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Bioavailability of Hydrophobic Organic Compounds in Thin-Layered Capped Sediments

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Abstract

The effect of a thin sand capping layer (7.5 cm) on the bioavailability of hydrophobic organic compounds (HOCs, i.e., PCBs and naphthalene) was studied using oligochaete worms, and the results compared to previously obtained bioavailability tests with a reactive core mat (RCM) cap. The study investigated the difference in HOC concentration in worms exposed to: a) a grab sample of sediment used as sampled for PCBs and spiked for PAHs; b) an initially clean mixture of sand and organic matter (*biouptake layer*) directly overlying the sediment; and c) the biouptake layer placed on top of the RCM-capped sediment. Benchscale experiments were performed to induce pore fluid flux through the sediment and into the overlying layer(s). Principal component analysis (PCA) was used to assess PCB homolog group concentrations. Results indicate that the thin sand cap alone reduced the average bioavailability of PCBs by a factor of 100 compared to direct exposure, but had no effect on the bioavailability of naphthalene. However, worms exposed to the RCM-protected biouptake layer show virtually the same HOC concentrations as those in the background worm samples, indicating effective isolation by the RCM.

Keywords

PCBs; naphthalene; biouptake; bioavailability; sediment; remediation

INTRODUCTION

When compared to terrestrial sediments, aquatic sediments: often contain higher organic content for increased adsorption; are generally more accessible to the food chain and potential human consumption; and have a greater likelihood of interacting with both surface and ground water as potential biological exposure pathways. Hydrophobic organic compounds (HOCs) are the major contaminants of concern at sediment sites, with the presence of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) dominating the ecological exposure risk at more than 20% of contaminated

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sediment sites and the contributing factor to the over 3,200 fish consumption advisories that have been issued nationwide [1].

Current approaches for risk assessment and management of aquatic contaminated sediment sites focus on the potential impacts of the contaminants of potential concern (COPCs) on the surrounding ecosystem [2,3].

Reactive core mats (RCMs) represent one class of aquatic sediment remediation tool, consisting of a reactive layer containing one or more neutralizing or otherwise reactive materials (e.g., organoclay, apatite, activated carbon) confined between two permeable geotextile filtering layers. The 1.25-cm thick RCM is placed on the sediment, and approximately 7.5–10 cm of overlying soil or armoring marine mattress is placed on the RCM for stability and protection. With their reactive material(s), RCMs have the potential not only to shift the redox zone to a more oxic environment and sequester the contaminants in the underlying sediment (as in traditional geomaterial caps), but also to adsorb and neutralize target contaminants in the sediment and retard contaminant breakthrough to the overlying, biologically active zone and water column [4,5]. RCM technology has recently been adopted at several U.S. EPA Superfund site projects as part of the overall remediation strategy [6].

Several studies have investigated the bioavailability of HOCs to freshwater oligochaete worms to better assess remediation methods [2,7–15]. This paper presents an experimental study to assess the efficacy of capping using a thin sand cap (7.5 cm) and RCM to isolate PCB and naphthalene contaminated sediment from a model biouptake layer, and to reduce bioavailability as indicated using freshwater worms (*Lumbriculus variegatus*).

MATERIALS AND METHODS

Sediment

The baseline sediment used was sampled from the Neponset River (Milton, Massachusetts, USA), upstream from the Tilestone and Hollingsworth Dam, a Massachusetts Department of Environmental Protection (MA DEP) cleanup site chosen in coordination with US EPA Region 1. Sampling was performed at mid-channel using an Ekman sediment dredge sampler (Wildco® Corp.). Collected sediment was transferred into clean, non-translucent 5 gallon HDPE buckets that were sealed, transported to the laboratory, and stored in a 10°C temperature room to reduce microbial activity. The sampled sediment from this location has trace levels of background PAH contamination and 10,619 ng/g total PCB concentration with a congener profile similar to Aroclor 1248.

Following a solids settling period, the overlying water was decanted by siphoning. Large organic debris and stones were removed from the sediment by hand. Using one sample from each bucket, organic carbon fraction [16], water content [17], specific gravity of solids [18], and hydraulic conductivity [19] of the sediment were determined. On average, the test sediment had 10.4% total organic carbon fraction, a water content of 248%, a specific gravity of solids, $G_s = 2.3$, and an initial hydraulic conductivity of 4×10^{-5} m/sec.

