SUMMARY REPORT

SERDP and ESTCP Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments

October 2016

Distribution Statement A

This document has been cleared for public release

SERDP DOD • EPA • DOE | ESTCP

Contributing Authors

Andrea Leeson, Ph.D.
SERDP and ESTCP

Tim Thompson
Science and Engineering for the Environment, LLC

Victor Magar, Ph.D.
Ramboll ENVIRON Inc.

Cara Patton
Noblis

Richard Luthy, Ph.D.
Stanford University

Kym Anderson
U.S. Army Corps of Engineers, Seattle District

Brenda Bachman
U.S. Environmental Protection Agency

Karl Gustavson, Ph.D.
U.S. Army Corps of Engineers, Engineer Research and Development Center

Kim Markillie
U.S. Naval Facilities Engineering Command Pacific

Mandy Michalsen, Ph.D.
U.S. Army Corps of Engineers

Gunther Rosen
SPAWAR Systems Center Pacific

Rob Webb, PE
Dalton, Olmsted, Fuglevand Engineers

Katrina von Stackelberg, Sc.D.
NEK Associates

TABLE OF CONTENTS

ACRONYM LIST ..... **IV**

EXECUTIVE SUMMARY ..... **VI**

1.0 INTRODUCTION **1**

2.0 METHOD **3**

3.0 RESEARCH, DEMONSTRATION, AND TECHNOLOGY TRANSFER NEEDS **5**

3.1 WORKING GROUP 1: REDUCING THE IMPACT OF STORMWATER DISCHARGE ON SEDIMENT RECONTAMINATION 5

3.1.1 Improved Understanding of the Relationship Between Stormwater Release and Sediment Recontamination or Recovery (Critical Priority Research and Demonstration) *7*

3.1.2 Development of New and Innovative Stormwater Control Practices Protective of Sediment Recontamination (Critical Priority Research) *7*

3.1.3 Demonstration of Methods for the Assessment of Long Term Performance of Treatment Technologies (Critical Priority Demonstration) *8*

3.1.4 State-of-the-Science Review of Stormwater Discharge and Sediment Recontamination at DoD Sites (Critical Priority Technology Transfer) *8*

3.1.5 Improved Measurement and Assessment Approaches Linking Stormwater Sediment Load to Benthic Impairment (High Priority Research) *9*

3.1.6 Develop Innovative and Remotely Operated Stormwater Discharge Monitoring Systems Protective of Sediment Recontamination (High Priority Research) *9*

3.1.7 Demonstration of Methods for Enhanced Flow Capacity for the Management of Stormwater Discharge Systems (High Priority Demonstration) *10*

3.2 WORKING GROUP 2: CLEANUP ACTIONS AND NAVIGATION DREDGING 10

3.2.1 Development and Demonstration of New and Innovative Technologies for Sustainable Remedial and Navigation Dredging (Critical Priority Research and Demonstration) *12*

3.2.2 Improved Methods for the Identification, Handling, and Disposal of Radioactive Commodities in Dredged Sediments (Critical Priority Research and Demonstration) *13*

3.2.3 Demonstration of Sustainable Dredged Material Disposal Alternatives: Confined Aquatic Disposal and Confined Disposal Facilities (Critical Priority Demonstration and Technology Transfer) *14*

3.2.4 Improved Methods for the Identification, Handling, and Disposal of Munitions of Explosive Concern at Remedial Dredged Sediment Sites (Critical Priority Demonstration) *16*

3.2.5 Demonstration of Sustainable Dredged Material Disposal Alternatives: Thin-Layer Placement of Dredged Material for Remediation or Habitat Restoration (High Priority Research and Demonstration) *16*

3.2.6 Demonstration of Sustainable Dredged Material Disposal Alternatives: Incorporation of Amendments into Dredged Contaminated Sediments for Placement at Open-Water Disposal Sites (High Priority Research) *17*

3.2.7 Development and Demonstration of Integrated Dredged Sediment Management (IDSM) Strategies for Remedial and Navigation Dredging Sites (High Priority Demonstration) *18*

3.3 WORKING GROUP 3: EMERGING CONTAMINANTS-OF-CONCERN IN SEDIMENTS 19

3.3.1 Improved Methods for Quantifying Concentrations and/or Toxicity of Emerging Contaminants (Critical Priority Research) *21*

3.3.2 Development of Modeling Framework for Fate and Transport of Emerging Contaminants Migrate to Support Risk Assessment (Critical Priority Research) *21*

3.3.3 Improved Methods for Establishing Porewater-based Sediment Management Standards for Emerging Contaminants (Critical Priority Research) 22
3.3.4 Improved Methods to Quantify Cumulative Risk Associated with Complex Contaminant Mixtures that Include Emerging Chemicals of Concern (Critical Priority Research) 23
3.3.5 Improved Methods for Identifying Ecological Risks Associated with Incidental Radiological Commodities in Sediments (Critical Priority Research and Technology Transfer) 23
3.3.6 Development of a Natural Attenuation Framework for Emerging Contaminants (High Priority Research) 23
3.3.7 Development of In Situ Remediation Strategies for Emerging Contaminants (High Priority Research).24
3.3.8 Development of Forensics for Source Tracking and Allocation of Emerging Contaminants (High Priority Research) 24
3.4 WORKING GROUP 4: INCREASING CONFIDENCE IN SEDIMENT CLEANUP LEVELS 24
3.4.1 Development of Innovative Alternatives to Establish Sediment Cleanup Goals (Critical Priority Research) 26
3.4.2 Demonstration and Validation of Passive Sampling-Based Cleanup Levels (Critical Priority Demonstration) 26
3.4.3 Development of Best Practices Guidance for Sediment Background Level Determination (Critical Priority Technology Transfer) 27
3.4.4 Improved Standardized Approaches for Measuring Porewater Contamination Concentrations (High Priority Research) 27
3.4.5 Improved Understanding of Input Variables to Food Web Models (High Priority Research) 28
3.4.6 Post-Remedy Evaluation of the Long-Term Utility of Food Web Models to Set Cleanup Goals at Contaminated Sediment Sites (High Priority Demonstration) 29
3.5 WORKING GROUP 5: MONITORING REMEDY EFFECTIVENESS 29
3.5.1 Development of Alternative Indicators for Fish and/or Biological Tissue Sampling (Critical Priority Research) 31
3.5.2 Development of New Tools and Processes to Optimize Remedial Monitoring: Lower Cost and Rapid Technologies (Critical Priority Research) 33
3.5.3 Demonstration of Noninvasive, Safer Methods for Monitoring the Physical and Chemical Integrity of Remedy (Critical Priority Demonstration) 33
3.5.4 Demonstration of EMNR as a Cost-Effective In Situ Remedial Alternative (Critical Priority Demonstration) 34
3.5.5 Develop Monitoring Guidance and Case Studies to Support Long Term Remedy Effectiveness Assessments (Critical Priority Technology Transfer) 34
3.5.6 Overarching Monitoring Needs (High Priority Research and Demonstration) 35

4.0 CONCLUSIONS 36

4.1 REDUCING THE IMPACT OF STORMWATER DISCHARGE ON SEDIMENT RECONTAMINATION 36
4.2 CLEANUP ACTIONS AND NAVIGATION DREDGING 36
4.3 EMERGING CONTAMINANTS-OF-CONCERN IN SEDIMENTS 37
4.4 INCREASING CONFIDENCE IN SEDIMENT CLEANUP LEVELS 37
4.5 MONITORING REMEDY EFFECTIVENESS 38

5.0 REFERENCES 39

APPENDIX A: SERDP AND ESTCP-RELATED PROJECTS A-1

APPENDIX B: MEETING AGENDA B-1

APPENDIX C: ATTENDEE LIST C-1

APPENDIX D: PROBLEMS FACING REMEDIAL MANAGERS AT U.S. NAVY SITES D-1

APPENDIX E: PRESENTATIONS E-1

List of Tables

Table 1. Definition of Research Need Prioritization 4

Table 2. Needs Identified in Working Group 1: Reducing the Impact of Stormwater Discharge on Sediment Recontamination 6

Table 3. Needs Identified in Working Group 2: Cleanup Actions and Navigation Dredging 12

Table 4. Needs Identified in Working Group 3: Emerging Contaminants-of-Concern in Sediments 22

Table 5. Needs Identified in Working Group 4: Increasing Confidence in Sediment Cleanup Levels 26

Table 6. Needs Identified in Working Group 5: Monitoring Remedy Effectiveness 31

ACRONYM LIST

AC	activated carbon
BMP	best management practice
CAD	Confined Aquatic Disposal
CDF	Confined Disposal Facility
C_{free}	freely dissolved concentration
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
COC	contaminant of concern
CSM	conceptual site model
CUL	cleanup level
DoD	Department of Defense
EMNR	enhanced monitored natural recovery
EPA	Environmental Protection Agency
ER	Environmental Restoration
ERDC	Engineer Research and Development Center
ESS	Explosives Safety Submission
ESTCP	Environmental Security Technology Certification Program
FWM	food web model
GHG	greenhouse gas
Hg	mercury
HOC	hydrophobic organic compound
IAEA	International Atomic Energy Agency
K_{OC}	organic carbon-water partitioning coefficient
K_{OW}	octanol-water partitioning coefficient
LTM	long term monitoring
MEC	Munitions of Explosive Concern
MGFD	munition with the greatest fragmentation distance
MNR	monitored natural recovery
MPPEH	material potentially presenting explosive hazard
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOSSA	Naval Ordnance Safety and Security Activity
NPDES	National Pollutant Discharge Elimination System

PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PE	polyethylene
PFAS	per- and polyfluorinated alkyl substance
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
PI	Principal Investigator
POM	polyoxymethylene
POP	persistent organic pollutant
PRG	preliminary remediation goals
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RG	remedial goal
RPM	Remedial Project Manager
SERDP	Strategic Environmental Research and Development Program
SCCP	short-chain chlorinated paraffins
SPME	solid phase micro-extraction
TCE	trichloroethene
TMDL	Total Maximum Daily Load
UCMR3	Third Unregulated Contaminated Monitoring Rule
USACE	U.S. Army Corps of Engineers
UXO	unexploded ordnance

EXECUTIVE SUMMARY

Sediment contamination remains a significant liability for the Department of Defense (DoD), with overall liabilities estimated to approach $2 billion. Contaminants at DoD sites include a wide variety of compounds such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, various metals and metalloids, and military-unique compounds such as munitions constituents. Most of these contaminants tend to remain in the sediment long-term, resulting in a persistent contamination source to environmental receptors. Environmental restoration and closure of these contaminated sites is a top priority for DoD.

Since 1996, the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) (the "Programs") have supported research and demonstration strategies for sediment characterization, site restoration, and long-term monitoring to support DoD restoration goals. The Programs' investments in this area were guided by the results of three workshops convened to examine the state of the science and engineering and to identify and prioritize research needs. Workshops were previously held in 2004, 2008, and 2012, to identify high priority needs for research, development, field demonstrations, and technology-transfer that would facilitate both long-term management decision making and long-term monitoring of these sites.

As DoD sediment site management priorities are changing, the Programs identified the need to update the strategic research investment plan. Over the next few years, the DoD programs will emphasize achieving site closure and will be completing feasibility studies, designing and implementing remedies, or engaging in the long-term monitoring of implemented alternatives at sediment sites. Any new investigation work will largely be associated with identifying recontamination sources within the local and regional watersheds, and with emerging contaminants. However, it is not uncommon for projects moving into the remedial design stage to discover that there are important data gaps (e.g., zones that have not been adequately characterized). Oftentimes, pre-design investigations are required before a project can move into the remedial action phase. In some cases, follow-on or supplementary investigation work may be required after the remedial action stage.

SERDP and ESTCP convened a Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments on 9-10 August 2016, in Seattle, WA. The objective of this workshop was to summarize the state of work conducted by the Programs to date, review where DoD facilities are in their restoration implementation, and learn directly from the Remedial Project Managers (RPMs) what specific research, demonstration, or technology transfer needs they have that will facilitate both restoration decision making and long-term monitoring of these sites. To that end, the workshop (1) examined the current state of the science and technology for the remediation and restoration of contaminated sediment sites, (2) reviewed the current and projected future status of DoD restoration activities, (3) identified data gaps that, if addressed, could aid in the restoration of contaminated sediments, and (4) prioritized research, demonstration and technology transfer opportunities to help facilitate regulatory and public acceptance of restoration of contaminated sediment sites.

Approximately 60 experts participated in the workshop that was designed to define the key issues and the critical and high-priority needs for both research and demonstration projects. The overarching issues that emerged from the discussions are listed in Tables 2 through 6.

1.0 INTRODUCTION

The Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) are the Department of Defense's (DoD) environmental research programs (herein referred to as "the Programs"), harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities. The Programs fund basic and applied research as well as field demonstration and validation efforts. For additional information, refer to www.serdp-estcp.org.

Sediment contamination remains a significant liability for the DoD. For example, the Navy has 500 sediment sites, with an estimated cost-to-complete of over $800M. Contaminants at these sites include a wide variety of compounds such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), various metals and metalloids, per- and polyfluorinated alkyl substances (PFASs), and military-unique compounds such as munitions constituents. Most of these contaminants tend to sorb and remain in the sediment long-term, resulting in a persistent contamination source to environmental receptors. Environmental restoration and closure of these contaminated sites is a top DoD priority.

Sound science and effective approaches that are accepted by the regulatory community are needed to characterize, remediate, manage, and monitor these sites in a manner that reduces risks. Since 1996, SERDP and ESTCP have supported research and demonstrations for sediment characterization, site restoration, and long-term monitoring to support DoD restoration goals. A list of the sediment-related projects funded under the Programs is presented in Appendix A.

SERDP and ESTCP investments in this area are guided by the results of three workshops convened to examine the state of the science and engineering and to identify and prioritize research needs. In 2004, an *Expert Panel Workshop on Research and Development Needs for the In situ Management of Contaminated Sediments* identified specific research needs. The objectives of this first workshop have largely been achieved, with successful projects including new tools for characterizing in-place contamination, a guidance document for monitored natural recovery (MNR), and demonstrations of in situ amendment remedial alternatives that sequester contaminants. In 2008, an *Expert Panel Workshop on Research and Development Needs for Understanding and Assessing the Bioavailability of Contaminants in Soils and Sediments* was held to discuss in greater detail the issue of contaminant bioavailability. Demonstrated bioavailability tools that were developed from the direction of the 2008 workshop included the demonstration of in situ tools for measuring bioavailability of PAHs, PCBs, and metals and relating those to uptake and biological effects.

The most recent planning meeting occurred in a 2012 workshop, *Expert Panel Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments*. The objective of this workshop was to summarize the state of work conducted by SERDP and ESTCP to date, review where DoD facilities are in their long-term management implementation of contaminated sediments, and learn directly from the Remedial Project Managers (RPMs) specific research, demonstration, or technology transfer needs that would facilitate both long-term management decision making and long-term monitoring of these sites.

A new planning process was needed to address changing DoD sediment site management priorities. In achieving site closure, these sites will be completing feasibility studies, designing, and implementing remedies, or engaging in the long-term monitoring of the success of those implemented alternatives. The Programs' research and demonstration priorities thus will be largely associated with issues related to identifying recontamination sources within the local and regional watersheds, and with emerging contaminants. This report, which documents the findings and recommendations of the workshop participants, will serve as a strategic plan to guide investments by the Programs in the area of contaminated sediments over the next 5 years.

The overarching objective of the workshop was to identify future research, demonstration and technology transfer needs to support DoD sediment management and restoration goals. To that end, this workshop (1) examined the current state of the science and technology for the long-term management of contaminated sediment sites, (2) reviewed the current and projected future status of DoD long-term management activities, (3) identified data gaps that, if addressed, could aid in the long-term management of contaminated sediments, and (4) prioritized research, demonstration and technology transfer opportunities to help facilitate regulatory and public acceptance of long-term management strategies for contaminated sediment sites.

2.0 METHOD

The SERDP and ESTCP *Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments* was held on 9-10 August 2016, in Seattle, Washington. Approximately 60 invited personnel representing DoD RPMs, federal and state regulators, engineers, researchers, industry representatives, and consultants were in attendance. The agenda for the Workshop is provided in Appendix B; the attendee and breakout session lists are provided in Appendix C. A steering committee composed of representatives from the various sectors assisted the Program in defining the meeting's scope and format.

A list of key questions was formulated by the Program Office and steering committee with input from some attendees. These questions, which were provided in advance to the participants, were:

- What innovative tools, methodologies or technologies could be developed to prevent or minimize the potential of stormwater discharges from recontaminating remediated sediment sites?
- What research and/or technology demonstrations can be done to facilitate the overlap between cleanup actions and navigation dredging? Are there synergies in terms of siting, design, long-term monitoring, sustainability, and public acceptance of sediment management and/or disposal?
- Are there emerging contaminants in sediments for which additional research and/or guidance documents may be needed to support risk assessment and remedial decisions?
- Are there new approaches and/or technologies that can be developed to support increased confidence in sediment remedial action levels that are based on either fish tissue values (human health consumption risks) and/or regional background concentrations?
- Are there new tools and/or approaches to support assessment of remedy effectiveness? This would include both short- and long-term assessment methods, metrics, and guidance to characterize, monitor, and maintain success following remediation at contaminated sediment sites.

The agenda (Appendix B) was designed to identify the most pressing needs in a focused manner, while ensuring that all participants could express their views. The workshop opened with several presentations (Appendix E) intended to summarize efforts supported to date to address research, demonstration and technology transfer needs at sites with contaminated sediments as well as provide insight into the status of the Service's restoration goals.

Two breakout sessions, each with five working groups, facilitated discussions of the current state of the science for sediment remediation, reviewed where DoD facilities are in their long-term management implementation of contaminated sediments, and determined what specific research, demonstration, or technology transfer needs existed that would facilitate both long-term management decision making and long-term monitoring of these sites. In each breakout session, participants were assigned to one of the following working groups:

- Reducing the impact of stormwater discharge on sediment recontamination
- Cleanup actions and navigation dredging
- Emerging contaminants of concern in sediments
- Increasing confidence in sediment cleanup levels
- Monitoring remedy effectiveness

In the first breakout session, each working group was given a list of issues and questions to consider unique to their topic. These questions are provided in the relevant subsections in Section 3.0. For each working group, participants reviewed the data gaps and technology needs in their assigned topic where additional research, demonstrations or technology transfer would improve the understanding and assessment of the long-term management of contaminated sediment sites.

The second breakout session built on the first by developing prioritized research, demonstration, and technology transfer needs and opportunities for the long-term management of contaminated sediments. Needs were prioritized as either critical or high priority, largely based on the sequence of events required to impact DoD sediment site decisions within 3 to 5 years after completion of the research and/or demonstration project (Table 1).

