FACT SHEET

Enhanced Monitored Natural Recovery (EMNR) for Sediment Sites

AUG 2025

Introduction

EMNR is an in situ remedial approach that involves placing a thin layer of clean sand or sediment over impacted sediment to accelerate natural recovery processes. This fact sheet outlines the technology background, criteria for selecting suitable sediment sites, and EMNR implementation. In addition, two case studies are included that demonstrate the successful application of EMNR at Navy sites. This information will aid in discussions with stakeholders about the benefits of implementing EMNR at impacted sediment sites.

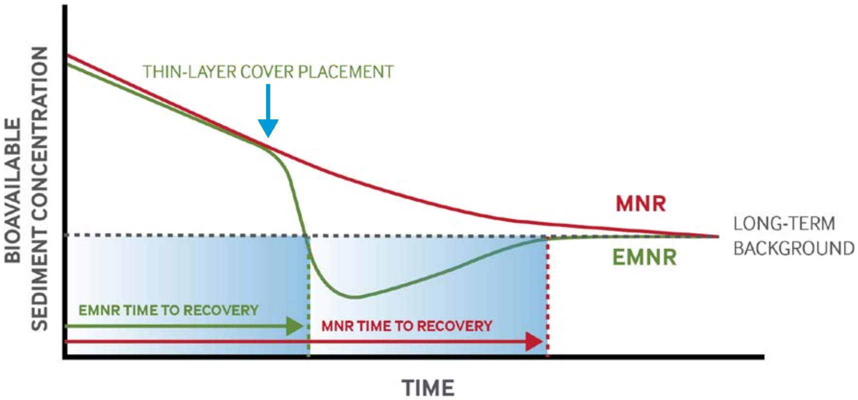

Figure 1. Time to Recovery Based on Theoretical Improvement in Bioavailable Sediment Concentrations over Time Using EMNR Compared to MNR (Courtesy of NAVFAC)

Note: Adapted from figures developed under the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) Project ER-201368 and Navy Environmental Sustainability Development to Integration (NESDI) Project 522.

Technology Background

EMNR is a remedial approach that builds upon monitored natural recovery (MNR), which relies on natural processes such as sediment deposition, dissolution, chemical transformation, and/or the reduction in exposure to chemicals in surficial sediment over time. In EMNR, natural recovery processes are accelerated through placement of a thin layer of material (10 to 30 centimeters [cm]) on top of impacted sediment. EMNR cover material is typically composed of clean sand, but natural sediment can also be used. To reduce erodibility of the thin layer in higher-energy water bodies, coarser material such as gravel or rock can be added to (or on top of) the EMNR layer. A reactive amendment (e.g., activated carbon) can also be mixed into EMNR materials to further reduce contaminant availability. More information can be found in the Federal Remediation Technologies Roundtable (FRTR) technology profile for EMNR (FRTR 2025).

How Does it Work?

Upon placement of EMNR (shown as the blue arrow in **Figure 1**), bioavailable chemical concentrations in sediment are rapidly decreased. This decrease is much more than would occur from MNR alone (shown by the divergence of the green and red curves in **Figure 1**). Over time, the thin layer cover mixes with the underlying sediment through bioturbation and physical processes that promote recovery, typically through chemical transformation, immobilization, and/or adsorption. Throughout the process, EMNR provides a habitat for benthic organisms that is lower in bioavailable chemicals than would be expected from MNR alone. Additionally, EMNR more rapidly reduces the potential for resuspension or transport of contaminated sediment particles (Palermo et al. 1998). In contrast to conventional capping that completely isolates the impacted sediment under 1 to 3 m of clean sand or granular material, the thin layer cover used in EMNR is only 10 to 30 cm thick. However, this thin layer cover placement helps to immediately reduce chemical concentrations in the surficial sediment. Over time, these materials gradually mix with the underlying material and newly deposited sediment (**Figure 2**).

How Can it Help?

Dredging and conventional capping are not always as effective as anticipated and can have adverse effects on mission-related activities and the environment (e.g., delaying scheduling and execution of shipyard operations, impacting benthic communities and aquatic habitats, and adversely impacting coastal communities). Furthermore, conventional isolation capping is not always practical in areas where navigational depths need to be maintained or in sensitive areas (i.e., wetlands). A primary benefit of EMNR is that it achieves risk-reduction goals more quickly and at lower costs than traditional remedies such as dredging or isolation capping.