Sediment Spiking

Since the sediment sampled from the Neponset River had sufficient background PCB concentration for testing (10.6 mg/kg) but only trace levels of PAH contamination (<0.1 mg/kg), the sediment was spiked with naphthalene. Naphthalene (Acros Organics 99%, #180902500) was chosen as the PAH model for spiking due to its 1 to 2 orders of magnitude higher solubility in water (12.5 to 34 mg/L) compared to other PAH compounds [20], and

availability of background PAH biouptake data on *L. variegatus* [10]. A nominal dry sediment concentration of 250 mg/kg was targeted.

Sediment samples were kept in their field-wet condition with natural hydration both before and during spiking to avoid biogeochemical alterations due to drying processes [21]. Spiking was performed in 1 L amber glass jars to prevent photo-induced excitation and photo-degradation. A high solvent volume technique [22] with solvent-to-solid ratio greater than 1:20 (volume of solvent:weight of compound) was adopted. Analytical grade acetone was used as the solvent with 1:8 solvent-to-naphthalene ratio. Given the large mass of sediment being spiked, the high solvent volume method was expected to provide better compound distribution by solvent permeation into the sediment [23]. Care was taken to avoid using excess acetone to minimize the likelihood of denitrification in the sediments [24]. The desired quantity of naphthalene (typically around 160 mg) and 20 ml of analytical grade acetone solvent (Fisher Scientific, A 928-4, Pittsburgh, PA) were first mixed separately to completely dissolve the naphthalene, and the resulting solution was added to each sample jar containing 640 grams dry mass of sediment.

The jars were then capped tightly with Teflon lined lids and mixed by rotation. Reid et al. [23] have suggested a spiking mixing time of two weeks (14 days), and this duration was adopted for the present study. At the end of spiking, the sediment-naphthalene mixture was immediately used in the experiment with no significant post-mixing storage duration.

Contaminant Transport Column: Device and Testing Procedures

The testing column device is a coupled, large-strain consolidation and contaminant transport mesocosm device that physically models the contaminated sediment, the RCM (when used), overlying clean sand layer with organic matter (biouptake layer) and water column. Column tests were demarcated “NEP-XX” (Neponset River sediment, “XX” = test number). Neponset River sediment in this device tends to consolidate hydromechanically very rapidly and with significant associated deformations, which creates consolidation-induced advective flux of the pore fluid to the overlying model of the biologically active benthic zone (described below) and water column [25].

For the tests reported, the biouptake layer consisted of a medium coarse sand mixed with 3% (by mass) Omega One® “trout chow” organic matter to promote retention of any contaminants that may break through the RCM, and thereby maximize the potential for contaminant exposures during the bioaccumulation tests using the sand-organic mixture (as opposed to non-reactive sand layer only). An approximately 7.5 cm thick layer of this sand-trout chow mixture was placed on top of the loading plate and the remainder of the column filled with deionized water. The development and proof-testing of this device is presented elsewhere [25,26].

Once the set-up procedures were completed, backpressuring of the system began until the final backpressure of 200 kPa was reached. Consolidation was induced using three progressively higher stress increments of 10, 25 and 55 kPa. To quantify the contaminant transport in the testing column, water samples (at least 5 mL volume for each) were taken from top and bottom sampling ports at the following elapsed times relative to application time for each loading increment: $t = 0^-$ (just before loading), 15 min, 30 min, 1 hr, 3 hr, 6 hr, 9 hr, 12 hr and 24 hr. Collected water samples were placed in 20 ml glass vials and refrigerated at 4°C until analysis was carried out. Water sample analysis is presented elsewhere [27].

At the end of the test, the overlying water was drained into a sampling bottle, the biouptake layer (sand-trout chow mixture) collected in a wide-necked sampling bottle, and the RCM

and the contaminated sediment each placed in individual, air-tight, zip-locked plastic bags, which were frozen and stored until subsequent bioaccumulation testing.