Table 1. Definition of Research Need Prioritization

	Critical	High
Research	Research that potentially could have a significant impact on cost-effective long-term management of contaminated sediments at DoD sites.	Research that is of high priority but may not be able to be initiated until critical priority research needs are addressed or may be more clearly defined after critical priority research needs are addressed.
Demonstration	Field demonstrations or assessments that can improve on cost-effective long-term management of contaminated sediments at DoD sites.	Field demonstrations or assessments that are of high priority but may not be able to be implemented until critical priority demonstrations or assessments are completed.
Technology Transfer	Specific actions or documents that could be undertaken immediately to promote technology transfer of key concepts or technologies.	Actions or documents that should be undertaken to promote technology transfer of key concepts or technologies once specific research and/or demonstrations have been completed.

The entire group participated in the final discussions of critical and high-priority research and demonstration needs. Several of the participants contributed to sections of this report describing specific issues and needs, and/or edited the draft versions.

3.0 RESEARCH, DEMONSTRATION, AND TECHNOLOGY TRANSFER NEEDS

The research, demonstration, and technology transfer needs identified during the workshop are described in the following sections. Each section corresponds to one of the five working groups with the needs identified within that group described. The needs are organized according to critical priority needs first, followed by high priority needs. The order does not imply any additional prioritization.

3.1 Working Group 1: Reducing the Impact of Stormwater Discharge on Sediment Recontamination

Stormwater discharge of contaminants remains the foremost critical challenge for protecting DoD investments in sediment cleanup as well as in the prevention of future contaminated sediment liabilities (SERDP & ESTCP, 2012). Stormwater control and treatment is at the nexus of this challenge, spanning virtually every DoD coastal site, and linked to every aspect of regulatory compliance including National Pollutant Discharge Elimination System (NPDES) permitting, Total Maximum Daily Load (TMDL) actions, Environmental Restoration (ER) Programs, and associated source control strategies. The ubiquitous and non-point source nature of these sources make them difficult to effectively characterize and control while at the same time, regulatory pressure to reduce them and cleanup adjacent water bodies is increasing.

The working group addressing stormwater issues was charged with discussing the questions listed below, although discussions did not necessarily have to be limited to these.

- What innovative tools, methodologies, or technologies could be developed to prevent or minimize the potential of stormwater discharges to recontaminate remediated sediment sites?
- How well do existing stormwater regulatory programs manage impairments to sediment quality?
- What are the approaches needed to identify potential sediment impairments from stormwater discharge that could be used in regulatory programs?
- What are the critical components in stormwater discharges that result in impairments to sediments? What approaches and/or technologies exist or should be developed to address those critical components?
- What technologies could be developed, or exist and should be demonstrated, to manage stormwater discharges that impair sediment quality? How and where would those technologies be most effectively applied: at the point-of-release, in the settling zone(s), or at upland sites prior to release?
- What are the approaches and/or monitoring strategies that could be used as part of the assessment of stormwater contributions to sediment sites and/or aide in long-term monitoring of the remedy selected?

The stormwater work group identified four research needs (two critical, two high), three demonstration needs (two critical, one high) and one technology transfer need as shown in Table 2. These needs are further described in the identified subsections.

Table 2. Needs Identified in Working Group 1: Reducing the Impact of Stormwater Discharge on Sediment Recontamination

	Critical	High
Research	3.1.1 Improved understanding of the relationship between stormwater release & sediment recontamination or recovery[1]	3.1.5 Improved measurement & assessment approaches linking stormwater sediment load to benthic impairment
	3.1.2 Development of new & innovative stormwater control practices protective of sediment recontamination	3.1.6 Development of innovative & remotely operated stormwater discharge monitoring systems protective of sediment recontamination
Demonstration	3.1.3 Demonstration of methods for the assessment of long term performance of treatment technologies	3.1.7 Demonstration of methods for enhanced flow capacity for the management of stormwater discharge systems
	3.1.1 Improved understanding of the relationship between stormwater release & sediment recontamination or recovery[1]	
Technology Transfer	3.1.4 State-of-the-Science review of stormwater discharge & sediment recontamination at DoD sites	

[1]Identified as both a research and demonstration need.

There are currently two SERDP and ESTCP projects that are evaluating tools for assessing stormwater impacts, although there is a clear need for further investigation.

- Assessment and Management of Stormwater Impacts on Sediment Recontamination (Dr. D. Reible, Principal Investigator (PI); SERDP Project ER-2428: https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Sediments/ER-2428/ER-2428)
- Demonstration of New Tools for Improved Source and Recontamination Potential Assessment (Dr. B. Chadwick, PI; ESTCP Project ER-201432: https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Sediments/ER-201432/ER-201432)

3.1.1 Improved Understanding of the Relationship Between Stormwater Release and Sediment Recontamination or Recovery (Critical Priority Research and Demonstration)

Research and demonstration of tools or approaches to quantify the source and rate of change in remediated sediment surface chemical concentrations remains a critical priority research and demonstration need. Uncertainties still exist in defining and quantifying connections between stormwater-associated sediment load, dissolved-phase contaminant concentrations, and contaminant-induced benthic impairment. This need focuses specifically on the contaminant load carried in stormwater releases to sediment recontamination or recovery.

Understanding the long-term performance of an implemented remedy requires an understanding of the particulate load, chemical concentrations in those loads, and rates of sediment accumulation at the remedial location. Increases on a sediment surface exceeding chemical performance criteria would suggest remedy failure and could trigger additional remedial actions. The ability to distinguish between chemical exceedances due to remedy failure, or due to contaminants from off-site sources (i.e., stormwater) are critical to site management. An equally important application of these tools and methods would be to document the rate and accumulation of chemically-clean particulates for sites where MNR or enhanced monitored natural recovery (EMNR) are the selected remedy.

Demonstration needs for these monitoring and modeling approaches are the application and extension of existing or new capabilities to remedial management decisions. The tools should integrate with existing modeling frameworks. The types of decisions to be addressed range from engineering stormwater controls to preventing recontamination, and/or remedial decisions for sites that employ MNR, EMNR, capping, or active amendment additions as remedial options.

3.1.2 Development of New and Innovative Stormwater Control Practices Protective of Sediment Recontamination (Critical Priority Research)

New and innovative approaches that improve stormwater control processes are needed to be protective of sediment recontamination. In-storm hydraulic management that could selectively promote or limit transport of specific chemical contaminants of concern in stormwater are of interest. Stormwater control processes are typically based on standard specifications and designs. Termed "best management practices (BMPs)," these designs are intended primarily to be protective of water quality, but are not well-validated in terms of hydraulic performance, management of particulate-bound contaminants, long term performance, or specifically with respect to sediment contamination. To this end, it is often unclear whether the adopted BMPs are effective at managing water and sediment quality.

Specific research of interest includes the following:

- Emerging stormwater control and treatment technologies, such as retention basins and weather forecasting coupled with geomedia-enhanced filters that improve stormwater management, prevent sediment recontamination and add to the existing water supply.
- Watershed modeling of new stormwater control processes that focus on sediment-related contaminants that could provide information on the efficiency needed and the number of systems deployed to prevent sediment recontamination and increase stormwater harvesting.

- Improved stormwater control practices would also allow for ways to beneficially utilize or harvest stormwater for reuse, aquifer recharge, or ecological restoration.

Benefits of this work would include linking improved control practices to reduced infrastructure and cost for sediment quality protection compared to current practice. By preventing the contamination of stormwater or treating stormwater, the loading of contaminants to sediments can be more effectively managed. Such a designed system that offers the potential to manage stormwater as a resource by harvesting, treating, and repurposing the water.

3.1.3 Demonstration of Methods for the Assessment of Long Term Performance of Treatment Technologies (Critical Priority Demonstration)

Continued exposure to low-level sources from permitted discharges, or stormwater discharge, from uncontrolled contaminated sites, can potentially slow or even reverse the improvements achieved through sediment remediation. With implementation of new treatment techniques, there remains a need to assess the long-term performance of those technologies, both at point-of-discharge and at the sediment bed/water interface.

Demonstrated systematic method(s) to assess the long-term performance of implemented treatment strategies, either ex situ (on point-source discharges) or in situ (e.g., placed amendments on the receiving sediment surface) is needed. These monitoring approaches (or arrays of approaches) would provide data on ongoing discharge and deposition loads (e.g., particulates by size class), target contaminant loads by grain size class, and depositional zones. Ideally, these approaches should be in situ, be able to remain in the sediment bed for long periods (e.g., 90 days), and provide a means for uploading data without having to remove the monitoring instrument. Sediment bed in situ assessment methods should be able to differentiate between surficial, recently deposited sediments and deep residual, post-remedial contamination while accounting for temporal and spatially variability.

3.1.4 State-of-the-Science Review of Stormwater Discharge and Sediment Recontamination at DoD Sites (Critical Priority Technology Transfer)

Stormwater management is an on-going activity for the DoD. At many of these sites, the services are being required to actively remediate contaminated sediments before source control has been achieved. Contaminants in stormwater are one potential source of recontamination of these remediated sites. In many cases, the links between stormwater sediment loads to recontamination of a remediated site are not known, or are insufficiently documented. This review may be best implemented prior to further development and investment in new stormwater control and treatment technologies. A well-researched review would provide a detailed view of stormwater management, collection and treatment, and identify where engineering gaps still exist.

There are a number of DoD and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup sites with sufficient data that could be parsed and evaluated to document the "state-of-the-science". This review would help focus additional work on measurement tools, models, and potentially control measures. Four scenarios that should be evaluated include:

- Stormwater loads that contribute directly to known sediment contamination. Examples of this condition include the Lower Duwamish Waterway in Seattle (PCBs), Puget

Sound Naval Shipyard (PCBs, PAHs, metals), and Paleta Creek adjacent to the Naval Base San Diego, CA (Copper, zinc, pyrethroid pesticides).

- Diffuse flow that is implicated in on-going contamination. Examples of these include surface flow through Yosemite Creek to bay sediments at Hunters Point Naval Shipyard (PCBs), Naval Air Station Joint Reserve Base Willow Grove, PA (PFASs) to streams.
- Sites where a clean sediment load in stormwater is contributing to natural recovery.
- Sites where permitted contaminant discharge limits in stormwater are higher than the cleanup levels (Joint Base Pearl Harbor-Hickam, Oahu, HI).

This case study report could be prepared as a stand-alone product, or as part of a project for monitoring tools and/or modeling approaches.

3.1.5 Improved Measurement and Assessment Approaches Linking Stormwater Sediment Load to Benthic Impairment (High Priority Research)

Stormwater management programs are predicated in part upon the seldom-demonstrated assumption that particulate-associated contaminant discharges lead directly to impairments to sediment benthic communities. Direct demonstration of benthic impairment from stormwater discharge was identified as a high priority research need. While a subset of the linkage questions are described above, data collection is needed to support, or refute, the premise that on-going stormwater discharge from a regulated facility directly impacts benthic infauna and epifauna living at the site.

Development of methods or approaches is needed to quantify contaminant influx to an actively managed area of concern that can be directly tied to a stormwater load contribution. The types of approaches envisioned include tracking changes to bedded sediment chemistry, toxicity, and benthic infaunal populations to stormwater load(s). This research should also include means to estimate TMDLs that would realistically reflect the observed changes in the receiving sediments.

3.1.6 Develop Innovative and Remotely Operated Stormwater Discharge Monitoring Systems Protective of Sediment Recontamination (High Priority Research)

Technologies are needed that allow for real-time and remotely-operated monitoring to better characterize and control stormwater, and to understand the impact that stormwater discharge has on sediment recontamination. Real-time and remote monitoring of stormwater discharge is necessary to determine overall performance and robustness during a discharge event, and to inform design and evaluation after an action is taken. Monitoring methods currently used rely on relatively simple composite samplers and are not linked to management of stormwater treatment systems. Innovative approaches and technologies to capture, treat, and monitor stormwater runoff to prevent sediment recontamination are necessary for overall improvement of sediment and water quality. Innovative operation refers to remote sensing and advanced data-driven management with software that may allow for low-cost and improved performance.

Research is needed on the application of emerging technologies for sensors, actuators and real-time controls to enhance stormwater capture and treatment to prevent sediment recontamination. Cloud computing and control systems that optimize stormwater treatment by reducing the mobilization of particle-associated and dissolved-phase contaminants and modulating flow to

treatment devices could be demonstrated. Other technologies include the use of real-time weather forecasting with in situ sensors to maximize capture, optimize treatment performance and minimize particulate-bound contaminant release to the environment. These integrated monitoring control systems should be configured to demonstrate robustness and treatment effectiveness over time. To the extent these emerging technologies could facilitate stormwater harvesting for reuse. aquifer recharge, or environmental restoration could also be considered.

3.1.7 Demonstration of Methods for Enhanced Flow Capacity for the Management of Stormwater Discharge Systems (High Priority Demonstration)

Identification and demonstration of active management of stormwater flow systems are needed to control contaminant discharge to sediments. Stormwater remains a particularly difficult water quality management challenge because hydraulic discharge varies across orders of magnitude during different storm events. The large variability in hydraulic loadings typically overwhelms the capability of detention and treatment systems to improve water quality, leading to unmanaged pollutant discharge at peak flows. This characteristic is particularly problematic for stormwater systems implicated in benthic recontamination, as larger, hard to treat, storm events are disproportionately responsible for loading of suspended solids that act as pollutant vectors to benthic environments.

Hydraulic management of flow during storm events usually relies upon physical infrastructure (e.g., detention basins, vaults, cisterns, drywells) to retain peak flows for subsequent treatment and discharge. While options for physical infrastructure, individual sites and technologies are generally well understood, stormwater management, which integrates detention, treatment, and discharge capabilities at watershed scales for optimal benthic outcomes, remains a research and demonstration priority.

To address these challenges, we seek:

- Options for active management of system detention, infiltration, evapotranspiration, or flow capacity at watershed scales to prevent or minimize benthic recontamination events based upon weather and hydraulic forecasting.
- Novel and innovative methodologies and integrated management approaches, including source identification and assessment of transport potential that optimize hydraulic capture, storage and treatment at watershed and basin scales.
- Innovative infrastructure options that provide substantial new detention or infiltration capacity.
- Advancements in techniques to capture and reuse stormwater to supplement existing water supplies.

3.2 Working Group 2: Cleanup Actions and Navigation Dredging

Dredging has, and remains the principal component of remedial actions at DoD sites (SERDP & ESTCP, 2012). In addition to environmental dredging for remedial actions, the Navy dredges approximately 300 million cubic yards annually for navigation purposes (SERDP & ESTCP, 2004). While much of that navigation-associated material is taken to open water disposal sites, between 1% to 4% of that volume require treatment and/or disposal to upland sites (NAVFAC,

2002). Despite the considerable advances of in situ management of contaminated sediments, dredging and removal to upland facilities remains the principal remedial alternative for contaminated sediment management. In addition, dredged material management and disposal options are increasingly constrained at both remedial action sites and for navigation dredging. Contaminated sediment cleanup projects are impinging on maintenance/construction projects (Moore et al., 2015). Cost effective options for managing dredged contaminated and navigation sediments are limited.

The working group addressing dredging issues was charged with discussing the questions listed below, although discussions did not necessarily have to be limited to these.

- What research and/or technology demonstrations can be completed to facilitate the overlap between cleanup actions performed under CERCLA and navigation dredging performed under U.S. Army Corps of Engineers (USACE) permit authority?
- What are the opportunities and conflicts between managing contaminated cleanups in federally authorized navigation channels and navigation dredging?
- Are there sustainable technologies (e.g., "green" dredging) for contaminated sediment and dredged material management for which additional research, technology demonstrations, or development of guidance documents could facilitate regulatory and public acceptance?
- Are there disposal alternatives common to cleanup and navigation (e.g., beneficial re-use of clean navigation-dredged sediment, confined aquatic disposal [CAD] cells, and/or confined disposal facilities [CDFs]) for which additional research, technology demonstrations, or development of guidance documents would facilitate regulatory and public acceptance?
- What existing monitoring information and data has been completed on existing in situ or ex situ sites to determine the risk associated with these sites? What long-term monitoring strategies or new approaches could be used to increase the acceptance of such strategies for dealing with both navigational and contaminated sediments?

The dredged sediment work group identified four research needs (two critical, two high), six demonstration needs (four critical, two high) and one technology transfer need as shown in Table 3. Supporting technical background and research needs are defined below.

Table 4. Needs Identified in Working Group 2: Cleanup Actions and Navigation Dredging

	Critical	High
Research	3.2.1 Development & demonstration of new & innovative technologies for sustainable remedial & navigation dredging[1]	3.2.5 Demonstration of sustainable dredged material disposal alternatives: thin-layer placement of dredged material for remediation or habitat restoration[1]
	3.2.2 Improved methods for the identification, handling & disposal of radioactive commodities in dredged sediments[1]	3.2.6 Demonstration of sustainable dredged material disposal alternatives: incorporation of amendments into dredged contaminated sediments for placement at open-water disposal sites
Demonstration	3.2.3 Demonstration of sustainable dredged material disposal alternatives: Confined Aquatic Disposal & Confined Disposal Facilities[2]	3.2.7 Development & demonstration an Integrated Dredged Sediment Management (IDSM) strategies for remedial & navigation dredging sites
	3.2.4 Improved methods for the identification, handling & disposal of munitions of explosive concern at remedial dredged sediment sites	*3.2.5 Demonstration of sustainable dredged material disposal alternatives: thin-layer placement of dredged material for remediation or habitat restoration[1]*
	3.2.1 Development & demonstration of new & innovative technologies for sustainable remedial & navigation dredging[1]	
	3.2.2 Improved methods for the identification, handling, & disposal of radioactive commodities in dredged sediments[1]	
Technology Transfer	*3.2.3 Demonstration of sustainable dredged material disposal alternatives: Confined Aquatic Disposal & Confined Disposal Facilities[2]*	

[1]Identified as both a research and demonstration need.

[2]Identified as both a demonstration and technology transfer need.

3.2.1 Development and Demonstration of New and Innovative Technologies for Sustainable Remedial and Navigation Dredging (Critical Priority Research and Demonstration)

The development and demonstration of cost effective and sustainable dredging practices was identified as a critical priority research and demonstration need. While there is an abundance of scientific and engineering literature on the current state dredging practices for contaminated and/or navigation projects (Palermo and Hays, 2014; NAVFAC, 2002; NAVFAC Dredging Web Site), there has been very little development into sustainable dredging practices.

Environmental restrictions are increasing on all dredging practices. This includes stringent release water quality criteria, seasonal restrictions to minimize ecology impacts, pollutant emissions and sound generation. These same environmental restrictions are reflected in the Navy's white paper *Sustainable Sediment Remediation* (NAVFAC, 2015). As remedial and navigation dredging practices continue to come under increased scrutiny, research into new dredging methods and equipment has not kept pace with the environmental restrictions. While some advancements have been made in dredging equipment including the use of electronic positioning systems based on global positioning system equipment, relatively little advancement has been made in developing new equipment or refining existing equipment to improve dredging performance.

