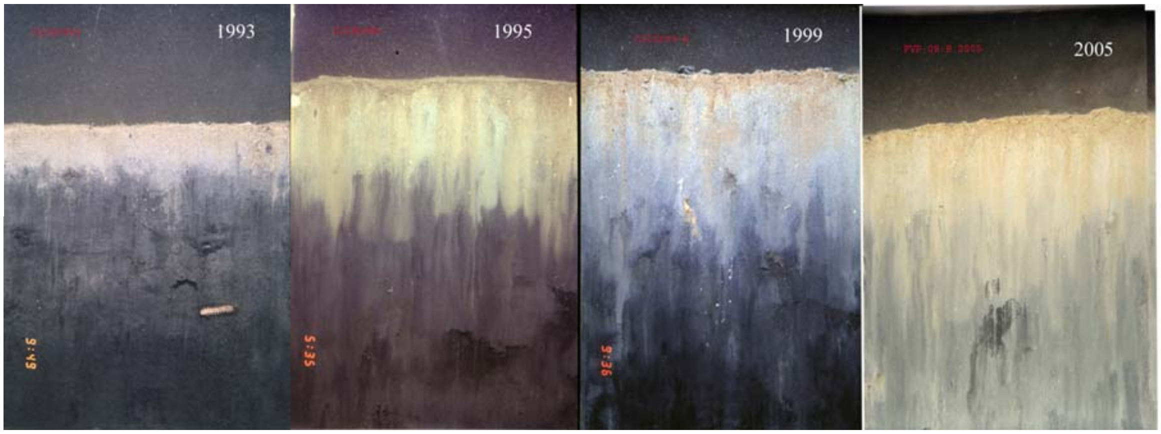


Figure 10: Sediment profile images from a flank station approximately 100 meters east of the center of the FVP mound taken in (from left to right) 1993, 1995, 1999, and 2005; note the increase of the thickness of the bioturbated, oxidized surface layer over time.

Benthic Habitat and Natural Recovery

The FVP mound has been one of the most intensively monitored mounds in the DAMOS Program over the past two decades and presents a unique case study for the long-term effects of placing material unsuitable for unconfined open-water disposal and employing an alternative remediation strategy of monitored natural recovery (MNR; Thibodeaux *et al*. 1994). While the standard rule of thumb for benthic community recovery after disposal of dredged material is anywhere from 2-5 years (Bolam and Rees 2003), the story of benthic community recovery at FVP has followed a more circuitous route than most other disposal mounds.

At the conclusion of the joint US EPA/COE FVP research program, researchers had documented that stations away from the direct center of the mound had recovered to background conditions within one year following disposal, while recruitment at the center station was lagging behind other stations (Scott *et al*. 1987). However, within two years following disposal, species numbers were similar at the center of the mound and at reference stations, with a more diverse assemblage being present on the mound. This finding was consistent with earlier observations that secondary benthic productivity is often enhanced on dredged material disposal mounds due to pulsed disturbance and recruitment of opportunistic species (Rhoads *et al*. 1978). If monitoring at the FVP had stopped at this point, it would have become merely another documented case study illustrating that benthic community recovery following open-water dredged material disposal occurs in about two years.

Continued monitoring of the FVP mound under the DAMOS Program, however, revealed that retrograde conditions in benthic community structure did occur occasionally. While the sediment profile camera survey in 1991 documented the continued presence of Stage 3 fauna on the disposal mound (Wiley and Charles 1995), the surveys in 1993 and 1995 documented degraded conditions around the center of the disposal mound (Morris 1997) related to seasonal hypoxia. The infaunal community on the FVP mound appeared to be more susceptible to seafloor disturbance and tended to recover at a slower rate relative to the CLDS reference areas and the surface of other CLDS disposal mounds following hypoxic events; the reason for this time lag was thought to be related to the additional stress from the chemical concentrations in FVP sediments on recruiting benthos. However, the results of the September 1999 sediment profile camera survey at FVP revealed benthic conditions over the mound that were better than anticipated, exceeding the conditions detected within the ambient sediments at the CLDS reference areas (SAIC 2002; Figure 11).