Bioaccumulation Tests Procedures

To prepare for the bioaccumulation experiments, 100 mL of the post-column test sand-trout chow mixture or sediment was placed into a 1 L glass beaker; this beaker served as the exposure test chamber. To this, 900 mL of standard, synthetic freshwater was added, and the beaker was then aerated for 14 days with twice weekly water changes [28] to remove ammonia-based toxins. Exposure tests were conducted in accordance with the U.S. EPA standard [29]. To begin the test, 1 to 5 grams (wet weight) of worms (*L. variegatus*; Aquatic Research Organisms, Inc.) were added to each beaker. Aeration was continued in each beaker throughout the exposure test by hoses at a rate of 50 cm³/min. A consistent light cycle of 16 hours light and 8 hours dark was provided by an automatic lamp with an illuminance range of 100–1000 lux. Beakers were placed in a circulating water bath to maintain an ambient temperature of 20±1°C and were loosely capped to prevent significant evaporation from the test chamber. Ammonia concentrations in beakers were measured regularly in accordance with the 4500-NH₃-F Phenate method [30] to assure that levels were below the toxic limit, reported to vary between 6.6 to 390 mg/L depending on pH [31]. In addition, dissolved oxygen (DO) concentrations were monitored using Thermo Scientific Orion Star A220 DO probe to ensure DO levels above 2.5 mg/L (levels below this can adversely impact *L. variegatus* [32]). The test chamber's overlying freshwater was refreshed throughout the test by changing half the water every 3 days. The worms were not fed during the exposure period.

At the end of the 28-day exposure test period, worms were removed, rinsed clean with water, and weighed. The worms did not undergo a gut elimination in clean sand prior to chemical analysis per the standard [29]. Worms were maintained at 4°C until extracted for lipid and chemical analysis. Sands, sediments, and other materials were kept frozen until analysis.

Table 1 summarizes the respective testing conditions for all tests performed.

Chemical Analysis

Upon completion of the exposure period, worm, sand and sediment samples were analyzed for either PCBs or naphthalene content using the methods described in Vorhees et al. [33] for PCBs and Vinturella et al. [34] for naphthalene. Samples were analyzed on an Agilent Gas Chromatograph, for naphthalene using mass selective detector in selected ion mode, and for PCB using a ⁶³Ni electron capture detector. For naphthalene, a 30 m, 0.18 mm i.d., 0.18 µm film thickness DB-KLB column was utilized to quantify naphthalene. For the PCBs, a 30 m, 0.25 mm i.d., 0.25 µm film thickness DB-5 capillary column (J&W Scientific, Folsom, CA) was used to separate the PCB congeners. Quantification was based on external standards containing surrogates, the internal standard, and the analytes of interest. Sixty-five target PCB congeners were measured. Several peaks were quantified as individual congeners but may contain a small contribution from co-eluting congeners (i.e., IUPAC 138, 153, and 170). Method detection limits were calculated for each analyte by multiplying by three the procedural blank standard deviation value for each analyte.

Principal Component Analysis

As part of the tests using PCB contaminated sediment, 6 duplicate sediment and biouptake layer samples, and 6 duplicate worm samples were each analyzed for 54 PCB congeners from various homolog groups that resulted in additional chemical data. Principal component analysis (PCA) was used to assess possible correlations and patterns within the multi-

dimensional dataset. Using data intensity modulation, PCA converts a multi-dimensional dataset into a two-parameter representation to understand trends and group test parameters [35–37].

RESULTS AND DISCUSSION

Sediment and Biouptake Layer Analysis

In tests using the RCM cap (NEP-15 and -16) and sand cap only (NEP-21 and -22) on naphthalene spiked sediment, pore fluid naphthalene concentrations of the original sediment were in the range of 2.24 ± 0.51 mg/L (RCM) and 1.76 ± 0.55 mg/L (sand only), while the overlying water concentration was 0.036 ± 0.02 mg/L and 0.18 ± 0.07 mg/L, respectively. This shows the enhanced ability of the RCM over that of a conventional sand cap to isolate the contaminated sediment from the water column. Meanwhile the control tests with no capping layer overlying the sediment had pore fluid concentrations in the sediment of 1.68 ± 1.02 mg/L and overlying water concentrations of 0.52 ± 0.34 mg/L, which likely reflects a dilution effect. Advection-based consolidation was completed in all tests for all stress increments within the test durations (as evidenced by the cessation of deformations under applied stress) [38].