These specific research and demonstration needs are specific to dredging; research on the transport, dewatering, and disposal is discussed as a separate need. Research on equipment or operational methods that can (1) improve dredging efficiency, (2) reduce environmental impacts, and (3) are sustainable would have significant benefits. Examples of research and demonstration identified include, but are not limited to:

- Equipment and operational modifications to improve environmental performance including released residuals or resuspension.
- Methods to improve accuracy and real time monitoring of dredging equipment.
- Dredge equipment using alternate fuel sources (e.g., liquid natural gas or diesel electric), have reduced emissions and/or increased fuel efficiency.
- Methods to limit environmental impacts due to noise.

3.2.2 Improved Methods for the Identification, Handling, and Disposal of Radioactive Commodities in Dredged Sediments (Critical Priority Research and Demonstration)

Chemically uncontaminated sediments have been dredged during Navy construction projects that contain small quantities of discrete radiological items. The items include dials, rope, buttons, and gauges with glow-in-dark paint containing either Radium-226 or Strontium-90. The source of these discrete items are historic Navy vessels that improperly discarded items in the 1940s and 1950s from the piers and wharfs.

The presence of these limited radioactive substances has complicated and limited sediment disposal options for both navigation and remedial projects. These specific sediments are not volumetrically radioactive compared to material found at nuclear power plants where the sediments are homogenously radioactive. Where radioactive commodities are suspected, the Navy is required to conduct intensive screening of dredged materials to identify whether radioactive materials are present. As these commodities are most commonly from radium deck dials that were scraped from naval vessels during ship commissioning, these items that can range in size from a tic-tac to a 50-inch piece of rope.

To facilitate management of these materials in sediments two research/demonstration topics are presented below.

Improved methods for handling and screening dredged materials for radioactive commodities. Screening for these commodities requires mechanical dredging, dewatering, drying, sifting, spreading dewatered material onto uplands to dry and then scanned for radioactivity. Due to the

manual handling, munitions must also be screened for due to safety reasons. This type of handling has cost the Navy several millions of dollars and significantly delayed in-water projects for a small recovery of radioactive commodities

There is a need for research and demonstration of technologies that would detect radioactivity (and potentially munitions) while reducing the handling of dredged sediment. These technologies would be able to segregate clean sediment (without sources/munitions) and sediments with possible radioactive/explosive detections.

Identification of ecological and human health risks associated with de minimis levels of radiological commodities in dredged sediments. All sediments dredged from sites where radioactive materials (typically radium dials) are suspected must undergo rigorous screening prior to disposal. Landfills located in California do not take any radioactive material. If their portal detectors, detect any type of radioactivity, the sediment will be sent back to the facility and will be recorded. If the site continues to send radioactive sediment to a landfill, the Base will be banned from using that landfill in the future and a fine will be implemented. Dredged materials that otherwise meet the evaluation criteria for ocean disposal (40 CFR 227), but contain small quantities of radioactive materials also have required the rigorous and expensive screening processes. While the U.S. is a signatory to the International Atomic Energy Agency (IAEA) 2015 Guidelines for the Application of the *De Minimis* Concept under Annex 9 of the London Convention and Protocol (IAEA, 2015a) there is no corollary U.S. guidance for identifying risks and/or *de minimis* quantities of radioactive materials in dredged sediments.

For ocean disposal, it must be shown that the sediment does not degrade any of the marine environment and is *de minimis* in nature (IAEA, 2015b). Although several studies have been performed on radioactive sediment and marine ecology, none have been performed on clean sediment with discrete, *de minimis* radioactive items with Ra-226/Sr-90 paint. As shown above, the savings from such open water placement can be significant.

Research, demonstration, and technology transfer projects are needed to define the risks, and mitigation of the risks associated with these small quantities of radioactive materials in dredged sediment. Examples of research, demonstration and technology transfer needs include the following:

- Collection of data to define the relative ecological risks to terrestrial (landfill) and marine organisms (CAD or Ocean Disposal).
- Development of standardized guidance for the radiological and biological evaluations required to obtain the necessary regulatory approvals/permits for disposal.
- Development of a guidance document for ocean disposal of *de minimis* radiological contamination.

3.2.3 Demonstration of Sustainable Dredged Material Disposal Alternatives: Confined Aquatic Disposal and Confined Disposal Facilities (Critical Priority Demonstration and Technology Transfer)

Cost effective and sustainable dredged material disposal alternatives is identified as a research and demonstration need. The principal impediments for dredging of impacted or contaminated

sediments are the costs associated with dewatering, translocation and disposal of contaminated sediments at upland landfills. The intensive re-handling associated with moving contaminated sediments to landfills results in increased project costs, fuel consumption, greenhouse gas (GHG) emissions, noise, and direct impacts to adjacent ecological and human communities. The use of upland landfills, themselves a limited and valuable commodity, for contaminated sediments may not be the best use of the landfill resource. Transporting dredged sediments hundreds of miles by rail has multiple risks and involves use of fossil fuels for transportation.

Research and demonstration needs identified by the working group include (1) technical guidance and improved public acceptance of CAD and/or CDFs; (2) beneficial reuse of clean dredged material for remediation (e.g., enhanced natural recovery, capping), (3) stabilization of moderate-levels of contaminants in dredged sediments that allow for beneficial reuse (e.g., habitat creation, nearshore fill) or potentially open-water disposal. CADs/CDFs research/demonstration needs are presented below. Beneficial reuse of dredged navigation sediment for remedial management is discussed in Sections 3.2.5 and 3.2.6, below

CAD and CDFs. In water or near shore disposal using CADs or CDFs offer the opportunity to significantly reduce costs, project schedules, consumption of valuable upland landfill space and reduce environmental impacts associated with large scale transportation of sediment to upland facilities whilst being protective of the environment. The most significant impediment to the use of CADs or CDFs appears to be public and political acceptance. This is often driven by a belief that such facilities are not adequately protective, that such facilities are not a proven concept and that if built will not be monitored or maintained.

The working group indicated that the major impediments to broader acceptance could be ameliorated from the demonstration and validation of constructed CAD/CDFs, the long-term monitoring results of constructed facilities, and technology transfer at a single source (e.g., web page) on the design, implementation, and long-term monitoring of CADs and CDFs.

Specific research, demonstration and technology transfer needs include:

- Environmental monitoring at selected CAD/CDF sites to demonstrate long term effectiveness.
- Compilation of data on existing CAD and CDF sites such as location, construction date, construction details, contaminants in material placed, monitoring during construction, monitoring after construction, and specific lessons learned.
- Preparation of a white paper on comparisons between CADs/CDFs to upland disposal in terms of overall-effectiveness, environmental protection, and sustainability factors (e.g., fuel consumption, GHG generation).
- Development of public outreach and communication materials to demonstrate effectiveness of CAD's/CDF's.
- Development of a guidance document and/or a website with lessons learned and upland testing manual for pathway evaluation and future site evaluation/design.

3.2.4 Improved Methods for the Identification, Handling, and Disposal of Munitions of Explosive Concern at Remedial Dredged Sediment Sites (Critical Priority Demonstration)

A critical priority demonstration need for the DoD is to improve the methods for handling Munitions of Explosive Concern (MEC) for sites that require remedial actions for the presence of contaminants of concern. A detailed white paper describing the problems facing remedial managers at Navy sites is attached to this report as Appendix D.

SERDP and ESTCP support on-going Munitions Response research for underwater environments. Much of that work is focused specifically on the identification and mitigation of MEC in place. ESTCP in cooperation with the U.S. Army Engineer Research and Development Center (ERDC) undertook a review of dredging equipment modifications for the detection and removal of ordnance, but concluded that there is not a commercial off-the-shelf technology available that could accomplish the project objectives. A general guidance document titled *Dredging in Sediments Containing Munitions and Explosives of Concern (*Whelp et al., 2008) has been published from that project.

Research and demonstration needs identified for remedial planning and sediment remediation at contaminated sites with MEC include the following:

- Guidance on how to incorporate presence of MEC into the remedy decision process at CERCLA and Resource Conservation and Recovery Act (RCRA) sites.
- Research on technologies and/or engineering processes for screening MEC from mechanically or hydraulically dredged sediments.
- Demonstration of developed MEC/unexploded ordnance (UXO) detection technologies for volumetric delineation for dredge planning at contaminated sediment sites.

3.2.5 Demonstration of Sustainable Dredged Material Disposal Alternatives: Thin-Layer Placement of Dredged Material for Remediation or Habitat Restoration (High Priority Research and Demonstration)

A vital intersection of maintenance dredging and contaminated sediment management is in the beneficial reuse of clean navigation sediments as fill or cover over for in-water remedial site management. Clean dredged channel maintenance sediments has been used as backfill after contaminated sediment removal, as a cap over residual and/or surface-contaminated sediments, or for EMNR.

The large volumes of clean sediment dredged to support commercial and recreational navigation in the U.S. annually (>300 million cubic yards) presents opportunities to sustainably leverage ongoing construction activities to access a source of sediments that could be used to reduce risks at clean-up sites through a spectrum of uses, including thin-layer placement as a part of enhanced natural recovery, backfill, residual capping, and degrees of more traditional cap designs. Thin-layer placement of sediment (operationally defined as the placement of inches rather than feet of sediment) has been used to accomplish several different purposes in the context of clean-up, navigation dredging, and habitat restoration projects (https://ewn.el.erdc.dren.mil/Tools.html).

While thin-layer sediment placement for EMNR has increasingly been accepted as a remedial alternative (USEPA, 2005), and is the focus of an on-going ESTCP project (ER-200827), there still remains substantial opportunity to improve the practice. Relevant research and demonstration targets for EMNR include:

- Short- and long-term performance of thin-layer covers of varying thickness.
- Short- and long-term performance of mixed-grain-size covers.
- Incremental capping through the placement of a succession of thin-layers over time.
- Engineering and performance of large-scale EMNR.
- Incorporation of habitat features and benefits as a part of placement and remedy design.

Concomitant with demonstration of the efficacy of EMNR is the need for alternative technologies and operations to harvest and apply the clean navigation-derived sediments. Efficiency is a primary goal of navigation dredging operations: moving as much sediment, in the shortest amount of time, at the lowest cost. The equipment used to accomplish navigation dredging is designed and operated to support this goal. Leveraging navigation dredging operations as a source of sediment for thin-layer placement and/or other capping uses in the context of remediation projects would be enhanced by the development of engineering and operational approaches, in the form of both equipment and practices that bridge the differences between navigation and remediation projects. For example, the equipment used in navigation dredging disposal and placement operations is not designed or operated to achieve thin-layer placement (i.e., deposits that are inches thick).

Research and demonstrations that would facilitate the integration of navigation dredging with remediation projects in this context could include:

- Research and demonstration of equipment to accomplish thin-layer placement in the context of navigation dredging project requirements.
- Demonstrated modifications in operational practices to accommodate the differences in production rates between navigation and remediation projects (e.g., the use of open-water temporary holding areas or basins).
- Scientific and engineering means to support the use of strategic sediment placement to support EMNR (strategic sediment placement refers to the placement of sediment in one location with the intention that this sediment will be moved, through natural processes (e.g., currents and waves) to other desired locations or areas).

3.2.6 Demonstration of Sustainable Dredged Material Disposal Alternatives: Incorporation of Amendments into Dredged Contaminated Sediments for Placement at Open-Water Disposal Sites (High Priority Research)

A significant constraint on dredging as a remedial alternative is the cost and effort of disposal of contaminated sediments to a contained facility; principally an upland landfill, but also to a CAD or CDF. Sediments dredged for navigation purposes often have low-levels of contaminants, but can be disposed of at low-cost open-water sites after testing to demonstrate that the contaminants are non-toxic to benthic organisms (via bioassays) and would not bioaccumulate into the food chain. Dredged contaminated sediments are generally prohibited from these open water sites, often

on the presumption that levels of contaminants would be toxic to benthic organisms and/or would bioaccumulate.

Application of activated carbon (AC) on contaminated sediments as a remedial alternative to sequester and render hydrophobic organic compounds (HOCs) biologically unavailable has been demonstrated through several SERDP and ESTCP projects, and increasingly is used for contaminated sediment management (USEPA 2005; 2013). One innovative extension would be to demonstrate that addition and mixing of AC into contaminated dredged sediment would sufficiently sequester the HOCs, so that the sediments could then be disposed of at open water disposal sites. At least one project recently begun by the Army Corps' ERDC laboratory is working to demonstrate open water placement of low-level contaminated dredged materials after adding AC for bioaccumulation control in Ashtabula Harbor, OH (Townsend, 2015).

Research and demonstration would be needed to show that efficient and cost-effective amendment mixing techniques could be developed and incorporated into dredging practices. These methods could include ways to introduce AC into the navigation plant streams (e.g., AC added to barge, to hopper discharge, hydraulic injection) and that the resultant material would pass the bioassay and bioaccumulation tests for a suitability determination for open water placement. Additional work would be needed to demonstrate that during the disposal event the AC would remain with the sediment dropped through the water column, confirmation testing that the AC was suitably distributed within the deposited sediments, and short-and long-term demonstration that organisms living within those disposal sites did not accumulate HOCs.

3.2.7 Development and Demonstration of Integrated Dredged Sediment Management (IDSM) Strategies for Remedial and Navigation Dredging Sites (High Priority Demonstration)

The use of navigation dredged material for beneficial uses is often touted as a potential cost reduction and best use of dredged material as a resource. However, the reality of annual funding and limited budgets for navigation dredging combined with the lead time for environmental placement approval and coordination pose significant barriers for potential reuse of dredged materials from many navigation projects. This annual funding and related uncertainty on when navigation projects may be performed makes it very difficult to link beneficial use to these navigation projects. The use of navigation material for capping or EMNR often makes logical and financial sense from many viewpoints but it is the schedule and volume uncertainties that create the impediment. Capping and EMNR projects, once planned, have a fixed schedule to which they must adhere. Basing such work on a material source that is then not available, because the navigation dredging project did not happen due to funding or other issues, puts the EMNR or capping project at risk. This risk often results in capping and EMNR projects procuring material from upland, commercial sources and the navigation material goes unused and is placed in deep water offshore, lost from the littoral system.

The purpose of the research study and demonstration would be to evaluate potential cost savings and environmental benefits that could be realized if sufficient certainty could be provided to navigation projects with a potential beneficial reuse component on greater than an annual budget cycle (i.e., the ability to plan a navigation dredging and beneficial reuse project three years in the future).

The demonstration/research needs identified include:

- Evaluating potential cost savings from considering navigation dredged material as a valuable resource. What are the potential savings if the annual funding impediment could be removed or reduced such that material availability can be guaranteed?
- Evaluating potential for rehandling facilities where dredged material can be cost effectively placed, stored and recovered for beneficial reuse in a way that can compete with upland commercial sources.
- Identifying methods/regulatory framework by which navigation dredged material can be considered a commodity to fund additional beneficial reuse projects. This may involve fees in areas with less other material resources and a greater market demand to fund projects in other areas.

3.3 Working Group 3: Emerging Contaminants-of-Concern in Sediments

The working group for emerging contaminants adapted a definition that "emerging contaminants" are any chemical or physical particle that has not to date been monitored at contaminated sediment sites but have the potential to cause adverse environmental impacts. Emerging contaminants include 1) "true or really new" emerging contaminants, new compounds or particulates that were not previously known or that just recently appeared in the scientific literature (e.g., nanoparticles), 2) contaminants of emerging interest which were known to exist but for which the environmental contamination issues were not fully realized or apprehended (e.g., perfluorooctanoic acid [PFOA]/perfluorooctane sulfonate [PFOS]), and 3) "old" contaminants, i.e., situations where new information is jostling our understanding of environmental and human health risks related to such legacy contaminants (Sauve and Desrosiers, 2014).

The working group addressing emerging contaminant issues was charged with discussing the questions listed below, although discussions did not necessarily have to be limited to these.

- What are the emerging contaminants of concern (COCs) relevant to DoD and U.S. Environmental Protection Agency (EPA)-led sediment sites for which additional research, technology demonstration, and/or guidance documents may be needed to support future risk assessment, remedial decisions, and site management?
- What COCs represent the most important targets for DoD and EPA to demonstrate the need for further research and demonstration projects, and why should these targets be designated for future research?
- What if any data gaps exist in the fundamental understanding of the risk, fate, and transport of these COCs?
- Are new or improved diagnostic tools needed for any of these COCs to understand their fate and transport mechanisms or potential modes of toxicity?
- Is there an opportunity to develop consistent site assessment, methodologies, and cleanup levels for these COCs?
- What technologies are most promising for effective and cost-efficient treatment of these COCs?

- What are the highest priority research and demonstration efforts needed to improve treatment of these COCs?

The emerging contaminants listed below were the ones discussed by the workgroup. For many of these, research is on-going concerning the fate, transport, toxicity and potential remedial alternatives in surface water, groundwater, and soils. There is very little published for the same set of environmental characteristics in sediment.

Per- and Polyfluorinated Alkyl Substances (PFASs). PFASs have been widely used by DoD installations as fire retardants. PFAS have been included on the USEPA's Third Unregulated Contaminated Monitoring Rule (UCMR3) list with guideline water quality criteria and health advisory levels in drinking water for PFOS and PFOA. PFAS toxicity and remediation is being actively investigated by SERDP and ESTCP for soils, surface water and groundwater. There is a relative paucity of information on transport of PFAS to sediments, as well as the fate and transport once there (Ahrens, 2011; Vierke et al., 2012).

1,4-Dioxane. Used as a stabilizer for solvents (including trichloroethene (TCE)-containing solvents) and as a laboratory reagent, 1,4-dioxane is also on the UCMR3 list for drinking water, and SERDP and ESTCP are actively funding research into dioxane remediation in groundwater and soils. With a relatively low organic carbon partitioning coefficient (Koc ~ 1.2) it is not likely that 1,4-dioxane will sorb to sediments, but the fate and effects are not well defined.

Pesticides. Pesticides continue to be a contaminant found in sediments at DoD facilities. Frequent use of pesticides has resulted in contaminated runoff and sediment contamination that the DoD must include in remedial action plans. For example, commonly sold and used pyrethroid insecticides are being found as potentially toxic to benthic invertebrates in sediments adjacent to U.S. Navy facilities in San Diego (Anderson et al., 2010). While not necessarily an "emergent contaminant", regulators have begun to focus on pesticides as DoD sites.

Low-level radiological commodities. The need to develop cost effective screening tools for low level radiological commodities in sediment was discussed in Section 3.2.2. Currently, handling of dredged material impacted with low-level radioactive waste is very expensive due to hand sorting of discreet items such as dials, rope, buttons, and gauges with glow-in-dark paint that contains either Radium-226 or Strontium-90. Also, the manual handling requires that munitions must also be screened for due to safety reasons.