Case Study 1: Site 99 Thin Layer Placement, Quantico Embayment, Quantico, Virginia | **Case Study 2: Sediment EMNR Evaluation, Pearl Harbor, Hawaii** | **Conclusions**

FACT SHEET

EMNR for Sediment Sites (Continued)

What Sites are Suitable for EMNR?

EMNR can be considered a remedy at most sediment sites, as the technology has been applied under various conditions to address a wide variety of chemical constituents. As with any sediment remedy, EMNR is best applied when source control has been achieved and natural recovery is ongoing. The following site conditions may suggest that EMNR offers advantages over other sediment remedial approaches:

- Sites that are too shallow for conventional isolation capping (i.e., thick capping layers will prohibit maintaining navigational water depths).
- Sites with existing ecologically valuable habitats (e.g., wetlands, eelgrass beds) that would be destroyed or altered by more invasive methods.
- Sites that may have a local source of clean sediment available for use as EMNR material (e.g., due to recurring navigational dredging in nearby areas).
- Sites that have sediment impacted with organic chemicals known to be sequestered by reactive amendments that could be mixed into the thin layer of sand or sediment.

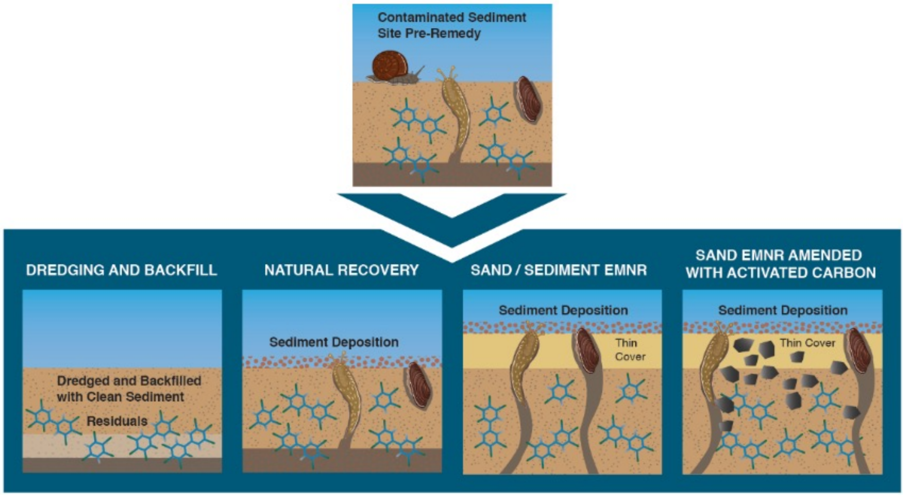

Figure 2. Conceptual Comparison of EMNR with Other Remedial Alternatives (Courtesy of NAVFAC)

How is EMNR Implemented?

During the Remedial Investigation/Feasibility Study (RI/FS) phase and before implementing an EMNR remedy, site characterization should be conducted to evaluate key aspects of EMNR. For example, it is best to confirm that natural recovery processes at the site are active and will aid EMNR. In most cases, this means evaluating site-specific natural sedimentation processes, generally using existing sediment or bathymetric data. Also, stability should be a design consideration for EMNR. In particular, it should be evaluated whether the thin layer material will remain in place or whether it will require materials to enhance its stability. For higher-energy sites with disturbances or high current/flow, hydrodynamic measurements or modeling may be beneficial. As with all sediment remedies, sources should be identified and source control either achieved or maximized (United States Environmental Protection Agency [EPA] 2005). If complete source control is not possible, an evaluation as to what extent ongoing sources will affect post-remedy natural recovery should be considered. In designing an EMNR remedy, additional consideration should be given to the nature and extent of contaminants of concern (COCs), size of the target area for placement, thickness of material to be placed (which typically targets the biologically active layer), material selection, and methods for post-EMNR monitoring.