For the analysis of PCB contaminated samples, concentrations of 54 congeners were evaluated for all solid samples, with PCB congeners #30 and #204 used as the surrogates to evaluate the recovery of extraction method. Samples of Neponset River sediment and overlying biouptake layer respectively yielded 88–116% and 76–87% surrogate recovery, which are within the acceptable range of recovery of 60–130% [15]. Neponset River sediment that was used in the experimental study was analyzed for total PCB concentration

Total PCB (tPCB) concentration of the biouptake layer overlying the RCM layer at the end of column tests averaged 0.395 ± 0.055 ng/g for NEP-4 to -6 (0.388 ng/g, 0.465 ng/g and 0.332 ng/g respectively), while the tPCB concentration of the biouptake layer without RCM cap layer at NEP-7 was 0.835 ± 0.051 ng/g (Fig. 1). The background tPCB concentration of the sand and trout chow mixture of the biouptake layer was 0.204 ng/g (Fig. 1). Thus, limited breakthrough of PCBs was observed in all tests regardless of the presence of the RCM.

In addition, as noted, the PCB homolog group distributions of the samples were analyzed by using comparative homolog group fractions plots (Fig. 2) and PCA analysis for: the natural sediment, test NEP-4 to -7 biouptake layers, and background biouptake layer samples (Fig. 3). PCA analysis resulted in principal components with the highest proportion of variance (69.0% and 26.2%, totaling 95.2%), which exceeds the recommended total variance of 75% [39]. The PCB homolog distribution plot (Fig. 2) shows that the PCB in Neponset River sediment is dominated by tri- and tetra-CB homologs. This is confirmed with the PCA analysis, in which the same behavior was observed given the loadings of the homolog groups relative to the raw Neponset River samples and the biouptake layers. In addition, the homolog group fractions of the biouptake layers with an applied RCM remediation layer (NEP-4 to -6) were dominated by penta- and hepta-CB homolog groups. While the corresponding loading and the positions along the PCA indicates the same, PCA also shows more similarity between NEP-4 and -5 biouptake layers compared to the NEP-6 biouptake layer. Similarly, the homolog group fractions of the biouptake layer with no RCM isolation (NEP-7) was dominated by penta- and hepta-CB homolog groups, and the PCA plot indicates biouptake layers in NEP-6 and -7 were closely correlated. However, the homolog group fraction of the initially clean biouptake layer sample had equally distributed homolog group fractions of tri- to hepta-CB, with the highest deca-CB percent among all the samples. This is represented in PCA space by being located between light and heavy homolog

loadings with a location close to deca-CB. Based on these results, it was clearly seen that overlying biouptake layers were enriched with higher chlorinated PCBs compared to Neponset River sediment and background biouptake layer samples, which indicates the efficacy of the RCM and biouptake layer in sequestering lower chlorinated PCB congeners. Neponset River sediment spiked with 250,000 ng/g nominal naphthalene concentration was analyzed at the end of the column tests and showed naphthalene concentrations from 20,838 to 42,205 ng/g ($33,903 \pm 9,350$ ng/g). The biouptake layers with RCM had an average naphthalene concentration of 2.489 ± 1.596 ng/g (1.253 ng/g and 4.445 ng/g respectively; Fig 4), whereas the biouptake layer with no RCM (tests NEP-21 and -22) had an average naphthalene concentration of 3000 ± 700 ng/g (2300 ng/g to 3700 ng/g respectively; Fig. 4). For comparison, the naphthalene concentrations of the initially clean biouptake layer and reference Neponset River sediment were 0.51 ng/g and 65 ng/g respectively.