Microplastics. Microplastic particles in aquatic environments are getting increased attention nationally and internationally. Microplastic particles can be the result of degeneration and weathering of plastic debris released into the oceans, but also have been used in commercial cosmetic products, as well as artificial fabrics (e.g., polyester). Recognized as a physical pollutant, some evidence exists to suggest that microplastics can accumulate hydrophobic organic contaminants such as PCBs, and then serve as vectors of HOCs to aquatic organisms, including fish that are consumed by people (USEPA, 2015). To date, microplastics have not been identified as an emergent contaminant for the DoD; however, microplastic pollution has been identified as an issue in the Great Lakes by the International Joint Commission, and its preliminary recommendations have been released (IJC, 2016).

Short-Chain Chlorinated Paraffins (SCCP). SCCPs are found world-wide in the environment, wildlife and humans (USEPA, 2009). They are reported as bioaccumulative in wildlife and humans, are persistent and transported globally in the environment, and toxic to aquatic organisms at low concentrations. Used as a component of lubricants and coolants in metal cutting and metal forming operations, SCCPs have been identified in all environmental media tested to date, including surface waters, sediments, and tissue. Prevalence of short-chain chlorinated paraffins at DoD and other sediment sites is unknown but due to their persistence, toxicity, and bioaccumulation potential, impacts are likely present. To date, SCCP has not been identified as an issue at DoD facilities.

Fuel Additives. Use of fuel additives is expanding rapidly and will likely continue to increase. Little is known about their toxicity and bioavailability, and their potential role in new generation alternative fuels procured by the DoD (e.g., Rosen et al., 2014). The working group had limited information on the nature or prevalence of fuel additives used at sites of interest.

The emerging contaminants work group identified eight research needs (five critical, three high), one demonstration need and one technology transfer need as shown in the Table 4. Any or all of the COCs identified above could be the subject of the research and demonstration work described below.

3.3.1 Improved Methods for Quantifying Concentrations and/or Toxicity of Emerging Contaminants (Critical Priority Research)

Standardized time- and cost-effective methods are needed to quantify concentrations and toxicity of emerging contaminants in sediments (and other media including stormwater and porewater). Methods should include quantification of precursors and derivatives where applicable. The methods should be adoptable by a wide range of commercial analytical laboratories. For example, methods for PFASs include USEPA537 but it is modified by many laboratories. Standard methods may allow for some flexibility; however, basic requirements must be standardized so that decision makers can obtain quality data required to inform ecological and human health risk-based decision making.

3.3.2 Development of Modeling Framework for Fate and Transport of Emerging Contaminants Migrate to Support Risk Assessment (Critical Priority Research)

Development of a modeling framework (that includes existing partitioning coefficients) is needed for emerging contaminants that will help predict how these chemicals are expected to migrate in different environments to support risk assessment. Specifically, reconciliation of K_{OW} or computational chemistry-based parameters to sediment and AC partitioning is needed as well as prediction of partitioning factors and bioaccumulation potential.

Table 6. Needs Identified in Working Group 3: Emerging Contaminants-of-Concern in Sediments

	Critical	High
Research	3.3.1 Improved methods for quantifying concentrations and/or toxicity of emerging contaminants	3.3.6 Development of a natural attenuation framework for emerging contaminants
	3.3.2 Development of modeling framework for fate & transport of emerging contaminants to support risk assessment	3.3.7 Development of in situ remediation strategies for emerging contaminants
	3.3.3 Improved methods for establishing porewater-based sediment management standards for emerging contaminants	3.3.8 Development of forensics for source tracking & allocation of emerging contaminants
	3.3.4 Improved methods to quantify cumulative risk associated with complex contaminant mixtures that include emerging chemicals of concern.[1]	
	3.3.5 Improved methods for identifying ecological risks associated with incidental radiological commodities in sediments.[2]	
Demonstration		*3.3.4 Improved methods to quantify cumulative risk associated with complex contaminant mixtures that include emerging chemicals of concern.*[1]
Technology Transfer	*3.3.5 Improved methods for identifying ecological risks associated with incidental radiological commodities in sediments.*[2]	

[1]Identified as both a research and demonstration need.

[2]Identified as both a research and technology transfer need.

3.3.3 Improved Methods for Establishing Porewater-based Sediment Management Standards for Emerging Contaminants (Critical Priority Research)

Extension of the passive sampling technology to emerging contaminants is needed. Specific needs include:

- Identify whether passive samplers provide a cost-effective method for measuring the freely dissolved concentration (C_{free}) of individual and mixed emerging contaminants present in sediment porewater;
- Determine whether existing or new polymers are suitable for quantifying emergent contaminant C_{free} concentrations in sediment porewater;

- Determine polymer-and contaminant-specific partitioning behavior, and suitable performance reference standards sufficient for commercial laboratories to perform appropriate analyses.

3.3.4 Improved Methods to Quantify Cumulative Risk Associated with Complex Contaminant Mixtures that Include Emerging Chemicals of Concern (Critical Priority Research)

Development of a methodology for quantifying cumulative risk posed by complex chemical mixtures of emerging chemicals of concern is needed. Such research would specifically pertain to mixtures of PFASs, pesticides, or SCCPs. Specific needs include:

- Define, describe and determine viability of cumulative risk assessment as an evaluation of combined effects from a mixture of chemicals with similar modes of toxic action and/or toxic endpoints or presence of multiple contaminant phases for multiple emerging contaminants.
- Determine if and how integrated chemical exposure and toxicity groups can be formed.

3.3.5 Improved Methods for Identifying Ecological Risks Associated with Incidental Radiological Commodities in Sediments (Critical Priority Research and Technology Transfer)

Research is needed to determine whether ocean disposal of sediment containing discreet radiological components degrades any of the marine environment and is *de minimis* in nature (London Convention). Although several studies have been performed on radioactive sediment and marine ecology, none have been performed on clean sediment with discrete, *de minimis* radioactive items with Ra-226/Sr-90 paint. Specific needs include the following:

- Determine the risk and health effect of the radioactive discrete items on the marine ecology.
- Evaluation of uptake from these discrete items into benthic organisms and food web transfer to mammals, birds, and humans that may consume higher trophic level fish.
- Development of guidance for ocean disposal of *de minimis* radiological contamination.

This need also was discussed under Section 3.2.2.

3.3.6 Development of a Natural Attenuation Framework for Emerging Contaminants (High Priority Research)

Developing an improved understanding of natural attenuation parameters of importance for multiple emerging contaminants is needed. For example, we need to know more about biodegradation pathways and associated processes/properties that control bioavailability. The proposed efforts should focus on understanding fate and transport mechanisms, biotic and abiotic transformations, bioavailability, and the impact on site variability for specific emerging contaminants.

3.3.7 Development of In Situ Remediation Strategies for Emerging Contaminants (High Priority Research)

Development of in situ remedial strategies that would remove, eliminate, or result in the reduction of emerging contaminant release and uptake to ecological receptors is needed. Highlighted in the 2012 Workshop Report, this area continues to be important for all contaminants in sediments, but especially for the emerging contaminants. Research and development needs include:

- Developing new and more effective amendments.
- Designing new and better ways to deliver amendments as part of caps or in situ treatment approaches.

Much of the recent work on sediment amendments has focused on adsorption by carbon or other substrates (e.g., organoclays, apatite). There remains continued interest from the regulatory community and public in approaches that remove the mass of the contaminants through treatment. These new technologies would meet a number of important criteria for in-placement management: reduce exposures through a combination of chemical adsorption, degradation and transformation; have low impact on native biota; have long-term effectiveness; be competitively priced from a life cycle perspective that considers all benefits and costs, and addresses complex mixtures of chemicals.

This research and development need is directed toward new technologies that may come from combinations of physical, chemical, and biological research efforts. Research could derive from the fields of nanotechnology, microbiology, enzyme systems, and tissue cultures.

3.3.8 Development of Forensics for Source Tracking and Allocation of Emerging Contaminants (High Priority Research)

Developing methodologies to verify the source of some prevalent emerging contaminants such as PFASs is needed. Proposed efforts should focus on forensics or other methods to determine the source of emerging contaminants that may have multiple sources in the environment.

3.4 Working Group 4: Increasing Confidence in Sediment Cleanup Levels

Sediment cleanup levels (CULs) are the contaminant concentrations in sediment to be achieved through active or passive (e.g., MNR) sediment remediation. Establishing numeric cleanup levels can be a time-consuming, controversial, and difficult process at contaminated sediment sites and often represents a point of contention between regulators and regulated parties as those concentrations will have a direct influence on the size, degree, and cost of cleanup.

At sites with sediments contaminated with persistent hydrophobic compounds such as PCBs, the goal is generally to reduce predicted risks to human and ecological health from consumption of contaminated fish. “Protective” fish tissue levels (i.e., fish tissue concentrations that do not pose unacceptable risks of cancer or other health effects) are derived based on a site-specific risk assessment process that generally assumes high-end fish consumption rates and durations of exposure. These fish tissue contaminant concentrations are then converted to sediment cleanup levels using a site-specific fish to sediment relationship, often based on a food web model (FWM). Thus, the ability of these FWMs to appropriately capture the sediment-(water)-fish relationships

is critical for establishing a management approach that will convey an appropriate level of protection.

At many sites, risk-based levels for persistent hydrophobic contaminants fall below "background" concentrations, so increasingly background levels are adopted as site-specific sediment cleanup levels[1]. This outcome emphasizes the need for approaches for developing credible estimates of background contaminant concentrations and standardizing definitions and methodologies.

With this background, the work group set out to address the workshop charge questions:

- Are there new approaches and/or technologies that can be developed to complement existing approaches to support increased confidence in the reliability and accuracy of sediment cleanup levels that are based on either fish tissue concentrations (e.g., human health consumption risks) and/or regional or local background concentrations?
- What approaches and/or technologies exist or could be developed to relate measured values of sediment contaminant concentrations to fish tissue concentrations and thus the sediment CULs?
- What improvements can be made, or new data collected, to reduce the uncertainty in the food web models used to set CULs?
- Are new or improved in situ/ex situ approaches needed to support long-term performance monitoring to evaluate the accuracy of food web model forecasts?
- What models or estimation methods are needed to better forecast (with uncertainty bounds) the projected cost of remedial actions used when evaluating alternatives and CULs?
- What approaches or opportunities exist to develop scientifically defensible assessment and statistical methods to develop watershed/site specific background, or regional background levels, to assist Risk Managers in setting achievable cleanup levels?

Group members agreed that innovative approaches were needed and that there were opportunities for research, demonstration, and technology transfer to help address these challenges. Project and site managers agreed that default CULs based on standardized assumptions would improve the efficiency of site decision making. The sediment CUL work group discussed that decision making at sites was frequently challenged by two central issues:

1. Determining reasonable and feasible cleanup levels.
2. Improving FWMs for remedial decision making.

Research and demonstration needs are organized around these two central issues. The sediment CUL group identified three research needs (one critical, two high), two demonstration needs (one

[1] The 2002 EPA Guidance: *Role of Background in the CERCLA Cleanup Program* (OSWER Directive 9285.6-07P) states: "Generally, under CERCLA, cleanup levels are not set at concentrations below natural background levels. Similarly, for anthropogenic contaminant concentrations, the CERCLA program normally does not set cleanup levels below anthropogenic background concentrations …"

critical, one high), and one technology transfer need as shown in Table 5. Supporting technical background and research needs are defined below.

Table 7. Needs Identified in Working Group 4: Increasing Confidence in Sediment Cleanup Levels

	Critical	High
Research	3.4.1 Development of innovative alternatives to establish sediment cleanup goals	3.4.4 Improved standardized approaches for measuring porewater contamination concentrations
		3.4.5 Improved understanding of input variables to food web models
Demonstration	3.4.2 Demonstration and validation of passive sampling-based Cleanup Levels	3.4.6 Post-remedy evaluation of the long-term utility of food web models to set cleanup goals at contaminated sediment sites
Technology Transfer	3.4.3 Development of Best Practices Guidance for sediment background level determination	

3.4.1 Development of Innovative Alternatives to Establish Sediment Cleanup Goals (Critical Priority Research)

FWMs typically use bulk dry weight sediment contaminant concentrations to represent the contaminant exposures from sediment. Porewater contaminant concentrations are estimated in the models using partitioning relationships and assumptions. Increasingly, passive samplers are used to directly measure contaminant concentrations in porewater. Passive samplers can be deployed in the water column and sediment bed to directly measure exposures to aquatic organisms. SERDP and ESTCP have devoted significant resources to basic and applied research on the use of passive samplers and the field has rapidly evolved.

Development of alternative approaches is needed to replace the complex mechanistic food web models that are currently used to establish cleanup goals. Specific topics that that could be addressed with this research include:

- Research that directly ties passive sampler-based measurements of freely-dissolved contaminants to uptake in aquatic organisms, and to ecological and human health effects from transfer through the aquatic food web.
- Methods to derive porewater-based cleanup levels for protection of ecological and human health from contaminants via the fish consumption exposure pathway.

3.4.2 Demonstration and Validation of Passive Sampling-Based Cleanup Levels (Critical Priority Demonstration)

Development, demonstration, and validation is needed of default CULs based on passive sampling-based measurements, in lieu of site specific risk assessments. Specific work that would need to be demonstrated would be to (1) develop default CULs, and (2) develop robust monitoring

over a range of environmental conditions, to include co-deployment of passive sampling technologies, fish tissue sampling, and water sampling. This will help to establish whether surrogate measures could supplement fish tissue sampling.

3.4.3 Development of Best Practices Guidance for Sediment Background Level Determination (Critical Priority Technology Transfer)

Technology transfer work is needed to develop the following:

- A summary document of sediment background definitions, determinations, and statistical manipulations used by different entities to establish sediment background-based cleanup levels.
- A best practices guidance for determining site specific sediment background levels, including appropriate definitions, derivation, and application.

Risk assessments may result in risk-based CULs that are below "background" levels of those contaminants. Thus, sediment background levels, even of anthropogenic contaminants, will be selected as the CUL. However, the intended definition of sediment background (e.g., regional, natural, anthropogenic, the recontamination level, upstream, reference) and the procedures used to derive sediment background levels vary by location and contaminant. A synthesis document that details definitions, methods, and procedures used by state or regulatory authorities would be a helpful resource. A best practices guidance for establishing site-specific sediment background levels as cleanup levels also is needed. That document would provide protocols for deriving site specific sediment background levels, including sampling, statistical approaches, and appropriate application. Another important issue is how future conditions should be considered. For example, the release of mercury (Hg) from the melting of glaciers may increase the "background" concentration of Hg according to regional deposition patterns. In other systems, sediment background concentrations of contaminants are anticipated to decline over time.

Are there other techniques besides sampling "background" areas and statistically comparing values? For example, can equilibrium based sediment background concentrations be derived from air concentrations? Could mass-balance approaches from contaminated media (water, sediments, biota) can be used to estimate sediment background?

3.4.4 Improved Standardized Approaches for Measuring Porewater Contamination Concentrations (High Priority Research)

Research is needed to establish the representativeness, accuracy, and reproducibility of standardized approaches for measuring porewater contamination concentrations.

Bulk-sediment contaminant concentrations have standardized analytical methods and a long precedent of use as cleanup levels at contaminated sediment sites. Those factors perpetuate their ongoing use, despite the recognition that freely-dissolved contaminant levels in porewater are better indicators of risk from contaminated sediment. There are currently a variety of methods available for measuring porewater concentrations, and there can be confusion regarding the optimal passive sampler, deployment configuration, and analytical technique for a given situation. Most techniques today are relatively robust, providing flexibility for site managers to use whichever method best suits their site conditions. For HOCs, three techniques stand out:

polyethylene (PE), polyoxymethylene (POM), and solid phase micro-extraction (SPME) materials. Ultimately, if porewater contaminant concentrations derived from passive sampler approaches will supplant bulk sediment contaminant concentrations, greater standardization of methods is needed.

3.4.5 Improved Understanding of Input Variables to Food Web Models (High Priority Research)

Increasingly fish tissue contaminant concentrations are the basis for developing sediment cleanup levels. Starting with tissue concentrations that are estimated to cause adverse ecological or human health effects from consumption of those fish or shellfish, FWM models are used to back-calculate sediment goals that presumably would be protective of those risks. Despite their widespread use and long history of application for HOCs, regulators and the regulated community alike continue to question FWM accuracy and precision in relating sediment and water exposure concentrations to resulting organism concentrations throughout the aquatic food web.

The current assumption that sediment remediation leads to commensurate declines in fish tissue concentrations to date has not been firmly established. While the SERDP and ESTCP 2012 Workshop identified potential research needs with respect to FWM application (SERDP & ESTCP, 2012), modeling the relationship between fish tissue contaminant concentrations and sediment-water exposure concentrations is a large and multi-faceted problem and significant research questions remain. For example, are there critical contaminant exposures that are being missed? Are fish being exposed to areas outside the site and are there key exposure areas within the site boundaries? Which environmental media, timeframes, and phenomena are responsible for the body burdens and are these being appropriately considered from a mechanistic perspective within the modeling framework? Fish tissue concentrations of persistent bioaccumulative contaminants such as PCBs primarily derive from dietary sources. Should the contaminant exposure history of fish diets be considered when deriving sediment CULs from FWMs?

Research is needed to develop technologies and approaches for documenting site specific fish diet and trophic level and establishing critical chemical exposures, time periods, and environmental processes that drive fish burdens to test the assumption that sediment remediation will decrease fish tissue concentrations. These technologies and approaches will explore the range of site-specific partitioning relationships for improving FWM performance.

A quantitative understanding of temporal and spatial variation in contaminant exposures is required to appropriately model aquatic food web exposures. For example, storm-related fluxes rapidly create large inputs that can influence organism concentrations. Water related influences and the dynamics between sediment and water represent a linkage that is currently under-emphasized with the consequence that the FWM may not have the "correct" exposure characterization. Under the assumption that chemical activity, rather than absolute concentration, is a more significant driver of contaminant uptake, should site-derived partitioning relationships (K_{OC} vs K_{OC} derived from assumed K_{OW}) or other methods be used? A common simplifying assumption at contaminated sites is that external loading of contaminants has been controlled. That decision simplifies modeling, but may not be realistic. Are these loads driving elevated fish tissue concentrations and a lack of observable declines after remediation?

3.4.6 Post-Remedy Evaluation of the Long-Term Utility of Food Web Models to Set Cleanup Goals at Contaminated Sediment Sites (High Priority Demonstration)

A systematic, retrospective analysis of FWM applications across a variety of large sediment sites could provide insight to help better define relationships between fish and sediment and water exposures based on existing applications. While a large number of site-specific food chain models coupled with fate and transport models have been developed (Great Lakes, Lower Fox River, Willamette River, Hudson River, San Francisco Bay), there is a lack of information on the extent to which these advanced food chain models/fate and transport models accurately predict long-term trends to changes in fish tissue concentrations.