Types of EMNR Materials

- Imported sand
- Natural sediment
- Sand or sediment layer with an amendment such as activated carbon
- Gravel or rocks for high-energy waters

EMNR implementation typically includes the following activities and practices:

- Implementation of a silt curtain or other best management practices (BMPs) during material placement to reduce water quality impacts.
- Preparation of materials (e.g., sourcing material, addition of amendments) and calibration of equipment for placement at a uniform depth.
- Water quality monitoring before, during, and after EMNR placement.
- Placement using accurate and controlled methods, such as a telescopic belt conveyor, direct placement, pneumatic spreader, hopper dredge, or other systems (such as surface release from a barge or sand slurry discharge from a pipeline).
- Post-EMNR placement confirmation monitoring to confirm depth and coverage (this may include sediment core samples, bathymetry, sediment profile imaging [SPI], or other lines of evidence).
- Post-EMNR placement monitoring to ensure reduced contaminant bioavailability and/or contaminant concentrations at the newly formed sediment surface.
- Regulatory and stakeholder oversight and input.

Return to Menu

CASE STUDY 1:

Site 99 Thin Layer Placement, Quantico Embayment, Quantico, Virginia

Background

Site 99 is within the Quantico Embayment adjacent to Quantico Marine Corps Base (MCB) in Quantico, Viriginia (**Figure 3**). The sediment is impacted with dichlorodiphenyltrichloroethane and its derivatives (DDX). An EMNR thin-layer cap (TLC) of sand was placed over sediment with moderate levels of DDX to prevent resuspension and transport of impacted sediment while providing viable habitat for several species and creating wetland habitat (Kirtay et al. 2017; Fetters et al. 2020). The case study results discussed below are based on research efforts conducted under DoD ESTCP Project ER-201368 and DoD ESTCP Project ER-201130.

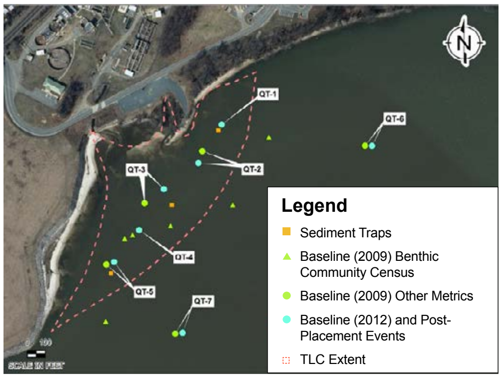

Figure 3. Site 99 TLC Extent at Quantico Embayment at Quantico MCB showing Sediment Trap Placement and Baseline Sampling Locations (Fetters et al. 2020)

Key Objectives

The overall objectives were to evaluate the effectiveness of the TLC in enhancing natural recovery, reducing contaminant bioavailability, and mitigating potential threats to higher trophic levels. Specific goals included: 1) evaluating the TLC placement accuracy, long-term stability, and sediment mixing; 2) evaluating efficacy for reducing DDX concentrations, bioavailability, and bioaccumulation at the sediment surface; and 3) evaluating impacts to the benthic community and the rate of recovery after placement.

Monitoring methods included sediment chemistry, SPI, sediment-friction sound probing, bathymetric mapping, sediment trap sampling, bioaccumulation testing, passive sampling, and benthic community analysis. Sampling events occurred at baseline prior to TLC placement and at 2, 14, and 25 months post-placement.

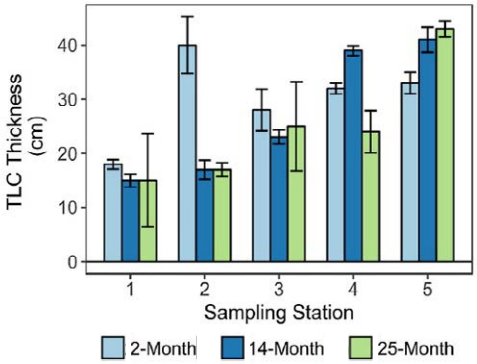

Figure 4. Monitoring Results for Cap Thickness across Five Stations (Fetters et al. 2020)

Results and Outcomes

The TLC was successful at enhancing natural recovery and reducing contaminant bioavailability and trophic transfer (Fetters et al. 2020). Specific results were as follows:

- The TLC was successfully placed, meeting a target depth of greater than 6 inches (15.2 cm) across the placement area and demonstrated adequate stability over 2 years of monitoring (**Figure 4**). The average cap depth was greater than 10 inches (25.4 cm) in the last round of monitoring, which was confirmed by core profiles and supported by bathymetry, SPI, and sediment-friction sound probing.
- Top-down mixing by invertebrates was observed as expected; importantly, however, bottom-up mixing, which could remobilize impacted sediment, did not significantly occur, supporting placement effectiveness.
- Concentrations of DDX in surface sediment remained below pre-placement levels, and recontamination of the sediment did not occur to an extent that would compromise the remedy effectiveness. After placement, DDX in sediment was reduced to below the preliminary remedial goal, with significant reductions over time relative to underlying native sediment (**Figure 5**).
- Sediment traps indicated relatively high deposition rates of material, with lower concentrations in post-placement events compared to baseline, suggesting that natural recovery was also occurring.

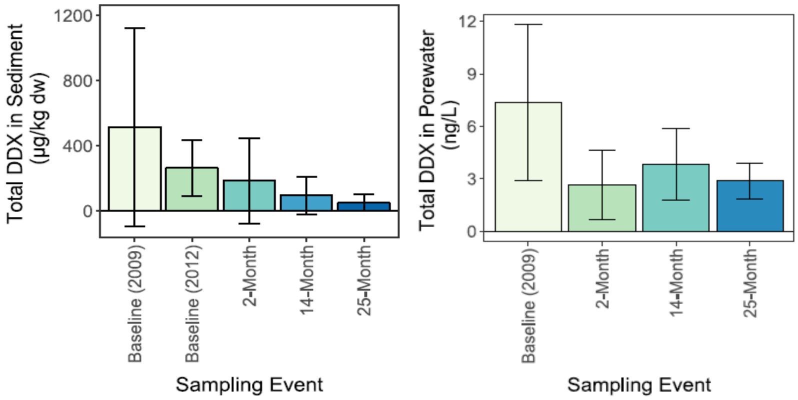

Figure 5. Depth Weighted Average of Total DDX in Sediment (left) and Porewater (right) Pre- and Post-Thin Layer Placement (Fetters et al. 2020)

- Significant reductions in total DDX in worm tissue (lipid basis) were observed after 2-months and 25-months. Reductions in total DDX in clam tissue were also observed in 2-months and 25-months.
- Total DDX in surface sediment porewater was reduced compared to baseline (**Figure 5**).
- The benthic community data indicated increasing abundance, richness, and diversity within the TLC placement area over the long-term.

EMNR in the form of placing a sand-based TLC provided reduced concentrations of DDX in surface sediment, reduced uptake of DDX into invertebrates, and reduced porewater concentrations of DDX over the 25-month monitoring period. In addition, the benthic community demonstrated recovery following placement of the TLC, indicating stability of EMNR performance over time.

CASE STUDY 2:
Sediment EMNR Evaluation, Pearl Harbor, Hawaii

Background

The Pearl Harbor Sediment Site is located adjacent to Joint Base Pearl Harbor-Hickam (JBPHH) in Oahu, Hawaii. The site has identified sediment impacts in distinct areas called Decision Units (DUs). Sediment cleanup planning and implementation is underway for these DUs to reduce the risks associated with several COCs in sediment including metals (copper, lead, cadmium, zinc, mercury) and polychlorinated biphenyls (PCBs) (Naval Facilities Engineering Systems Command [NAVFAC] 2018). EMNR is one remedial approach being employed within certain DUs. An evaluation of EMNR was conducted at DU N-2 of the Pearl Harbor Sediment Site (**Figure 6**). This study addressed the potential beneficial use of a clean sediment (i.e., dredged material from Pearl Harbor) as the thin layer for EMNR within the DU N-2 area. Beneficial use of dredged material would significantly reduce remediation costs by eliminating the need to procure clean sand and transport excess material for ocean disposal.