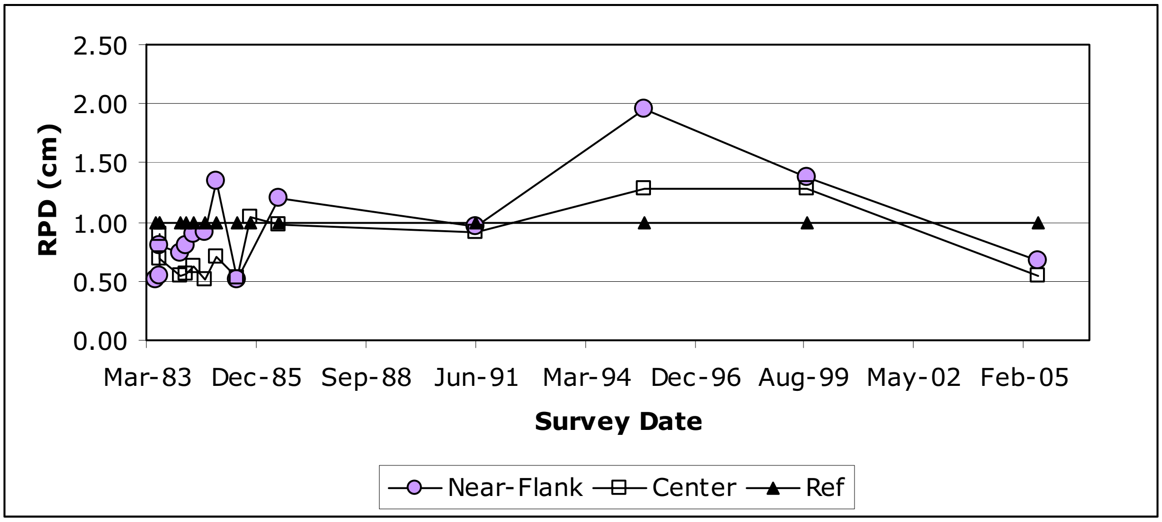


Figure 11. Historical trend of mean apparent RPD (cm) values normalized to mean reference values at near-flank, mound center, and reference stations. Points above 1:1 line indicate aRPDs greater than reference; lower than this line indicate aRPDs less than reference.

Even though there has been no additional disposal of dredged material since the original placement operations in May of 1983, it is notable that the signature of historic disposal is still quite evident in the cross-sectional image profiles of the mound stations. There is a marked change in the reflectance of the subsurface mud under the oxidized surface layer corresponding to the organic content of the sediment (the higher the organic content, the darker the reduced mud appears to the eye); the gradation in reflectance of the subsurface mud is quite dramatic as one moves from on the mound to the apron and finally to the reference station (Figure 12).

The results of this current survey in 2005, like the 1999 survey results, showed the widespread presence of Stage 3 fauna at the disposal mound; the benthic communities on both the mound and historic apron area are functionally equivalent to those found at the reference station. The notable characteristics of the sediments at this disposal mound that separate it from others surveyed in the DAMOS program are: 1) the persistence of the dredged material optical signature in the subsurface sediments, and 2) the relatively shallow aRPD found at stations on the mound and the lack of intense, bioturbational re-working of the sediments at depth. These two phenomena are definitely related; while evidence was found of animals venturing into the subsurface zone of black, high-organic sediment, the sediments on the mound are still not as biogenically mixed as those found in the near-field surrounding area where the historic mound deposit apron occurred. While one management strategy suggested has been to cap the sediments at FVP (SAIC 2002), the site continues to provide a unique opportunity to look at the suitability and effectiveness of employing MNR as a management strategy for contaminated marine sediments.

Figure 12. These 2005 profile images show the dramatic presence, lingering trace, and absence of historic dredged material (black subsurface mud) as one moves off the mound (far left), onto the historic flank (center) and finally to the reference station (right).

CONCLUSIONS

Twenty two years of periodic monitoring at the uncapped FVP mound, in combination with a wealth of studies in this area of Long Island Sound, provides an unprecedented database to investigate the long-term environmental impact of a discrete mound of contaminated sediment. A clear picture of natural recovery, hampered by periodic events of surface sediment disturbance, has emerged from this investigation:

- Natural recovery of the historic flank and apron sediments of FVP has resulted in little biological and chemical difference relative to reference sediment, although a trace of the historic presence of Black Rock Harbor material remains as indicated by the presence of sand, and in slightly elevated concentrations of chemical contaminants relative to reference.
- Ambient sedimentation is the dominant catalyst for this recovery, although biological mixing is an important process both in defining the mixing zone between historical dredged material and ambient sedimentation, and also stabilizing the surface oxidized layer of the flank sediments.
- The sediment at the center of the mound has also received significant sedimentation since mound disposal, but the presence of BRH material or mixed BRH and ambient sediment below 10 cm continues to impact biological recovery.
- The continued acoustic signature of FVP sediment above the 19.5m contour demonstrates the stability of the mound, and that the distinct topographic signature and surface texture continues to differ from background sediment. The height of mound above ambient bottom, regional surveys of this area of Long Island Sound, and previous monitoring data suggest that surface sediments at the center of the mound are periodically resuspended, acting as a catalyst to occasional retrograde biological recovery.
- Samples collected for benthic triad testing suggest that the surface sediments of FVP are not a source of toxicity to the benthic environment; thus one management option could be to leave the mound uncapped to provide a continued long-term record of choosing monitored natural recovery for a remediation strategy for contaminated sediments on the seafloor in Long Island Sound.

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