This retrospective analysis would be beneficial at remediated sites where fish tissue contamination by persistent HOCs was the risk driver(s) and where CULs were set using FWMs with an expectation of reduction in fish tissue concentrations after implementation of the remedy. Specific needs include the following:

- In-depth analysis of existing long-term data (pre-, post, and long term after remediation) and modeling efforts at selected sites.
- Completion of a post-hoc analysis of sites that have undergone remediation (capping, dredging, in situ treatment, or MNR) and compare designed/predicted to measured/ achieved recoveries.
- Evaluation of modeling approach(es) originally used to select a remedy, and long-term trends actually achieved at the sites.
- Evaluation of how porewater and water column measures contributed to, or should have been used to improve understanding of the performance of the FWM.

3.5 Working Group 5: Monitoring Remedy Effectiveness

Performance monitoring of a sediment remedy is an integral component of the remediation process to verify and document remedy effectiveness and permanence. As part of the remedy design process, both short- and long-term maintenance and monitoring programs are developed. Short-term monitoring determines whether remedy implementation meets design specifications. Long-term monitoring focuses on evaluating whether remedies achieve Remedial Goals (RGs) and Remedial Action Objectives (RAOs). RGs generally specify the expectations for reductions in contaminant concentrations while RAOs specify the broader objectives for reducing risk and restoring beneficial uses. All effective monitoring programs should be able to document reduction of risk and progress towards recovery.

Post remedial monitoring, or long-term monitoring (LTM), is typically considered after the remedy evaluation and selection process is complete. The working group advocated that the monitoring process should start at the beginning of the site characterization and remedy evaluation process and carry through remediation to post-remediation monitoring. The following recommendations are intended to improve monitoring at contaminated sediment sites, building on the theme of early monitoring and adaptive management approaches:

1. LTM should be considered early in the RI/FS/RD/RA process, when developing the conceptual site model (CSM) and when developing remedy alternatives. This approach

can improve and clarify CSMs and remedy selection outcomes while establishing clear expectations for remedy effectiveness and long-term monitoring.

2. Site managers should consider how site-specific goals will be measured and monitored when developing RAOs and RGs, directly tying LTM goals to RAOs and RGs. If goals are not measurable, remedial managers should work with stakeholders to create measurable goals. Working through LTM objectives while developing RAOs and RGs can help refine the CSM, ferreting out misconceptions and disagreements about remediation endpoints and remedy effectiveness.
3. Monitoring objectives and methods should be developed with the clear intent to meet RAOs and compare remedy outcomes against cleanup levels. This can help define which metrics and endpoints are best suited monitoring effectiveness and the appropriate statistical methods to apply for hypothesis testing.
4. Monitoring and remedy effectiveness evaluations should be flexible and adaptable. As monitoring data is collected, periodic assessment of the selected approach's ability to meet the monitoring objectives should be assessed and revised, where appropriate, to ensure that remedy effectiveness can be determined.

The working group also noted that a primary driver at many contaminated sediments sites is the risk of consumption of contaminated biota (e.g., fish, shellfish). Monitoring approaches are needed to inform site managers whether the selected remedies are working. When evaluating monitoring metrics, all aspects of the biological food web may be considered; however, the measurement endpoints need to be tied to the remedy. Examples include:

- Sediment: Is the bioavailable fraction of chemical decreasing? Have source pathways been controlled? Are sediments sinks or sources of chemicals?
- Porewater: Did remedy reduce porewater concentrations of chemicals of concern?
- Lower biological trophic levels: Did remedy reduce bioaccumulation in tissues of plankton, zooplankton, and macro-invertebrates?
- Young-of-the-year: Did remedy improve recruitment of species of concern?
- Upper biological trophic levels: What is the connection between remedy and upper trophic levels? Have the bioaccumulation pathways to upper trophic levels been reduced?

These different endpoints within the site specific food web are likely to provide measureable change at different time scales (i.e., at different rates). For example, top predatory fish, often the focus of a remedy performance, can be slow to respond to changes that happen in exposure from remediated sediments. By focusing on the exposure pathways to fish instead of long-term accumulation in fish, it may be possible to perform timely assessments of a remedy progress and mechanistically explain observed changes. There is a critical need to clearly link the remedy performance to risk goals and then tailor the monitoring program to assess risk reduction.

With these considerations, the work group addressed the following charge questions:

- What tools and/or approaches are needed to support the assessment of remedy effectiveness following remediation at contaminated sediment sites?

- What is the state-of-the science in terms of short and long-term assessment methods, metrics, and guidance to characterize, monitor, and maintain success post-performance monitoring?
- Where MNR is a component of the cleanup, what methods can be used to predict (with bounded uncertainty) the time to achieve all RAOs, cleanup levels, and remedial goals or targets, and what are the approaches needed to measure and assess that progress?
- What are the most promising opportunities or strategies to increase the credibility and accuracy of long-term monitoring results, while optimizing the cost of monitoring?
- What are the highest-priority research and demonstration efforts needed to develop and deploy more efficient long-term monitoring methods and strategies?

The monitoring remedy effectiveness group identified three research needs (two critical, one high), three demonstration needs (two critical, one high), and one technology transfer need as shown in Table 6. Supporting technical background and research needs are defined below.

Table 8. Needs Identified in Working Group 5: Monitoring Remedy Effectiveness

	Critical	High
Research	3.5.1 Development of alternative indicators for fish and/or biological tissue sampling	3.5.6 Other over-arching monitoring needs[1]
	3.5.2 Development of new tools and processes to optimize remedial monitoring optimization: lower cost and rapid technologies	
Demonstration	3.5.3 Demonstration of noninvasive, safer methods for monitoring the physical and chemical integrity of remedy	
	3.5.4 Demonstration of EMNR as a cost-effective in situ remedial alternative	*3.5.6 Other over-arching monitoring needs*[1]
Technology Transfer	3.5.5 Develop monitoring guidance and case studies to support long term remedy effectiveness assessments	

[1]Identified as a research and demonstration need.

3.5.1 Development of Alternative Indicators for Fish and/or Biological Tissue Sampling (Critical Priority Research)

Several measurement tools have been developed in the last decade (e.g., polymeric passive samplers for freely dissolved concentrations and diffusive gradients in thin films [DGTs]) that allow measurement of the freely dissolved concentrations of persistent organic pollutants (POPs) and metals. While some studies have attempted to link abiotic measurements to concentrations in fish, there is currently a lack of field data to validate that approach. Current understanding and modeling of how bioavailability changes in sediments impact bioaccumulation in fish and other

biological receptors remains limited to laboratory experimental observations (Fadaei et al., 2015). Further research is needed to build confidence in biological models that predict relationships between sediment and aquatic chemical concentrations and chemical levels in biological endpoints that result in exposure to receptors, especially in field situations.

In addition, there are uncertainties on how to monitor remediation goals that approach background, particularly when achieving low, asymptotic levels that may be overwhelmed by data variability. Questions to be answered by this research are:

- Where risk is generally in the consumption of contaminated biota near the top of the food web, are there alternative endpoints/metrics that may indicate a reduction in risk is expected due to reductions in sediment contaminant concentrations, and contaminants lower in the food web?
- What is the expected biological response to the remedy and how do we use food-web modeling to better understand monitoring goals and metrics?
- Do chemical concentrations of sessile organisms (e.g., transplanted mussels), epibenthic invertebrates, or infaunal invertebrates serve as intermediate indicators of remedy performance sooner than fish? Do these methods over predict (or under predict) risk by creating artificial conditions that accelerate fish exposures to contaminants in the environment?
- For sites where fish are the primary receptor, can passive sampler approaches be developed to better mimic chemical uptake and bioaccumulation in fish?
- Alternatively, can passive samplers be integrated with biota sampling in a way that reduces uncertainty, minimizes impacts to fisheries, and reduces monitoring costs?
- How do we monitor goals that approach background, particularly when achieving low, asymptotic levels may be overwhelmed by data variability?

There is a critical need to build confidence in models that relate abiotic measurements (including passive sampling) to accumulations in shell fish, resident, migratory, and top predatory fish. More accurate information on impact of contaminant uptake at the base of the food chain on fish, fish foraging behavior, range etc. are needed to create and validate such models. These could include novel fish tagging techniques, potentially to not only measure foraging and migratory behavior but also the associated exposure concentrations.

Further validation of food chain models with existing field data is needed to build confidence in the modeling approach. Such validations could involve post-hoc analysis of existing data from contaminated DoD sites, possibly using the large amount of data collected over many years at many DoD sites. These analyses, which also were discussed in Section 3.4.5, include concentrations in various environmental media including fish or other biota. Specific needs include the following:

- Compare and validate modeling approaches already used to develop and inform site data interpretation.
- Evaluate more advanced modeling (e.g., including passive sampling data and fish foraging behavior) with additional data collection where necessary to develop

approaches that allow accurate predictions of fish and other animal receptor concentrations, based on geochemical characteristics of the contaminated media, site-specific fate and transport characteristics, and exposure scenarios.

- Develop much simpler modeling approaches that can be used to develop preliminary remediation goals (PRG) for use at smaller sites where the high cost associated with developing a detailed site-specific advanced model may not be supportable.

3.5.2 Development of New Tools and Processes to Optimize Remedial Monitoring: Lower Cost and Rapid Technologies (Critical Priority Research)

Monitoring costs represent a significant and increasing burden on DoD. The development and demonstration of innovative and lower-cost monitoring techniques should result in cost effective monitoring that results in more temporal and spatial data, thereby reducing uncertainty in assessing LTM goals. Sample compositing strategies should be rigorously evaluated and demonstrated for potential broader application in sediment, in particular with respect to advantages for LTM. Sediment-specific methods for determining the numbers of samples per composite and the number of composites per test condition as determined by a statistical power analysis should be evaluated. Trade-off analysis and optimization of the increased field sampling costs of these methods versus the lower analytical costs would help to guide practitioners in the application.

At many sites, monitoring for reduction in biological endpoints such as fish can drive a substantial fraction of the monitoring cost. Such monitoring can be very labor intensive, complex and costly. In addition, it is often performed at time intervals that have no basis to the known or unknown recovery rate of the site. As an alternative, monitoring methods that utilize lower cost bioavailability measures such as passive samplers, cage organisms, or laboratory exposures as initial proxies for recovery could be used in an adaptive framework to guide decisions on when fish sampling or other complex monitoring events should take place. Questions to be answered by this research are:

- What are optimal strategies to reduce monitoring costs through composite/incremental sampling methods?
- How can lower cost bioavailability measures be integrated with higher trophic level sampling events in an adaptive framework that would reduce monitoring costs?

3.5.3 Demonstration of Noninvasive, Safer Methods for Monitoring the Physical and Chemical Integrity of Remedy (Critical Priority Demonstration)

Demonstration work is needed is to provide noninvasive, safer methods for monitoring, such as passive sampling and other techniques, to help site managers easily select which methods are most appropriate for their needs. For example, advancements in monitoring methods are needed to use passive samplers in armored caps, to reduce the need for diver deployments, and to compress the time for deployments from weeks to days. Diver-assisted monitoring is associated with increased costs as well as significant safety risks. More advanced development and demonstration of additional diverless monitoring tools, including those that may use physical-chemical characteristics (e.g., vertical profiles of grain size; e.g., Chadwick et al., 2014) to assess the cap integrity or other performance metrics of a given remedy are included in this need.

Questions to be answered by this demonstration work are:

- How do we broaden the use and proper application of bioavailability-based samplers to improve monitoring outcomes for remedy effectiveness?
- How can our monitoring tools be advanced to work under a broader range of conditions (e.g., armored caps, amended caps) while minimizing cost to the monitoring program?
- Can we incorporate monitoring access directly into the remedy design in a way that improves monitoring without sacrificing remedy effectiveness?
- Are there more automated or in-place instrumentation that can be integrated into our remedies that would support better monitoring outcomes?
- Can we incorporate monitoring methods that minimize, self-heal, or otherwise repair potential impacts to the remedy associated with the monitoring activities themselves?

3.5.4 Demonstration of EMNR as a Cost-Effective In Situ Remedial Alternative (Critical Priority Demonstration)

Pilot studies are needed that further demonstrate the value of EMNR. There is tremendous potential cost-benefit of EMNR through coordination among navigational dredging, cleanup, compliance, restoration, and ecosystem recovery activities at sites. For example, natural sediments that are uncontaminated but have a greater potential to sequester organic contaminants than clean sand may be available from navigational dredging operations, providing a cost effective and potentially better source for thin-layer capping that can be assessed by LTM.

A question to be answered by these studies is how should EMNR be monitored in a relatively dynamic system where the EMNR cover is not intended as a permanent isolation cap and instead serves to accelerate MNR through rapid sedimentation, surface sediment dilution, and reduced surface sediment biological exposures?

3.5.5 Develop Monitoring Guidance and Case Studies to Support Long Term Remedy Effectiveness Assessments (Critical Priority Technology Transfer)

The U.S. Navy is evaluating methods to monitor EMNR under the ESTCP project ER-201368 (e.g., Chadwick et al., 2013, Chadwick et al., 2014, Rosen et al., 2016). This demonstration project has involved multiple pre- and post-remedy monitoring events incorporating a suite of traditional and recently advanced physical, chemical, and biological measurements at regular intervals.

Site managers are expected to orchestrate a broad array of specialized technical expertise to successfully craft and implement remedies and outside expertise can be limited in availability. Developing guidance on how to determine and apply appropriate statistical methods for designing LTM to assess remedy effectiveness across a site that often contains a range of technology applications, physical conditions, and habitat utilization is needed to determine if selected remedies can meet the RAOs. Guidance is needed on improved statistical approaches for long-term monitoring, including how best to use surface-weighted concentration assessments, and appropriate statistics to compare different populations in the face of small differences between those populations, high data variability, or changes approaching long and extended asymptotic end points. Case studies identifying limitations and innovative methods in monitoring programs and the factors in risk assessment and development of RAOs critical to LTM design could be one part of guidance development.

Guidance on appropriate hypothesis testing to address a variety of endpoints, sampling methods, and RAOs also is needed. In particular, new methods like incremental sampling and other compositing methods lack accepted statistical approaches needed to allow approaches to address long-term monitoring goals. Development of these methods and how and when to incorporate them into LTM design could expand the ability to successfully test hypotheses that would improve assessment of remedy effectiveness.

Updated guidance and compilation of data from existing sites where EMNR was the selected remedy is identified as a critical priority technology transfer need. Specific needs include the following:

1. Initiate case studies to create a base of knowledge and experience for remedial managers for monitoring post-remediation remedy performance. Case studies may be based on leveraging against on-going programs, past experience, or may involve new projects, and can target in situ and ex situ remedies.
2. Develop improved guidance for long-term monitoring for remedial managers, site owners, and regulators to integrate monitoring methods, approaches to monitoring, and case studies. Monitoring guidance should focus on many of the aspects discussed in this section, including early monitoring, integrating monitoring goals at the RI/FS stage, cost effectiveness, adaptive sampling strategies, and exit strategies / site closure.

3.5.6 Overarching Monitoring Needs (High Priority Research and Demonstration)

Other over-arching monitoring needs identified by the work group included the following research and demonstration studies:

- Demonstrate noninvasive methods for monitoring the physical integrity of a remedy (e.g., innovative temperature or flow sensors).
- Develop improved statistical methods and approaches to design and evaluate long-term monitoring data for remedy effectiveness assessments. These may include such approaches as how best to use surface-weighted concentration assessments, and appropriate statistics to compare different populations in the face of small differences between those populations, high data variability, or changes approaching long and extended asymptotic end points.
- Further develop and demonstrate the use of statistical designs for composite sampling methods to address long-term monitoring goals and evaluate long term trends in environmental data.

4.0 CONCLUSIONS

Sediment contamination remains a significant liability for DoD. In particular, the Navy has 500 sediment sites, with an estimated cost-to-complete of over $800M. Contaminants at these sites include a wide variety of compounds such as PCBs, PAHs, various metals and metalloids, and military- unique compounds such as munitions constituents. SERDP and ESTCP have been conducting these planning meetings since 2004, and have used the work identified by Workshop participants to fund over 85 research and demonstration projects (Appendix A). Common issues across these Workshops have been risk characterization in setting cleanup goals, measurement and use of contaminant bioavailability, and monitoring approaches for and assessing the efficacy of in situ remedies (e.g., MNR, EMNR, amendment addition). Two additional topics addressed at this 2016 Workshop included managing stormwater to prevent sediment recontamination, and setting cleanup goals given climate change and sea level rise.

The result of this workshop is a strategic plan to guide SERDP and ESTCP investments in research and demonstration needs to support the acceptance of in situ remediation technologies for the long-term management of contaminated sediments over the next five to ten years, ultimately benefiting environmental restoration efforts at DoD sites.

In order to better integrate research, development, test, and evaluation efforts supported by SERDP and ESTCP, Workshop participants highlighted several overarching recommendations to guide future investments over the next 5 years, which are summarized in the following sections. These recommendations reflect high-priority DoD needs in the area of contaminated sediments. While some recommendations are technology-specific, others encompass numerous processes and technologies. Recommendations range from fundamental to applied.

4.1 Reducing the Impact of Stormwater Discharge on Sediment Recontamination

Stormwater discharge of contaminants remains the foremost critical challenge for protecting DoD investments in sediment cleanup as well as in the prevention of future contaminated sediment liabilities (SERDP & ESTCP, 2012). Stormwater control and treatment is at the nexus of this challenge, spanning virtually every DoD coastal site, and linked to every aspect of regulatory compliance.

Research needs identified focused on monitoring approaches that would link stormwater release to sediment benthic impairment and management practices that would limit or prevent those impacts. Demonstration needs included approaches to assess long-term performance of treatment technologies, as well as methods to enhance flow capacity during stormwater events. A state-of-the-science review of stormwater discharge and sediment recontamination was identified as an important technology transfer product.

4.2 Cleanup Actions and Navigation Dredging

Dredging has, and remains, the principal component of remedial actions at DoD sites (SERDP & ESTCP, 2012). In addition to dredging for remedial actions, the Navy dredges approximately 300

million cubic yards annually for navigation purposes (SERDP & ESTCP, 2004). Even with the considerable advances of in situ management of contaminated sediments, dredging and removal to upland facilities remains the principal remedial alternative for contaminated sediment management. Cost effective options for managing dredged contaminated and navigation sediments are limited. Dredging alternatives do not meet the Navy's own guidelines for green and sustainable remediation (NAVFAC, 2015).

Research needs identified were for sustainable dredging and disposal practices that could be applied to both maintenance and remedial dredging projects. Research and development of sustainable dredging equipment that utilize alternative fuel sources (e.g., natural gas) would lead to lower costs and greenhouse gas emissions. Sustainable disposal alternatives, including confined aquatic disposals, confined disposal facilities, beneficial reuse by thin-placing of dredged material, and addition of contaminant-binding amendments (e.g., activated carbon) to dredged material to allow for placement at open water disposal sites were discussed. In addition, two DoD unique, but critical priority, research and demonstration needs related to low-level radioactive commodities and/or munitions of explosive concern in dredged sediments were identified.