L. Variegatus Tissue Residue Analysis

Post-column test biouptake layer material from RCM-capped tests (NEP-4 to -6), a sand-capped- only test (NEP-7), and clean control sand samples were used to investigate bioavailability of PCBs. The organisms were also analyzed for the selected 54 PCB congeners. PCB congeners PCB-30 and PCB-204 were used as surrogates to measure recovery, which was 85 to 93% after blank correction. Worms used in the experiments had 2.1 to 4.8% lipid content, consistent with existing data [3,10,40–46]. Analyzed worm tissues exposed directly to PCB contaminated Neponset River sediment had total PCB concentration of 1,644 ng/g (Figure 5). The biouptake layer sampled at the end of column tests NEP-4 to -6 (with RCM layer between the sediment and the biouptake layer) showed 1.85 ± 0.62 times higher PCB concentrations compared to worm tissue background concentration (5.515, 5.729, and 2.383 ng/g respectively, versus 2.443 ng/g), while worms exposed to the biouptake layer sampled at the end of the no RCM layer test (NEP-7) showed a tissue concentration of 9.896 ng/g (Fig. 5).

Similarly, the PCB worm tissue homolog group distributions were analyzed by using comparative homolog group fraction plots (Fig. 6) and the PCA analysis for worms exposed to Neponset River sediment, NEP-4 to -7 biouptake layers, and background biouptake layer samples (refer to Fig. 3). PCB homolog fractions in the worms (Fig. 6) obtained from NEP-4 to -7 have a bell-shaped distribution as compared to the control samples, which are primarily comprised of tri- to hexa-CB homologs, consistent with the PCA analysis plot indicating a cluster of worm tissue loading between tri- to hexa-CB loadings (Fig. 3).

The bioavailability of naphthalene at pre- and post-remediation stages were evaluated on column tests with RCM capping applied (NEP-15, and -16), and those with only sand and organic mixture capping applied (no RCM; NEP-21, and -22). In addition, *L. variegatus* was directly exposed to PCB- and naphthalene-contaminated sediment to measure reduction in bioavailability after various capping options were applied. Similar to experiments on PCBs, control worms (i.e., upon receipt from the vendor) were analyzed for PAHs prior to any testing to obtain any traceable background concentrations as a baseline. Moreover, worms exposed to reference sediment, which was spiked with naphthalene, were analyzed to quantify any potential biouptake from the reference sediment itself. PAH 1-fluoronaphthalene was used to measure the efficacy of the extraction process for biouptake tests using material from NEP-15, -16, -21 and -22, and resulted in recovery rates from 75 to 92%.

Worms exposed to the biouptake layer overlying the RCM from NEP-15 and -16 tests had post-test naphthalene concentrations of 11.92 ng/g and 67.57 ng/g, respectively, while those worms exposed to the biouptake layer without an underlying RCM layer from NEP-21 and -22 tests had naphthalene concentrations of 2200 ng/g and 3540 ng/g, respectively (Figure

7). Worms directly exposed to naphthalene spiked sediment had concentrations ranging from 1291 ng/g to 7300 ng/g. Finally, the worms exposed to the control biouptake layer (sand and trout chow) and reference sediment (prior to spiking) yielded to 17 and 55 ng/g naphthalene, respectively (Fig. 7).

Sediment and Biouptake Layer Test Results

Naphthalene concentrations measured in the pore fluid samples are similar for all tests (1.76 to 3.08 mg/L) except for lower values observed in the NEP-13 and -14 (sand and trout chow overlying sediment, no RCM; 0.42 ± 0.09 mg/L). Tests NEP-15 and -16 (sand and trout chow overlying sediment and RCM) showed the lowest average breakthrough concentration in the overlying water (0.036 ± 0.02 mg/L), a 63-fold reduction from the average pore fluid concentration measured (2.24 ± 0.51 mg/L). Tests NEP-13 and -14 (w/ sand and trout chow) also had low overlying water concentrations (0.042 ± 0.03 mg/L), corresponding to only a 10-fold decrease from the sediment fluid concentration. This difference was hypothesized to be related to the low initial pore fluid concentration (0.42 ± 0.09 mg/L). NEP-18 and NEP-19 tests (only sand over sediment, no RCM) on overlying water samples resulted in a slightly higher concentration (0.23 ± 0.13 mg/L), representing an 11-fold reduction compared to pore fluid concentration (2.53 ± 0.54 mg/L) as in the NEP-13 and NEP-14 tests. The NEP-20 test with no overlying barrier resulted in only a 6-fold difference between the pore fluid (3.08 ± 1.02 mg/L) and overlying water concentrations (0.52 ± 0.34 mg/L), which is related to dilution of upflowing pore fluid into initially clean overlying water.