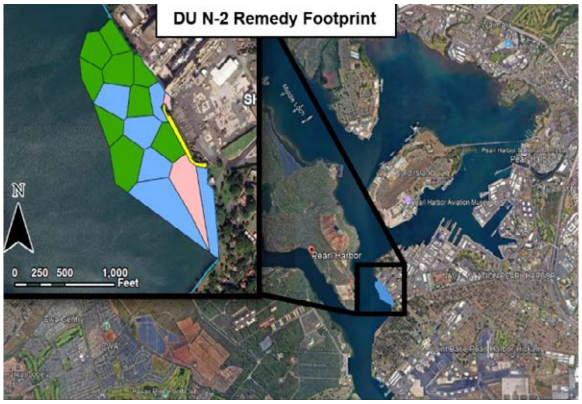

Figure 6. DU N-2 Site within the Pearl Harbor Naval Shipyard, Pearl Harbor, HI (Adapted from Rosen et al. 2020)

Key Objectives

The objective of this study was to evaluate EMNR using different clean sediments at a mesocosm scale within the DU N-2 remedy footprint at the Pearl Harbor Naval Shipyard. A 10-month field study was performed using remedy and recontamination assessment (RARA) arrays developed under the DoD Strategic Environmental Research and Development Program (SERDP) Project ER-2537 (Chadwick et al. 2017). The research was also sponsored under NESDI Project 522.

Four cap materials were evaluated, along with a control (**Figure 7**): a sand-only cover, a low carbon dredged material, a high carbon dredged material, and an activated carbon amended sand cover. The following performance monitoring parameters were evaluated: 1) surface sediment contaminant concentrations; 2) contaminant bioavailability using passive samplers and worm bioaccumulation; 3) benthic recolonization; and 4) remedy stability.

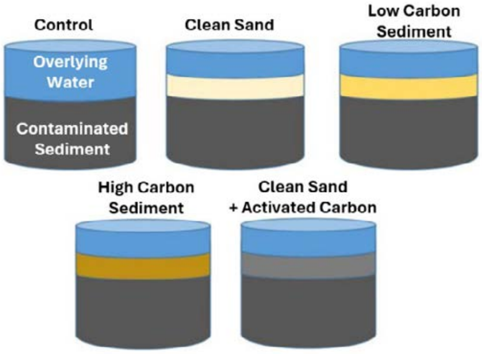

Figure 7. EMNR Treatments Evaluated to Assess Efficacy at Reducing Bioavailable Porewater PCBs (Adapted from Rosen et al. 2020)

Results and Outcomes

Both clean sediment from navigation dredging and sand (with and without carbon) were effective as TLCs at reducing surface bulk sediment PCBs (top 3 inches or 7.62 cm). This resulted in reductions in porewater PCBs and PCB bioaccumulation within worms after 10 months (**Figure 8**). Additionally, impacts to the benthic community health were not observed in any treatment, and intact cores showed high stability of the TLCs.

In conclusion, the results of this study demonstrated that clean sediment from navigation dredging is a valuable resource as a cover material that can be beneficially used in EMNR to enhance natural recovery, reduce contaminant bioavailability, and reduce remediation costs.

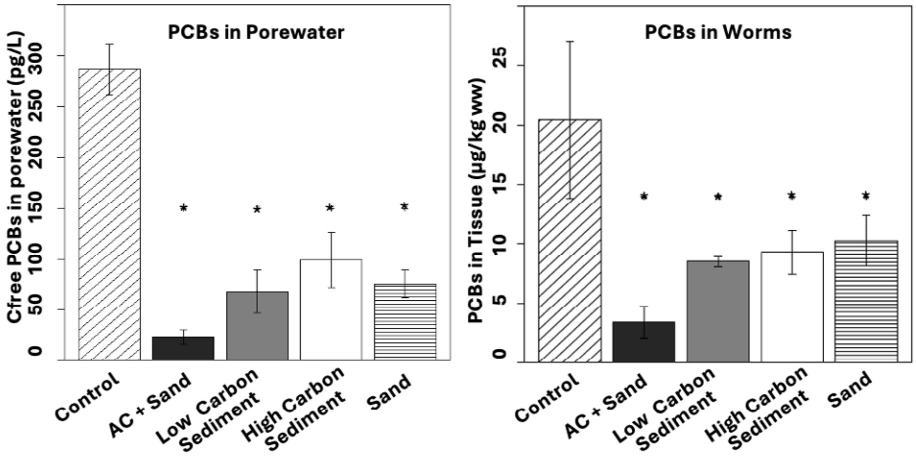

Figure 8. Bioavailable PCBs in Porewater at 10-Month Post-Treatment (Left) and Bioaccumulated PCBs in the Polychaete Worm Following 28-Day Ex Situ Bioassay from 10-Month Post-Treatment Sediment Cores (Right) (Adapted from Rosen et al. 2020)

Notes: AC: activated carbon PCBs: polychlorinated biphenyls pg/L: picograms per liter
* means significant reduction relative to control ($p<0.05$)

Return to Menu

Conclusions

Conclusions

Remediation of impacted sediment by dredging and conventional capping is not always feasible; can have adverse affects on mission-related activities and the environment; and can have major cost implications (DoD 2016). One alternative remedial approach for contaminated sediment is EMNR, which can achieve risk-reduction goals more quickly and at lower costs than traditional remedies.