4.3 Emerging Contaminants-of-Concern in Sediments

Emerging contaminants were defined as any chemical or physical particle that to date has not been monitored at contaminated sediment sites, but have the potential to cause adverse environmental impacts.

Emerging contaminants that are identified before beginning site investigations can be incorporated into the RI/FS process, but for those identified after a cleanup decision has been made and implemented are unique challenges. The principal emerging contaminants discussed included PFASs, 1,4-dioxane, low-level radioactive commodities, pesticides, SCCPs, and fuel additives. PFASs, low-level radioactive commodities, and pesticides are currently issues at DoD sediment sites.

Research needs principally related to developing robust analytical methods (quantification), assessing contaminant fate and transport, understanding ecological risks to aquatic organisms, and developing remedial alternatives or disposal options for sites where emerging contaminants are identified as an environmental health risk. The need to be able to quantify cumulative risks associated with complex contaminant mixtures with PFASs or pesticides (e.g., DDx) were called out as a research and demonstration need. Identification, ecological risks, and disposal alternatives for sediments with low-level radiological commodities also was identified as a specific research and demonstration need.

4.4 Increasing Confidence in Sediment Cleanup Levels

Sediment CULs are the contaminant concentrations in sediment to be achieved through sediment remediation. When establishing numeric cleanup levels at sites with sediments contaminated with persistent hydrophobic compounds, such as PCBs, the goal is generally to reduce predicted risks to human and ecological health from consumption of contaminated fish. "Protective" fish tissue levels (i.e., fish tissue concentrations that do not pose unacceptable risks of cancer or other health

effects) are derived based on a site-specific risk assessment process, and sediment CULs are set on the presumption that the fish tissue levels will then be reduced to levels that are protective of human health. FWMs have typically been used to set CULs, but these have high degrees of uncertainty and there has not been any post hoc analyses to validate (or invalidate) the FWM-predicted CULs achieved the intended result. At many sites, risk-based levels for persistent hydrophobic contaminants fall below "background" concentrations, so increasingly background levels are adopted as site-specific sediment cleanup levels.

Research and demonstration needs were identified as relating to (1) methods for determining CULs, (2) improving the ability of FWM to set CULs, and (3) research and guidance on setting site background levels. Research needs on CULs included developing methods to set porewater CULs from passive sampling measures, while relying on additional work to standardized passive sampling measures, and correlating those measures to uptake in aquatic organisms. Improvements to FWM could occur with additional research to improve input variables to the models, and by a post hoc analyses of predictions versus outcomes after remediation. A critical priority technology transfer need was to develop a best practices guidance to set background levels.

4.5 Monitoring Remedy Effectiveness

Performance monitoring of a sediment remedy is an integral component of the remediation process to verify and document remedy effectiveness and permanence. Monitoring approaches are needed to inform site managers whether the selected remedies are working. Post remedial monitoring is typically considered after the remedy evaluation and selection process is complete. Tools and processes are needed to initiate monitoring at the beginning of the site characterization and remedy evaluation process and carry through remediation to post-remediation monitoring. Given that a primary driver at many contaminated sediments sites is the risk of consumption of contaminated biota (e.g., fish, shellfish), different endpoints within the site specific food web are likely to provide measureable change at different time scales.

Research needs identified focused on the need to understand and develop alternative measures (e.g., passive samplers) that would serve as indicators for changes in fish or other biological indicators chemical concentrations. This workgroup also noted the need for improvements to FWMs, and for post hoc analyses of predictions versus outcomes after remediation. An additional research need is the ability to deploy these monitoring tools at lower cost, with safer operations and faster turn-around times for the data. Improved understanding of EMNR as a remedial alternative was identified as a critical priority and continuing demonstration need. In addition, a monitoring guidance document with case studies to support long term remedial monitoring was noted as a critical priority technology transfer need.

5.0 REFERENCES

Ahrens, L. 2011. Polyfluoroalkyl compounds in the aquatic environment: a review of their occurrence and fate. *Journal of Environmental Monitoring* 13: 20-31.

Anderson BS, Phillips BM, Hunt JW, Clark SL, Voorhees, JP, Tjeerdema RS, Casteline J, Stewart M, Crane D, Mekebri A. 2010. Evaluation of methods to determine causes of sediment toxicity in San Diego Bay, California, USA. Ecotoxicol. Environ. Saf. 73:534-540.

Chadwick et al., 2013. Demonstration and Validation of Enhanced Monitored Natural Recovery at Department of Defense Sediment Sites. Environmental Security Technology Certification Program (ESTCP) Project ER-201368. https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Sediments/ER-201368/ER-201368/(language)/eng-US

Chadwick et al., 2014. Demonstration of an In Situ Friction-Sound Probe for Mapping Particle Size at Contaminated Sediment Sites. Space and Naval Warfare Systems Center Pacific (SSC Pacific) Technical Report #2040. 61 pp. https://www.serdp-estcp.org/content/download/28241/278679/file/ER-200919-FR.pdf

Fadaei, H, A Watson, A Place, J Connolly, and U Ghosh. 2015. Effect of PCB Bioavailability Changes in Sediments on Bioaccumulation in Fish. *Environ. Sci. Technol.* 49:12405–12413.

IAEA, 2015a. Annex 9. 2015 Guidelines for the Application of the *De Minimis* Concept under the London Convention and Protocol. IAEA-LC 37/16, IAEA, Vienna (2015).

IAEA, 2015b. Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure. IAEA-TECDOC-1759, IAEA, Vienna (2015). Available online at http://www-pub.iaea.org/books/IAEABooks/10841/Determining-the-Suitability-of-Materials-for-Disposal-at-Sea-under-the-London-Convention-1

Internal Joint Commission (IJC). 2016. Preliminary International Joint Commission Recommendations on Microplastics in the Great Lakes. http://ijc.org/files/publications/IJC_Preliminary_Recommendaitons_%20Microplastics_in_GL_Draft.pdf. Accessed 24 October 2016.

Moore, D., B. Chadwick, and V. Magar. 2015. Maintenance vs Environmental Dredging at US Navy Installations. Parallel Universes? Navigating the Wormhole. Proceedings of *Dredging 2015* conference. http://dredging2015.pianc.us/docs/Proceedings/6B_Session-_Spadaro_moderator/6B1-_Moore-_Maintenance_vs_Environmental_Dredging_at_US_Navy_Installations_Parallel_Universes_Navigating_the_Wormhole%20.pdf

NAVFAC. 2015. *Sustainable Sediment Remediation*. Naval Facilities Engineering Command, Engineering and Expeditionary Warfare Center. Technical Report. TR-NAVFAC EXWC-EV-1515.

http://www.navfac.navy.mil/content/dam/navfac/Specialty%20Centers/Engineering%20and%20Expeditionary%20Warfare%20Center/Environmental/Restoration/er_pdfs/s/navfacexwc-ev-tr-1515-sustainable-sed-wp-2015.pdf

NAVFAC. 2002. *Contaminated Sediments at Navy Facilities: Cleanup Alternatives*. Naval Facilities Engineering Command Tech Data Sheet. TDS-2092-ENV. December 2002. https://clu-in.org/download/contaminantfocus/sediments/contaminated-sed-at-navy-facilities-tds-2092-sed.pdf

NAVFAC. 2015. Sustainable Sediment Remediation. Naval Facilities Engineering Command Technical Report. TE-NAVFAC EXWC-EV- 1515. September 2015. https://clu-in.org/download/contaminantfocus/sediments/Sediment-EV- TR-1515- 2015.pdf

Palermo, M., and D. Hays, 2014. Sediment Dredging, Treatment and Disposal. ***In*** (D. Reible, editor). *Processes, Assessment and Remediation of Contaminated Sediment*. SERDP and ESTCP Remediation Technology Monograph Series. Springer Science+Business Media, NY. x*l* + 462 pp.

PSEMP 2016. Puget Sound Ecosystem Monitoring Program. https://sites.google.com/a/psemp.org/psemp/

Rosen et al., 2016. Demonstration and Commercialization of the Sediment Ecosystem Assessment Protocol (SEAP). Environmental Security Technology Certification Program (ESTCP) Project #ER-201130. Draft Final Report Submitted July 2016. https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Sediments/ER-201130.

Sauve, S., and M. Desrosiers, 2014. A review of what is an emerging contaminant. Chemistry Central Journal 8: 15. Published online 2014 Feb 26. doi: 10.1186/1752-153X-8-15. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3938815

SERDP and ESTCP. 2004. Expert Panel Workshop on Research and Development Needs for the In Situ Management of Contaminated Sediments. SERDP & ESTCP, Alexandria, VA. http://serdp-estcp.org/content/download/8048/99399/version/1/file/SedimentsFinalReport.pdf.

SERDP and ESTCP, 2012. SERDP and ESTCP Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments. SERDP & ESTCP, Alexandria, VA. https://serdp-estcp.org/content/download/16022/182923/version/3/file/Sediment+Workshop+Report_October+2012.pdf

Townsend, A. 2015. Corps Studies Contaminated Sediment Treatment with Activated Carbon. International Dredging Review. November-December 2015. http://www.dredgemag.com/November-December-2015/Corps-Studies-Contaminated-Sediment-Treatment-with-Activated-Carbon/

USEPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-

540-R-05-012. http://semspub.epa.gov/src/document/HQ/174471 . Accessed 29 September 2016.

USEPA. 2009. Short-Chain Chlorinated Paraffins (SCCPs) and Other Chlorinated Paraffins Action Plan. U.S. Environmental Protection Agency. December 2009. https://www.epa.gov/sites/production/files/2015-09/documents/sccps_ap_2009_1230_final.pdf Accessed October 3, 2016.

USEPA. 2013. *Use of Amendments for In Situ Remediation at Superfund Sediment Sites*. OSWER Directive 9200.2-128FS. US Environmental Protection Agency Office of Solid Waste and Emergency Response. https://semspub.epa.gov/work/HQ/174766.pdf.

USEPA. 2015. *Summary of Expert Discussion Forum on Possible Human Health Risks from Microplastics in the Marine Environment.* EPA Forum convened April 23, 2014. U.S. Environmental Protection Agency, Marine Pollution Control Branch, Office of Wetlands, Oceans and Watersheds. February 6, 2015, https://www.epa.gov/sites/production/files/2015-02/documents/trash_free_waters_microplastics_expert_forum_meeting_summary_2-6-15.pdf Accessed October 1, 2016.

Vierke, L., C. Staude, A Biegel-Engler, W. Drost, and C. Schulte. 2012. Perfluorooctanoic acid (PFOA) — main concerns and regulatory developments in Europe from an environmental point of view. *Environmental Sciences Europe* 24:16. https://enveurope.springeropen.com/articles/10.1186/2190-4715-24-16

Whelp, T., G. Follett, M. Crull, and C. Pollock, 2008. Dredging in Sediments Containing Munitions and Explosives of Concern (MEC). Environmental Security Technology Certification Program and Dredging Operations and Environmental Research Program. ESTCP Project No 200321. ERDC/CHL TR-08-12. August 2008. Available on the web at http://www.dtic.mil/dtic/tr/fulltext/u2/a486382.pdf. Accessed 29 September 2016.

APPENDIX A

SERDP and ESTCP-Related Projects

SERDP and ESTCP Sediment-Related Projects

Project Number (where "–xx" = year of initiation for SERDP projects or ER-xxxxyy = year of initiation for ESTCP projects), Project Title, Lead Investigator, (Program), (Status)

Fate and Transport

ER-201432, Demonstration of New Tools for Improved Source and Recontamination Potential Assessment, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (ESTCP) (In Progress)

ER-2124-11, TNT Incorporation and Mineralization by Natural Microbial Assemblages at Frontal Boundaries Between Water Masses and in Underlying Sediments in Coastal Ecosystems, Mike Montgomery (U.S. Naval Research Laboratory) (SERDP) (In Progress)

ER-2123-11, Photochemical Transformation of Munitions Constituents in Marine Waters, Dianne Luning Prak (U.S. Naval Academy) (SERDP) (Complete)

ER-2122-11, Tracking the Uptake, Translocation, Cycling, and Metabolism of Munitions Compounds in Coastal Marine Ecosystems Using Stable Isotopic Tracer, Craig Tobias (University of Connecticut) (SERDP) (In Progress)

ER-201031, Evaluation of Resuspension from Propeller Wash, Dredging and Extreme Storm Events in DoD Harbors, PF Wang (U.S. Navy SPAWAR Systems Center) (ESTCP) (In Progress)

ER-1495-06, Modeling and Decision Support Tools Based on the Effects of Sediment Geochemistry and Microbial Populations on Contaminant Reactions in Sediments, Jeanne vanBriesen (Carnegie Mellon University) (SERDP) (Complete)

ER-1453-05, Defining Munitions Constituents (MC) Source Terms in Aquatic Environments on DoD Ranges, Bill Wild (U.S. Navy SPAWAR Systems Center) (SERDP) (Complete)

ER-1431-05, Biotic and Abiotic Attenuation of Nitrogenous Energetic Compounds (NEC) in Coastal Waters and Sediments, Mike Montgomery (U.S. Naval Research Laboratory) (SERDP) (Complete)

ER-1209-01, Pathway Interdiction: A System for Evaluating and Ranking Sediment Contaminant Transport Pathways In Support of In-Place Management, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (SERDP) (Complete)

Site Characterization and Monitoring

ER-2537-15, Remedy and Recontamination Assessment Array, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (SERDP) (In Progress)

ER-201214, Demonstration of Fluorescent Magnetic Particles for Linking Sources to Sediments at DoD Sites, Jim Leather (U.S. Navy SPAWAR Systems Center) (ESTCP) (In Progress)

ER-201128, Microelectrode Observatory for In Situ Monitoring of Metals Concentration and Mobility in Contaminated Sediments, Nancy Ruiz (NAVFAC ESC) (ESTCP) (In Progress)

ER-200919, Demonstration of an In Situ Friction-Sound Probe for Mapping Particle Size at Contaminated Sediment Sites, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

ER-200826, Integrated Forensics Approach to Fingerprint PCB Sources using Rapid Screening Characterization (RSC) and Advanced Chemical Fingerprinting (ACF), Jim Leather (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

ER-1502-06, Application of Tools to Measure PCB Microbial Dechlorination and Flux into Water during In Situ Treatment of Sediments, Joel Baker (University of Maryland) (SERDP) (Complete)

ER-1497-06, Develop Accurate Methods for Characterizing and Quantifying Cohesive Sediment Erosion under Combined Current-Wave Conditions, Joe Gailani (U.S. Army ERDC-EL) (SERDP) (Complete)

ER-200422, Monitoring of Water and Contaminant Migration at the Groundwater-Surface Water Interface, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

ER-199717, Rapid Sediment Characterization, James M. Leather (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

ER-199712, Quantifying In Situ Contaminant Mobility in Marine Sediments, Brad Davidson (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

Passive Samplers

ER-2543-15, Nanofiber-Enabled, Multi-Target Passive Sampling Device for Determination of the Freely-Dissolved Sediment Pore Water Concentrations of Organic Contaminants, Andres Martinez (The University of Iowa) (SERDP) (In Progress)

ER-2542-15, Optimization of Integrative Passive Sampling Approaches for Use in the Epibenthic Environment, Jason Belden (Oklahoma State University) (SERDP) (In Progress)

ER-2541-15, Multipurpose Sediment Passive Sampler with Improved Tissue Mimicry to Measure the Bioavailable Fraction, Paul Edmiston (ABS Materials, Inc.) (SERDP) (In Progress)

ER-2540-15, Actively Shaken In Situ Passive Sampler Platform for Methylmercury and Organics, Upal Ghosh (University of Maryland Baltimore County) (SERDP) (In Progress)

ER-2539-15, Development of an In Situ Passive Sampler for the Detection and Remediation of Explosive Compounds, Penny Vlahos (University of Connecticut) (SERDP) (In Progress)

ER-2538-15, Development of a Passive Multisampling Method to Measure Dioxins/Furans and Other Contaminant Bioavailability in Aquatic Sediments, Rainier Lohmann (University of Rhode Island) (SERDP) (In Progress)

ER-201433, Validation of Passive Sampling Devices for Monitoring of Munitions Constituents in Underwater Environments, Gunther Rosen (U.S. Navy SPAWAR Systems Center) (ESTCP) (In Progress)

ER-201431, Integrated Passive Sampler-Food Web Modeling Framework for Monitoring Remedy Effectiveness, Philip Gschwend (Massachusetts Institute of Technology) (ESTCP) (In Progress)

ER-2431-14, Quantitative Thermodynamic Exposure Assessment (Q-TEA) Supporting Resilient Contaminated Sediment Site Restoration, Todd Bridges (U.S. Army ERDC) (SERDP) (In Progress)

ER-2429-14, Combining Mass Balance Modeling with Passive Sampling at Contaminated Sediment Sites to Evaluate Continuing Inputs and Food Web Responses to Remedial Actions, Philip Gschwend (Massachusetts Institute of Technology) (SERDP) (In Progress)

ER-201216, Sediment Bioavailability Initiative (SBI): Development of Standard Methods and Approaches for the Use of Passive Samplers in Assessment and Management of Contaminated Sediment, Charlie Menzie (Exponent) (ESTCP) (In Progress)

ER-200915, Passive PE Sampling in Support of In Situ Remediation of Contaminated Sediments, Philip Gschwend (Massachusetts Institute of Technology) (ESTCP) (Complete)

ER-1496-06, Using Passive Polyethylene Samplers to Evaluate Chemical Activities Controlling Fluxes and Bioaccumulation of Organic Contaminants in Bed Sediments, Philip Gschwend (Massachusetts Institute of Technology) (SERDP) (Complete)

Bioavailability of Contaminants

ER-1771-10, Assessing Mercury and Methylmercury Bioavailability in Sediment Porewater Using Mercury-Specific Hydrogels, Victor Magar (ENVIRON) (SERDP) (Complete)

ER-1750-10, The Biology of Bioavailability: The Role of Functional Ecology in Exposure Processes, Todd Bridges (U.S. Army ERDC-EL) (SERDP) (In Progress)

ER-1749-10, Verifying Food Web Bioaccumulation Models by Tracking Fish Exposure and Contaminant Uptake, Karl Gustavson (U.S. Army ERDC) (SERDP) (Complete)

ER-1748-10, Development of an Electrochemical Surrogate for Copper, Lead, and Zinc Bioaccessibility in

Aquatic Sediments, Aaron Slowey (U.S. Geological Survey) (SERDP) (Complete)

ER-1747-10, Robust Means for Estimating Black Carbon-Water Sorption Coefficients of Organic Contaminants in Sediments, Philip Gschwend (Massachusetts Institute of Technology) (SERDP) (Complete)

ER-1746-10, Predicting the Fate and Effects of Resuspended Metal Contaminated Sediments, Allen Burton (University of Michigan) (SERDP) (In Progress)