For experiments with PCB-contaminated sediment (see Table 1), concentrations observed in the biouptake layer at the end of each column test are not significantly different from one another (NEP-4 to -6, 0.395 ± 0.055 ng/g; NEP-7, 0.835 ± 0.051 ng/g). Similarly, total post-test PCB concentrations in the biouptake layers in tests NEP-4 to -6 (RCM, sand and trout chow) averaged about two times the background PCB concentration of the biouptake layer (0.194 ng/g), and in test NEP-7 is 4.3 times higher than the background. Compared to bottom sediment total PCB concentration (10,619 ng/g), all analyzed biouptake layers showed more than 4 orders of magnitude less PCB (Fig. 5). These results show that limited breakthrough of PCBs occurred during NEP-4 to -7 tests regardless of the cap composition. The limited breakthrough can be related to: a) high octanol-water partitioning coefficient (K_{ow}) of the PCBs (log K_{ow} was estimated to be ~ 6.34 by KOWWIN^{TM} based on congener profiling); and b) effectiveness of both capping materials (the RCM and the sand/trout chow combination). This finding lends support to the concept of active capping using geomaterials like sand mixed with a reactive material such as organoclay or activated carbon.

For the naphthalene tests, analysis of the post-column experiment sediment from NEP-15, -16, -21 and -22 showed significantly lower naphthalene concentrations than the spiking concentration ($33,903 \pm 9,350$ ng/g versus 250,000 ng/g). This may be due to the combined effects of the relatively low efficiency of the spiking process [47], desorption and dissolution in pore fluid and/or overlying water [38,48], sorption by the RCM, and volatilization losses during sample handling and analysis. Similar to PCB contaminated column tests, analyses of samples from naphthalene spiked sediment column tests were performed on NEP-15 and -16 (RCM, sand/trout chow) showed concentrations more than 4 orders of magnitude lower in the biouptake layer (2.489 ± 1.596 ng/g) compared to the sediment concentration ($33,903 \pm 9,350$ ng/g). The biouptake layer concentrations of NEP-15 and -16 were only slightly higher than background biouptake layer concentration (0.51 ng/g; Fig. 4). However, tests NEP-21 and -22 (sand and trout chow) showed much higher concentrations ($3,000 \pm 700$ ng/g) compared to NEP-15 and -16 (RCM, sand and trout chow).

L. Variegatus Tissue Residue Results

Worms exposed to sand-trout chow mixture collected from NEP-4 to -6 tests (RCM, sand and trout chow) showed total PCB concentrations that were twice as high as the control samples, with hepta- and octa-PCBs having the highest increase (Figs. 5 and 6). Similar to the previous discussion of the homolog group fractions in the sand and trout chow mix, this change may be due primarily to low concentrations of these homolog groups in the control sample (Fig 5). Consistent with the biouptake layer PCB concentrations, worms exposed to NEP-7 (sand and trout chow) showed about 2 times higher PCB concentrations compared to NEP-4 to -6 and more than 5 times higher PCB concentrations than that of the control sample. The PCA analysis results were in agreement with the conventional homolog group fraction bar charts, similar to the sediment and biouptake layer analysis.

For the biouptake layer naphthalene content, worms exposed to the biouptake layer above the RCM cap (NEP-15 and -16) for the naphthalene contaminated tests have significantly lower concentrations compared to the worms exposed to biouptake layer from NEP-21 and -22 tests (sand and trout chow, no RCM). Also the worms exposed directly to bottom sediment showed two orders of magnitude higher concentrations compared to worms exposed to biouptake layer from NEP-15 and -16 tests. However, no significant difference was observed between worms exposed directly to sediment and worms exposed to the biouptake layer from NEP-21 and -22 tests (Fig. 7).