Additional benefits of EMNR include the following:

- Cover material types and designs are flexible such as using clean imported sand, erosion resistant layers, and amendments.
- Beneficial reuse of clean dredged materials as a cover material enables cleanup site and dredged material programs to efficiently work in tandem.
- Implementation is less biologically damaging than dredging or capping.
- Ongoing maintenance is not required (as opposed to engineered isolation caps).
- TLC depth (typically 10 to 30 cm) can be designed to avoid or minimize loss of navigational water depth.
- Natural recovery processes are enhanced.
- EPA has accepted EMNR at multiple Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites.

Responses to critiques of its use should consider the following:

- Monitoring is conducted for EMNR (as with any sediment remedy), and if long-term goals are not met, adaptive management can be applied.
- Even when using best available practices, dredging leaves a layer of contaminated residual sediment behind on the newly exposed sediment surface. These layers are often thick and sufficiently impacted to result in potentially unacceptable levels of risk, necessitating management with techniques such as EMNR, capping, or reactive amendments.

Disclaimer

References

Chadwick D., M. Colvin, B. Davidson, G. Rosen, A. Burton, and D. Moore. 2017. Final Technical Report Remedy and Recontamination Assessment Array. SERDP Exploratory Development Project ER-2537. March. Available at: https://serdp-estcp.mil/projects/details/0008d50b-b007-4486-b029-e77c570e7e45.

DoD. 2016. SERDP and ESTCP Workshop on Research and Development Needs for Long- Term Management of Contaminated Sediments. August. Available at: https://serdp-estcp.mil/events/details/9a88473b-760f-4591-8b24-14bd4f5ffbec.

EPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012. Office of Solid Waste and Emergency Response. December. Available at: https://clu-in.org/download/contaminantfocus/sediments/epa- contaminated-sed-remediation-guidance.pdf.

FRTR. 2025. "Monitored Natural Recovery and Enhanced Monitored Natural Recovery." Available at: https://www.frtr.gov/matrix/Monitored-Natural-Recovery-and-Enhanced-Monitored-Natural-Recovery/.

Fetters, K., G. Rosen, V. Kirtay, B. Chadwick, J. Conder, V. Sacks, M. Grover, and V. Magar. 2020. "*Demonstration and Validation of Enhanced Monitored Natural Recovery at a Pesticide-Contaminated Sediment Site*." Journal of Soils and Sediments 20(1):204–219.

Kirtay, V., G. Rosen, M. Colvin, J. Guerrero, C. Katz, B. Chadwick, K. Fetters, V. Magar, J. Arblaster, M. Grover, J. Conder, M. Greenberg, A. Humphrey, and T. Weidner. 2017. Final Technical Report: Demonstration and Validation of Enhanced Monitored Natural Recovery at Department of Defense Sediment Sites. ESTCP Project ER-201368. August. Available at: https://serdp-estcp.mil/projects/details/4a8ef259-a073-4c65-ac3d-1338d1bd84af.

NAVFAC. 2018. Final Record of Decision, Pearl Harbor Sediment, Joint Base Pearl Harbor-Hickam, Oahu, Hawaii. Naval Facilities Engineering Systems Command. September.

Palermo, M., S. Maynord, J. Miller, and D. Reible. 1998. Guidance for In Situ Subaqueous Capping of Contaminated Sediments. EPA 905-B96-004. Great Lakes National Program Office, Chicago, Illinois. September.

Rosen, G., I. Rivera, J. Carilli, D. Moore, J. Conder, and K. Markillie. 2020. Final Report Sediment Enhanced Monitored Natural Recovery Evaluation using Remedy and Recontamination Assessment Arrays. NESDI Project 522. October.