ER-1745-10, Coupling between Pore Water Fluxes, Structural Heterogeneity & Biogeochemical Processes Controls Contaminant Mobility, Bioavailability, & Toxicity in Sediments, Aaron Packman (Northwestern University) (SERDP) (In Progress)

ER-1744-10, Bioavailability and Methylation Potential of Mercury Sulfides in Sediments, Heileen Hsu-Kim (Duke University) (SERDP) (Complete)

ER-200916, Validation of an In Vitro Bioaccessibility Test Method for Estimation of Bioavailability of Arsenic from Soil and Sediment, Susan Griffin (U.S. EPA) (ESTCP) (Complete)

ER-200709, The Determination of Sediment Polycyclic Aromatic Hydrocarbon (PAH) Bioavailability using Supercritical Fluid Extraction (SFE) and Ultra-Trace Porewater (UTP) Analysis, Dave Nakles (RETEC) (ESTCP) (Complete)

ER-200624, Demonstration and Evaluation of Solid Phase Microextraction for the Assessment of Bioavailability and Contaminant Mobility, Danny Reible (University of Texas) (ESTCP) (Complete)

ER-1503-06, Biological Processes Affecting Bioaccumulation, Transfer, and Toxicity of Metal Contaminants in Estuarine Sediments, Celia Chen (Dartmouth College) (SERDP) (Complete)

ER-1494-06, An Integrated Field and Laboratory Study of the Bioavailability of Metal Contaminants in Sediments, Nick Fisher (Stonybrook University) (SERDP) (Complete)

ER-1095-98, Assessment & Prediction of Biostabilization of PAHs in Sediment, Jeff Talley (U.S. Army ERDC-EL) (SERDP) (Complete)

ER-1081-98, Genosensor-Based Ecotoxicity Response Assessment, Kenneth Beattie (Oak Ridge National Laboratory) (SERDP) (Complete)

In Situ Treatment

Amendments

ER-201639, Application of an In Situ PCB Removal Technique for Contaminated Sediments, Joey Trotsky (Naval Facilities Engineering Command) (ESTCP) (In Progress)

ER-201580, Long-Term Stability and Efficacy of Historic Activated Carbon (AC) Deployments at Diverse Freshwater and Marine Remediation Sites, Todd Bridges (U.S. Army ERDC) (ESTCP) (In Progress)

ER-201215, Evaluating the Efficacy of Bioaugmentation for In Situ Treatment of PCB Impacted Sediments, Kevin Sowers (University of Maryland, Baltimore County) (ESTCP) (In Progress)

ER-201131, Demonstration of In Situ Treatment with Reactive Amendments for Contaminated Sediments in Active DoD Harbors, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (ESTCP) (In Progress)

ER-2136-11, Activated Biochars with Iron for In Situ Sequestration of Organics, Metals, and Carbon, Upal Ghosh (University of Maryland, Baltimore County) (SERDP) (Complete)

ER-2135-11, Application of Biofilm Covered Activated Carbon Particles as a Microbial Inoculum Delivery System for Enhanced Bioaugmentation of PCBs in Contaminated Sediment, Birthe Kjellerup (University of Maryland, College Park) (SERDP) (In Progress)

ER-2134-11, A Permeable Active Amendment Concrete (PAAC) for Contaminant Remediation and Erosion Control, Anna Knox (Savannah River National Laboratory) (SERDP) (Complete)

ER-200835, Evaluating the Efficacy of a Low-Impact Delivery System for In Situ Treatment of Sediments Contaminated with Methylmercury and Other Hydrophobic Chemicals, Charlie Menzie (Exponent) (ESTCP) (Complete)

ER-200825, In Situ Wetland Restoration Demonstration, Amy Hawkins (NAVFAC ESC) (ESTCP) (Complete)

ER-1492-06, Quantifying Enhanced Microbial Dehalogenation Impacting the Fate and Transport of Organohalide Mixtures in Contaminated Sediments, Max Haggblom (Rutgers University) (SERDP) (Complete)

ER-1491-06, Rational Selection of Tailored Amendment Mixtures and Composites for In Situ Remediation of Contaminated Sediments, Upal Ghosh (University of Maryland, Baltimore County) (SERDP) (Complete)

ER-200510, Field Testing of Activated Carbon Mixing and In Situ Stabilization of PCBs in Sediment, Dick Luthy (Stanford University) (ESTCP) (Complete)

ER-1207-01, In Situ Stabilization of Persistent Organic Contaminants in Marine Sediments, Dick Luthy (Stanford University) (SERDP) (Complete)

ER-1208-01, In Situ Enhancement of Anaerobic Microbial Dechlorination of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans in Marine and Estuarine Sediments, Max Haggblom (Rutgers University) (SERDP) (Complete)

Active Caps

ER-2427-14, Understanding the Relationships Among Low Level Metal Influx, Remediated Sediments, ad Biological Receptors, Anna Knox (Savannah River National Laboratory) (SERDP) (In Progress)

ER-1501-06, Innovative In Situ Remediation of Contaminated Sediments for Simultaneous Control of Contamination and Erosion, Anna Knox (Savannah River National Laboratory) (SERDP) (Complete)

ER-1493-06, Reactive Capping Mat Development and Evaluation for Sequestering Contaminants in Sediments, Amy Hawkins (NAVFAC ESC) (SERDP) (Complete)

ER-1371-04, Integrating Uncertainty Analysis in the Risk Characterization of In-Place Remedial Strategies for Contaminated Sediments, Peter Adriaens (University of Michigan) (SERDP) (Complete)

ER-1370-04, Characterization of Contaminant Migration Potential through In-Place Sediment Caps, Bruce Sass (Battelle) (SERDP) (Complete)

Monitored Natural Recovery

ER-200827, Demonstration and Validation of Enhanced Monitored Natural Recovery at DoD Sites, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

ER-200622, Development of DoD Guidance for Monitored Natural Recovery at Contaminated Sediment Sites, Victor Magar (ENVIRON) (ESTCP) (Complete)

Ecological Risk Characterization

ER-2428-14, Assessment and Management of Stormwater Impacts on Sediment Recontamination, Danny Reible (Texas Tech University) (SERDP) (In Progress)

ER-201130, Demonstration and Commercialization of the Sediment Ecosystem Assessment Protocol (SEAP), Gunther Rosen (U.S. Navy SPAWAR Systems Center) (ESTCP) (In Progress)

ER-2125-11, Ecological Risk Assessment of Munitions Compounds on Coral and Coral Reef Health, Cheryl Woodley (NOAA) (SERDP) (Complete)

ER-1551-07, Bacterial and Benthic Community Response to Inorganic and Organic Sediment Amendments, Yolanda Arias-Thode (U.S. Navy SPAWAR Systems Center) (SERDP) (Complete)

ER-1552-07, Measurement and Modeling of Ecosystem Risk and Recovery for In Situ Treatment of Contaminated Sediments, Dick Luthy (Stanford University) (SERDP) (In Progress) (Complete)

ER-1550-07, Sediment Ecosystem Assessment Protocol (SEAP): An Accurate and Integrated Weight-of-Evidence Based System, Allen Burton (University of Michigan) (SERDP) (Complete)

ER-200523, Demonstration of an Integrated Compliance Model for Predicting Copper Fate and Effects in DoD Harbors, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (ESTCP) (Complete)

ER-1158-00, Speciation, Sources and Bioavailability of Copper and Zinc in DoD-Impacted Harbors and Estuaries, Martin Shafer (University of Wisconsin) (SERDP) (Complete)

ER-1157-00, Speciation, Fluxes, and Cycling of Dissolved Copper and Zinc in Estuaries: The Roles of Sediment Exchange and Photochemical Effects, Stephen Skrabal (University of North Carolina) (SERDP) (Complete)

ER-1156-00, Determining the Fate and Ecological Effects of Copper and Zinc Loading in Estuarine Environments: A Multi-Disciplinary Program, Bart Chadwick (U.S. Navy SPAWAR Systems Center) (SERDP) (Complete)

ER-1129-99, Biological Assessment for Characterizing Contaminant Risk of Military Unique Compounds at the Genetic-, Individual-, Population-Level, Todd Bridges (U.S. Army ERDC-EL) (SERDP) (Complete)

Munitions Constituents

ER-2125-11, Ecological Risk Assessment of Munitions Compounds on Coral and Coral Reef Health, Cheryl Woodley (NOAA) (SERDP) (Complete)

ER-2124-11, TNT Incorporation and Mineralization by Natural Microbial Assemblages at Frontal Boundaries Between Water Masses and in Underlying Sediments in Coastal Ecosystems, Mike Montgomery (U.S. Naval Research Laboratory) (SERDP) (In Progress)

ER-2123-11, Photochemical Transformation of Munitions Constituents in Marine Waters, Dianne Luning Prak (U.S. Naval Academy) (SERDP) (Complete)

ER-2122-11, Tracking the Uptake, Translocation, Cycling, and Metabolism of Munitions Compounds in Coastal Marine Ecosystems Using Stable Isotopic Tracer, Craig Tobias (University of Connecticut) (SERDP) (In Progress)

ER-1453-05, Defining Munitions Constituents (MC) Source Terms in Aquatic Environments on DoD Ranges, Bill Wild (U.S. Navy SPAWAR Systems Center) (SERDP) (Complete)

ER-1431-05, Biotic and Abiotic Attenuation of Nitrogenous Energetic Compounds (NEC) in Coastal Waters and Sediments, Mike Montgomery (U.S. Naval Research Laboratory) (SERDP) (Complete)

ER-1129-99, Biological Assessment for Characterizing Contaminant Risk of Military Unique Compounds at the Genetic-, Individual-, Population-Level, Todd Bridges (U.S. Army ERDC-EL) (SERDP) (Complete)

APPENDIX B

Meeting Agenda

Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments

August 9 – 10, 2016
Seattle, WA

TUESDAY, AUGUST 9, 2016			
0800	**Registration & Coffee/Tea Service**		
0830	**Welcome and Introduction** **Workshop Objectives and Structure**	Andrea Leeson SERDP and ESTCP	
0845	SERDP and ESTCP Thirty Years of Sediment Management Research and Development • Sediment Project List • Pre-Meeting Identified Research and Technology Transfer Needs	Andrea Leeson SERDP/ESTCP	Tim Thompson SEE LLC
0900	Welcome	Lt. Colonel Park USACE Seattle	
0915	Case Studies: Challenges and Lessons Learned in Sediment Remediation	Kristen Kerns & Marlowe Laubach USACE Seattle	
0945	Sediment Site Restoration: Current Status and Barriers to Achieving those Goals – Regulatory Perspective	Kevin Parrett & Sarah Greenfield Oregon DEQ	
1015	**Coffee Break**		
1030	National Perspective on Sediment Restoration Technologies	Young Chang U.S. EPA	
1050	RPM Perspective on Sediment Restoration • Data Needs to Guide Selection of a Restoration Alternative • Science and Demonstration Needs for In Situ Remedy Selection • Engineering and Cost Considerations for Sediment Restoration	Kim Markillie NAVFAC Pacific	
1110	Recontamination Potential for Remediated Sediment Sites	Bob Johnston SPAWAR	
1130	Sustainability Considerations in Sediment Management	Victor Magar Ramboll ENVIRON	
1150	**Lunch**		
1300	**Breakout Session I Discussions** • Reducing Impact of Stormwater Discharge on Sediment Recontamination • Cleanup Actions and Navigation Dredging • Emerging Contaminants-of-Concern in Sediments • Increasing Confidence in Sediment Cleanup Levels • Monitoring Remedy Effectiveness	Breakout Groups	
1500	**Refreshment Break**		
1515	**Breakout Session I Discussions (Continued)**	Breakout Groups	
1600	Recap of Day/Overview for Next Day	Andrea Leeson SERDP and ESTCP	
1615	**Meeting Adjourn**		

WEDNESDAY, AUGUST 10, 2016		
0830	**Coffee/Tea Service**	
0900	Report from Breakout Session I	Breakout Session Chairs
1030	**Coffee Break**	
1045	**Breakout Session II Discussions** • Data Gaps & Priority Ranking	Breakout Groups
1230	**Lunch**	
1330	**Breakout Session II Discussions (Continued)**	Breakout Groups
1500	**Refreshment Break**	
1515	Reports from Breakout Session II	Breakout Session Chairs
1700	Closing Summary and Remarks	Andrea Leeson SERDP and ESTCP
1715	**Workshop Adjourn**	

APPENDIX C

Attendee List

Name		Organization	DAY 1 Breakout Group	DAY 2 Breakout Group
Last	First			
Anderson	Kym	USACE Seattle District	**Cleanup/Navigation (C)**	**Cleanup/Navigation (C)**
Ashoori	Negin	Stanford	Stormwater	Stormwater
Aylward	Michelle	Naval Base Kitsap	Stormwater	Stormwater
Bachman	Brenda	U.S. EPA	**Emerging Contaminants (C)**	**Emerging Contaminants (C)**
Bireta	Paul	Chevron	Cleanup/Navigation	Remedy Effectiveness
Brandenberger	Jill	Pacific Northwest National Laboratory	Stormwater	Stormwater
Bridges	Todd	USACE ERDC	Remedy Effectiveness	Cleanup/Navigation
Brown	Kim Parker	NAVFAC HQ	Cleanup/Navigation	Cleanup Levels
Brown	Ellen	NAVFAC - NW	Cleanup Levels	Cleanup/Navigation
Chang	Young	USEPA Region 2 - Grasse River	Remedy Effectiveness	Cleanup/Navigation
Cieniawski	Scott	Great Lakes National PO	Cleanup/Navigation	Remedy Effectiveness
Coghlan	Gunarti	NAVFAC HQ	Emerging Contaminants	Stormwater
Cook	Anna-Marie	EPA Region 9 - Marine Debris	Emerging Contaminants	Emerging Contaminants
Fuglevand	Paul	Dalton, Olmsted, Fuglevand Engineers	Cleanup/Navigation	Cleanup/Navigation
Gala	William	Chevron	Remedy Effectiveness	Cleanup/Navigation
Ghosh	Upal	University of Maryland Baltimore County	Cleanup Levels	Emerging Contaminants
Ginn	Dina	NAVFAC - NW	Remedy Effectiveness	Emerging Contaminants
Greenberg	Marc	USEPA Superfund	Emerging Contaminants	Remedy Effectiveness
Greenfield	Sarah	Oregon DEQ	Cleanup Levels	Remedy Effectiveness
Gschwend	Phil	Massachusetts Institute of Technology	Cleanup Levels	Cleanup Levels
Gustavson	Karl	USACE ERDC	**Cleanup Levels (r)**	**Cleanup Levels (r)**
Hale	Elly	USEPA Region 10	Remedy Effectiveness	Stormwater
Hawkins	Amy	NAVFAC	Cleanup/Navigation	Emerging Contaminants
Johnston	Robert	Naval Base Kitsap	Stormwater	Remedy Effectiveness
Katz	Chuck	SPAWAR	Emerging Contaminants	Stormwater
Kerns	Kristen	USACE Seattle District	Cleanup Levels	Remedy Effectiveness
Kito	Melanie	NAVFAC SW	Cleanup/Navigation	Remedy Effectiveness
Kjellerup	Birthe	University of Maryland College Park	Emerging Contaminants	Emerging Contaminants
Kolodziej	Edward	University of Washington	Stormwater	Stormwater
Laubach	Marlowe	USACE	Cleanup/Navigation	Remedy Effectiveness
Leeson	Andrea	SERDP and ESTCP	unassigned	unassigned
Lohmann	Rainer	University of Rhode Island	Emerging Contaminants	Cleanup Levels
Luthy	Dick	Stanford	**Stormwater (C)**	**Stormwater (C)**
Magar	Victor	Ramboll Environ Inc	**Remedy Effectiveness (C)**	**Remedy Effectiveness (C)**
Markillie	Kim	NAVFAC - Pacific	Cleanup/Navigation	Stormwater
Michaelsen	Mandy	USACE ERDC	**Emerging Contaminants (r)**	**Emerging Contaminants (r)**
Miller	Jerry	USACE ERDC	Emerging Contaminants	Cleanup Levels
Mills	Marc	USEPA ORD	Remedy Effectiveness	Cleanup Levels
O'Brien	Allison	U.S. Army - Aberdeen RPM	Remedy Effectiveness	Remedy Effectiveness

Name		Organization	DAY 1 Breakout Group	DAY 2 Breakout Group
Last	First			
Parrett	Kevin	Oregon DEQ	Remedy Effectiveness	Cleanup Levels
Pitt	Robert	University of Alabama	Stormwater	Stormwater
Pound	Michael	U.S. Navy	---	Cleanup/Navigation
Reible	Danny	University of Texas Austin	Stormwater	Cleanup Levels
Rosen	Gunther	SPAWAR	**Remedy Effectiveness (r)**	**Remedy Effectiveness (r)**
Sheldrake	Sean	USEPA Region 10	Cleanup Levels	Stormwater
Sowers	Kevin	University of Maryland Baltimore County	Emerging Contaminants	Remedy Effectiveness
Stern	Jeff	King County	Remedy Effectiveness	Cleanup Levels
Thompson	Tim	SEE LLC	**Stormwater (r)**	**Stormwater (r)**
Trotsky	Joey	NAVFAC	Emerging Contaminants	Cleanup/Navigation
von Stackelberg	Katrina	NEK Associates	Cleanup Levels	Cleanup Levels
Wakeman	John	USACE Seattle District (retired)	Cleanup/Navigation	---
Webb	Rob	Dalton, Olmsted, Fuglevand Engineers	**Cleanup/Navigation (r)**	**Cleanup/Navigation (r)**
White	Patty	Battelle	Stormwater	Cleanup/Navigation

APPENDIX D

Problems Facing Remedial Managers at U.S. Navy Sites

1.0 Introduction

Pearl Harbor has a long history of munition use since the naval base was first established in 1899. Total of 235 ordnance-related structures have been constructed throughout the harbor; seven of which are on or near the waterfront. Since 1934, the naval magazine in West Loch has been the primary location for ordnance storage and handling for the military in the Pacific, and the West Loch channel and Whiskey Wharves are regularly used for ammunition conveyance, shipping and receiving. The 1941 Pearl Harbor attack included deployment of torpedoes, cannons, bombs and thousand rounds of machine gun ammunitions, some of which may not have been recovered from the harbor. Between 1991 and 2013, approximately 370 submerged munitions have been recovered from the harbor. Explosive Ordnance Disposal (EOD) incident reports document EOD emergency responses during dredging projects in West Loch and Middle Loch. The recovery and disposal of one 75 mm projectile and two 3 inch projectiles was documented during dredging operations in these areas. The largest munition discovered during screening of dredge materials is a 5-inch projectile.