In conclusion, the experimental evidence shows that the RCM with Organoclay PM-199 core provides some level of enhanced contaminant isolation of the overlying water from the sediment, and further decrease the bioavailability of COPCs compared to conventional thin layer capping options. This enhanced isolation can be attributed to: the physical filtering capacity of the RCM, particularly in the early stages of each stress application when high advective flux may not allow the RCM to effectively chemically adsorb contaminants attached to natural and dissolved organic matter, but does allow it to capture those particulates via filtering; and, the chemical adsorption of the RCM, particularly at later, lower advective rate stages of the stress increments. Thus, it is concluded that the physical filtering capacity of the RCM is as important as its reactive capacity. For naphthalene (low K_{ow}) spiked tests, the sand layer with trout chow provided less effective isolation than the tests with RCM but fairly good isolation especially for PCB (high K_{ow}) breakthrough from underlying sediment, and provides evidence that sand can be fairly effective as a capping material for sites with high K_{ow} (less mobility) contaminants and no upflow conditions. In addition, the PCA method has shown that further insight of the dataset could be obtained compared to conventional analysis methods on multi-dimensional datasets and allow better clustering of samples with similar homolog profiles.

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Highlights

- Reactive core mat provides enhanced contaminant isolation of overlying water from sediment.
- RCM decreases bioavailability of contaminants of potential concern (COPC).
- Enhanced isolation by RCM can be attributed to the physical filtering capacity of the RCM
- The PCA method allows for further insights of the dataset to be obtained.

Figure 1. Total PCB Concentrations of Neponset River Sediment, post ICSTAC-NEP-4, -5, -6 (with RCM & Sand & Trout Chow) and NEP-7 (with Sand & Trout Chow) Biouptake Layers, and Background Biouptake Layer

Figure 2. PCB Homolog Profile and Concentrations of: (a) post NEP-4 Biouptake Layer (with RCM & Sand & Trout Chow); (b) post NEP-5 Biouptake Layer (with RCM & Sand & Trout Chow); (c) post NEP-6 Biouptake Layer (with RCM & Sand & Trout Chow); (d) post NEP-7 Biouptake Layer (with Sand & Trout Chow); (e) Biouptake Layer Background; (f) Neponset River Sediment

Figure 3. Principal Component Analysis Results for PCB Homolog Group Distribution of: a) Sediment and Biouptake Layer Collected at The End of ICSTAC Tests (red boxes); and b) Worms Exposed to Sediment and Biouptake Layer Collected at The End of ICSTAC Tests (orange boxes)

Figure 4.
Total Naphthalene Concentrations of Spiked Neponset River Sediment, post ICSTAC-NEP-15, -16 (with RCM & Sand & Trout Chow) and NEP-21, -22 (with Sand & Trout Chow) Biouptake Layer, Reference Sediment and Background Biouptake Layer

Figure 5.

Total PCB Concentrations of Freshwater Worms (*L.variegatus*) Exposed to Neponset River Sediment, post ICSTAC-NEP-4, -5, -6 (with RCM & Sand & Trout Chow) and NEP-7 (with Sand & Trout Chow) Biouptake Layers, and Control Samples

Figure 6. PCB Homolog Profile and Concentrations of Worms: (a) Exposed to post NEP-4 Biouptake Layer (with RCM & Sand & Trout Chow); (b) Exposed to post NEP-5 Biouptake Layer (with RCM & Sand & Trout Chow); (c) Exposed to post NEP-6 Biouptake Layer (with RCM & Sand & Trout Chow); (d) Exposed to post NEP-7 Biouptake Layer (with Sand & Trout Chow); (e) Background Concentration; (f) Exposed to Neponset River Sediment

Figure 7. Naphthalene Concentrations of Freshwater Worms (*L. variegatus*) Exposed to Spiked Neponset River Sediment, post ICSTAC-NEP-15 and -16 (with RCM & Sand & Trout Chow) and NEP-21 and -22 (with Sand & Trout Chow) Biouptake Layers, Reference Sediment (Non-Spiked Neponset River Sediment), and Clean Control Biouptake Layer

Table 1

Summary of Testing Conditions

Test Name	Contaminant Used	Contaminant Type	Capping Material		
			RCM	Sand	Trout Chow
NEP-4	PCBs	Sampled	•	•	•
NEP-5	PCBs	Sampled	•	•	•
NEP-6	PCBs	Sampled	•	•	•
NEP-7	PCBs	Sampled		•	•
NEP-15	Naphthalene	Spiked	•	•	•
NEP-16	Naphthalene	Spiked	•	•	•
NEP-21	Naphthalene	Spiked		•	•
NEP-22	Naphthalene	Spiked		•	•