For Pearl Harbor, any intrusive activities such as dredging requires an initial assessment of the potential for encountering munition of explosive concern (MEC) and/or material potentially presenting explosive hazard (MPPEH). In areas assessed as having high potential for MEC encounter based on historical ordnance-related activities or evidence of previous munition recoveries, an Explosives Safety Submission (ESS) must be prepared, submitted and approved by NOSSA in order to proceed with the intrusive work. The ESS must identify the type of munition with the greatest fragmentation distance (MGFD) and the response actions required to mitigate the hazard from the MGFD. For areas assessed as having low potential for MEC encounter, an ESS determination request letter documenting the justifications on why ESS is not required will need to be submitted and approved prior to starting the activities. Anomaly avoidance is also typically employed as part of the activity in addition to keep the potential for encountering munition to a minimum.

2.0 Dredging Procedures in Areas of High Potential for MEC/MPPEH Encounter

Dredging activities in areas of high potential for MEC need to consider the explosives safety requirements based on the identified MGFD. Currently in Pearl Harbor, the MGFD is identified as the 5-inch 38 caliber Mk 35 projectile based on type of munitions recovered from previous dredge material. For explosives safety purposes, dredging activity is divided into five phases:

- Dredging and transport of material in a barge to offload area
- Transfer of dredge material from barge to offload area for initial screening
- Transport of dredge material to CDF cell for stockpiling
- Screening for and removal of MEC from dredge stockpile in CDF
- Disposal of MEC-free dredge material to final disposal site

The following procedures were developed to mitigate the risk from potential detonation of the identified MGFD during the first four phases of dredging operation:

- Implement an exclusion zone (EZ) for public and non-essential personnel based on the potential blast radius of the MGFD (for the 5-inch projectile, EZ will be 343 feet on land and aboard vessels, and 483 feet for in-water).
- Shielding of essential personnel operating heavy machinery bullet resistant glass, plexi-glass, or lexan of specified thickness depending on the material selected.
- Maintain a minimum separation distance between essential personnel and potential detonation point to protect from blast overpressure hazard (for the 5-inch projectile = 45 feet or 33 with double hearing protection).

Initial screening of dredge material at the offload area was intended to screen out larger material and munitions, therefore effectively reducing the MGFD and the associated requirements for the subsequent phases of dredging operation. For Pearl Harbor, a 3-inch screen will be deployed which will remove all materials larger than 75 mm in diameter and still maintain reasonable rate of operation. The use of smaller screen although could reduce the size of the MGFD further, could potentially reduce the rate of work significantly as the screen would need to be cleared out frequently from clogging. The initial screening of dredge material result in replacing the MGFD from 5-inch projectile to a 40-mm projectile for transport the CDF and screening at the CDF phases. This significantly reduces the size of the EZ and the minimum separation distance required, as well as reducing the thickness requirement for shielding.

3.0 Screening and Removal of Munition from Dredge Material Stockpile

Dredged material stockpiled at the CDF will be screened for MEC prior to final disposal. Procedures for screening operations are presented in the ESS for MEC Removal at the Confined Disposal Facility (DON 2013). Screening for MEC will be done mechanically and manually. Mechanized screening operation will use an armored front-end loader for excavation, loading and stockpile of dredge material and a mobile 2-way trammel screener with a ¾ inch screen to separate potential MEC/MPPEH and other debris from dredge materials. Unexploded Ordnance (UXO)-certified technician will conduct the screening and removal of munitions from dredge material. Strict control of EZs, installation of shielding front-end loader and maintaining minimum required separation distance between UXO technician and excavator bucket would be employed to minimize risk from potential detonation. Manual screening will use a metal detector to detect any anomalies potentially representing MEC, and manual excavation of MEC in 8-inch lifts in either orientation (from side or top). Strict control of EZs, installation of shielding front-end loader and maintaining minimum required separation distance between UXO technician and excavator bucket would be employed to minimize risk from potential detonation.

3.1 MEC Inspection and Handling

If the UXO technicians identify a suspect MEC or MPPEH, screening operations will be temporarily stopped while the UXO technician inspects the item for the presence of explosives safety hazards. Items that pose an actual or potential explosive safety risk will be classified by the UXO technicians as MEC or MPPEH, record the GPS location and mark them in-place for inspection by a Senior UXO Supervisor (SUXOS) and the Unexploded Ordnance Safety Officer (UXOSO). Both SUXOS and UXOSO will inspect the item to determine if the item is acceptable to move to the MEC/MPPEH magazine. If the item is deemed unacceptable to move, then it will be disposed of by blow-in-place method by the UXO technician.

3.2 Classification, Transportation, Storage

The UXO contractor will classify all recovered MEC and MPPEH as hazard C/D 1.1 in accordance with NAVSEA OP 5. The UXO contractor will not transport recovered MEC or other material documented as an explosive hazard (MDEH) offsite. The UXO contractor will strictly observe all applicable Navy and Department of Transportation (DOT) transportation requirements for on-site transportation of ammunition and explosives. Recovered MEC and MPPEH that are acceptable to move will be stored in a Bureau of Alcohol, Tobacco, Firearm, and Explosives (BATFE) Type-2 portable magazine as hazard C/D 1.1 to a maximum quantity of 100 lbs. net explosive weight (NEW). UXO technician will assess and document MPPEH as Material Documented as Safe (MDAS) if the material can be 100 percent visually inspected. Any MPPEH that can't be certified as MDAS will be managed on site as MEC. UXO technician will demilitarize MDS on-site prior to release to an off-site recycler. The MDAS will be transported in a sealed container along with the appropriate documentation. The recycler will issue a certificate of destruction for all MDAS. Other debris will be discarded as solid waste.

3.3 Disposal

Disposal of MEC will be conducted in compliance with provisions of the permit submitted to Hawaii State Department of Health (DOH) during detonation operations. Sandbags will be used to mitigate fragmentation and blast effects. For certain types of MEC where sandbags cannot be used, a Buried Explosion Module (BEM) will be used instead.

For MEC deemed unacceptable-to-move and for disposal of a single MEC item, a blow-in-place (BIP) disposal will be conducted in accordance with NAVSEA OP 5. UXO technician will construct a sandbag enclosure of the required thickness to mitigate fragments and blast and use shape charges (e.g., oil well perforators) as the initiating technique. Certain MEC type will require implementation of BEM or to contact EOD MU 3 DET Mid-Pacific for Level 1 emergency response support as appropriate. Before detonation, additional precautionary actions will be conducted including visual spotters in all quadrants, filing a Notice to Airmen (NOTAM), and contacting various agencies and organizations.

4.0 Potential Path Forward

Requirements for explosives safety presents challenges to conducting dredging activities in areas identified as high potential for encountering MEC. There is additional cost associated with modification of dredging equipment such as installing shielding, use of certain types cranes or excavators that are able to maintain the required minimum separation distance. Dredging efficiency will also be reduced with potential delays as MECs are recovered during any phase of the dredging. Explosives safety requirements prevent direct disposal of dredge material that are suitable for ocean disposal as the dredge material will need to be stockpiled and screened for MEC prior to disposal. The screening process can potentially take up to a year, which likely will cause space and storage issues at the CDF. Dredging activities will also adversely impact surrounding non dredging-essential activities that are included within the EZ since buildings and non-essential personnel located within the EZ will need to be evacuated during dredging operations.

The following are several potential options that could be implemented to improve the efficiency of dredging in a high potential MEC encounter areas and reduce the impact of dredging to the surrounding base operations:

- **Site-specific Assessment.** Current dredging operations assume a 5-inch projectile as the MGFD based on the largest size of projectile found in a stockpiled dredge material consolidated from multiple areas within the harbor. These projectiles may only be limited to certain locations within the harbor such as West Loch and West Loch channel where there were historical records of presence of these projectiles. Site-specific assessment needs to be conducted for each dredging area to determine whether the potential for MEC encounter and/or the appropriate munition type to be identified for that specific project area. Additional assessment of previous dredging in the area where no munitions were recovered should also be conducted to provide additional justification for relatively low potential for MEC encounter. Dredge material stockpiles need to be better managed and documented as to which area they were dredged from, which will provide additional information for site-specific assessment for future projects.
- **Screening During Mechanical Dredging.** Current dredge operation will screen dredged material at the offload area. Alternatively, a screen can be installed on the bucket or the dredge material barge prior to transport to offload area, which will potentially eliminate MEC or reduce the size of the MEC for the subsequent phases of dredge operations.

Hydraulic Dredging. The use of hydraulic dredge with a screened intake could potentially eliminate the need to manage potential risks from MEC as the process will essentially screen potential MEC and other larger materials and leave them on the harbor bottom. The potential for detonation is limited only where the intake is underwater, which would cause minimal impact to operations with regard to explosives safety.

The drawback from hydraulic dredging is the potentially large amount of water in the slurry dredge material that will need to be managed and disposed of properly.

APPENDIX E

Presentations

SERDP and ESTCP
Thirty Years of Sediment Management Research and Development

SERDP/ESTCP Seattle Planning Meeting
August 9 – 10, 2016

Long-Term Investment Strategy

- 2004 Research and Development Needs for In Situ Sediment Management
- 2008 Soil and Sediment Bioavailability
- 2011 DOD Investment Strategies for DoD Restoration Goals Workshop
- 2012 Long Term Management of Contaminated Sediments
- 2016 Workshop on Research and Development Needs for Long Term Management of Contaminated Sediments

2012 Identified R&D Needs

- Understanding and use of passive sampling measures
- Long-term effectiveness of in situ amendments and amended caps
- Tools for measuring facilitated transport in sediment
- New approaches for implementing in situ amendments or amended caps
- Demonstration of enhanced monitored natural recovery design and operation

2012 Identified R&D Needs

- Demonstration of tools to evaluate amendment placement
- Evaluation of food web models in setting remedial goals and long term monitoring requirements
- Off-site source assessment and potential recontamination of sites
- Evaluation of confined aquatic disposal for dredged materials

Active and Recently Completed SERDP and ESTCP Projects

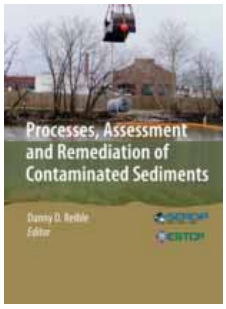
- See handout

Workshop-Directed Tools and Guidance

- *Development of Guidance for Monitored Natural Recovery at Contaminated Sediment Sites*
  - ER-200622
- *Demonstration and Validation of Enhanced Monitored Natural Recovery at DoD Sites*
  - ER-200827 and ER-201368
- *Framework Guidance Manual for In Situ Wetland Restoration Demonstration*
  - *ER-200825*

Workshop-Directed Tools and Guidance

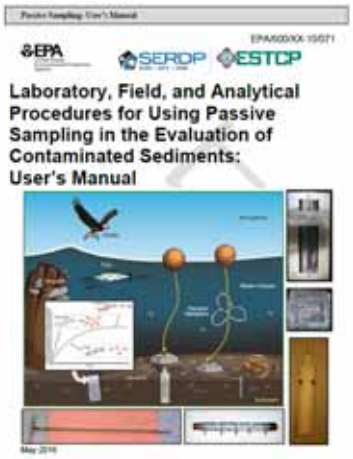
- *Processes, Assessment and Remediation of Contaminated Sediments*
  - Reible et al, 2014. (Springer)



- *Review and synthesis of evidence regarding environmental risks posed by munitions constituents (MC) in aquatic systems* (ER-2341)
  - On-line by January 2017

Workshop-Directed Tools and Guidance

- Passive Sampling Guidance
  - SERDP/ESTCP and EPA joint document
  - *Integrating Passive Sampling Methods into Management of Contaminated Sediment Sites: A guide for DoD Remedial Project Managers*



- New Web Page: *Measuring Bioavailability at Contaminated Sediment Sites*
  - Guidance Documents
  - SOPs developed by Reible and Gschwend projects
    - ER-200624 and ER-200915
  - SPME and PE PRC correction tools
  - PE demonstration videos

Workshop-Directed Tools

- Activated Carbon Web Site
  - Technical Guidance
  - Detailed Case Studies
    - Engineering Design
    - Monitoring Plans and Results
  - Application Videos
  - Links to other relevant sites
- Completed
  - Live by end of 2016

www.serdp-estcp.org

R&D Needs for Long Term Management of Contaminated Sediments (2016)

- Strategic planning session to identify and prioritize research needs that could have the greatest impact on sediment site restoration in the next 5 years
- Focuses on site closure, completing feasibility studies, designing and implementing remedies, and/or engaged in the long-term monitoring of the implemented alternatives
- Organized this Workshop to learn
  - What data gaps in addition to technology needs where additional research and development or field demonstrations would improve the understanding and assessment of the long-term management of contaminated sediments

Pre-meeting Identified "Needs"

- Pre-meeting phone calls
  - Navy, Army, Air Force, EPA, DOE, RPMs
  - Discussed what they saw as problematic issues with their own sites/projects
  - Asked their view of issues related to the charge questions
- Input from the Sediment Technical Review Panel

- This should only be a starting point for discussion
  - Want to learn what are the best investments the Program can make to positively impact the way remedial decisions are made

Breakout Session 1: Data Gaps and Technology needs

- Identify additional R&D or field demonstrations that would improve the understanding and assessment of the long-term management of contaminated sediments
- Charge questions include, but not limited to:
  1. Reducing Impact of Stormwater Discharge on Sediment Recontamination
  2. Cleanup Actions and Navigation Dredging
  3. Emerging Contaminants
  4. Sediment Cleanup Levels
  5. Monitoring Remedy Effectiveness

Breakout Session 2: Identify and prioritize research, development, demonstration, and technology transfer needs, building on the results of Breakout Session I.

- Identify and prioritize the research and development needs that will have the greatest impact on cost-effective long-term management of contaminated sediments.
- Identify and prioritize the demonstration and technology transfer efforts needed to improve cost-effective long-term management of contaminated sediments.

"Other" Research Needs

- Improving Technical Transfer
- Managing sea level rise
- Connecting Ecosystem Services to Restoration
- Reconstruction of habitat post-remediation
- Decision Support Tools
- Scale for capping or in situ projects

Visit www.serdp-estcp.org for more information about…

- **Funding Opportunities:** View solicitations and deadlines.
- **Program Areas:** Learn more about our investments in Energy & Water, Environmental Restoration, Munitions Response, Resource Conservation & Climate Change, and Weapons Systems & Platforms.
- **Featured Initiatives:** Explore the latest developments in science, engineering, and technology.
- **Tools & Training:** Put innovative research and technology to use.
- **E-mail Distribution Lists** and **RSS:** Sign up to receive notification of updates in your areas of interest.

www.serdp-estcp.org

Workshop on Research and Development Needs for Long-Term Management of Contaminated Sediments

Case Studies: Challenges and Lessons Learned in Sediment Remediation

Kristen Kerns and Marlowe Laubach,
Seattle District, US Army Corps of Engineers
August 9, 2016

Purpose and Outline

- Purpose
  - Present sediment remediation case studies with challenges, lessons learned, and potential needs
  - Perspective from practitioners responsible for designing and implementing remediation and monitoring
- Case Studies
  - McCormick and Baxter Superfund Site, Stockton, CA
  - Lower Duwamish Waterway Superfund Site, Seattle, WA
  - Manchester Annex Formerly Used Defense Site, Manchester, WA
  - Wyckoff Superfund Site, Bainbridge Island, WA

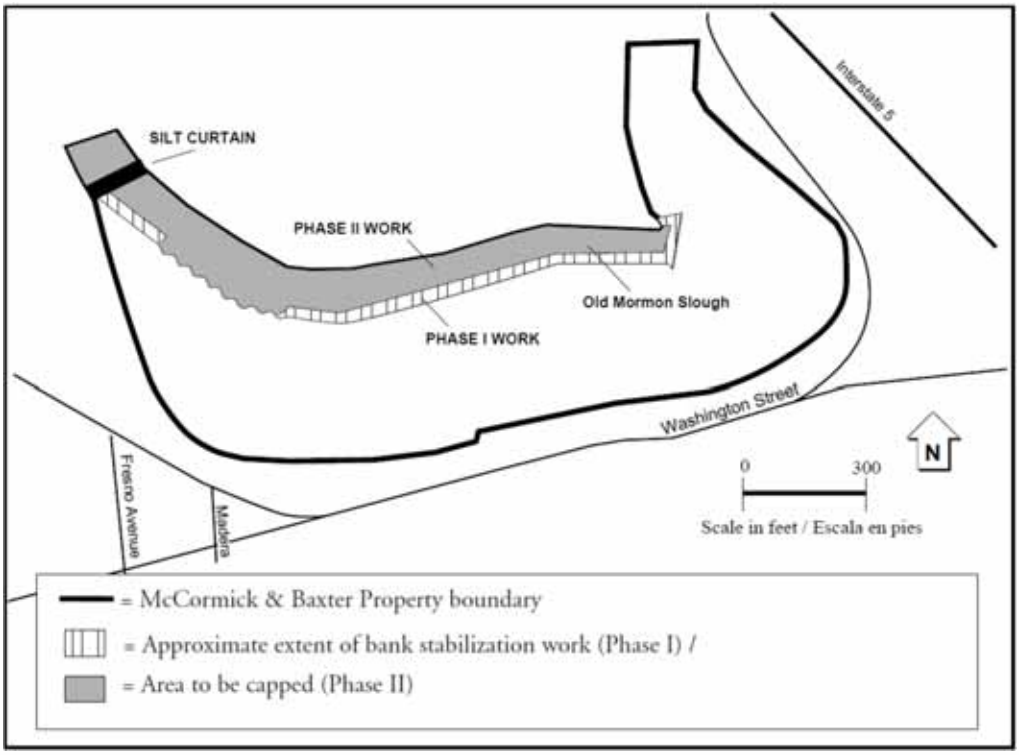
McCormick & Baxter Superfund Site, Stockton, CA

Sediment OU Selected Remedy

- Sediment cleanup standards identified for Total PAHs and Dioxin
- In situ capping with minimum 2 feet fine sand to isolate areas of principal threat waste (approx. ¾ of the slough)
- Armored with rip-rap and gravel filter layer where needed
- Bank stabilization needed to cut off source of potential recontamination
- Institutional controls required

Old Mormon Slough, McCormick & Baxter

Sediment OU Remedy



Sediment Remedy OU

Post Construction and Long Term Monitoring

- All areas of the cap were at least 18in thick, 99.5% of the cap was greater than 18in thick, and the average cap thickness was 2.6ft
- Concerns over depth to top of cap
- Sediment competence to support a cap was incompletely characterized
- Monitoring showed while consolidation had occurred, no significant recontamination

Lessons Learned at McCormick and Baxter

- Insufficient technology for assessing unconsolidated material
- Unknowns regarding what potential recontamination could occur from porewater upward migration
- In retrospect, site would have been a good candidate for thin layer capping with amendment
  - Shallow water, quiescent system, soft underlying sediments
  - Need to continue to change our mindset that a thicker cap is not always a better cap

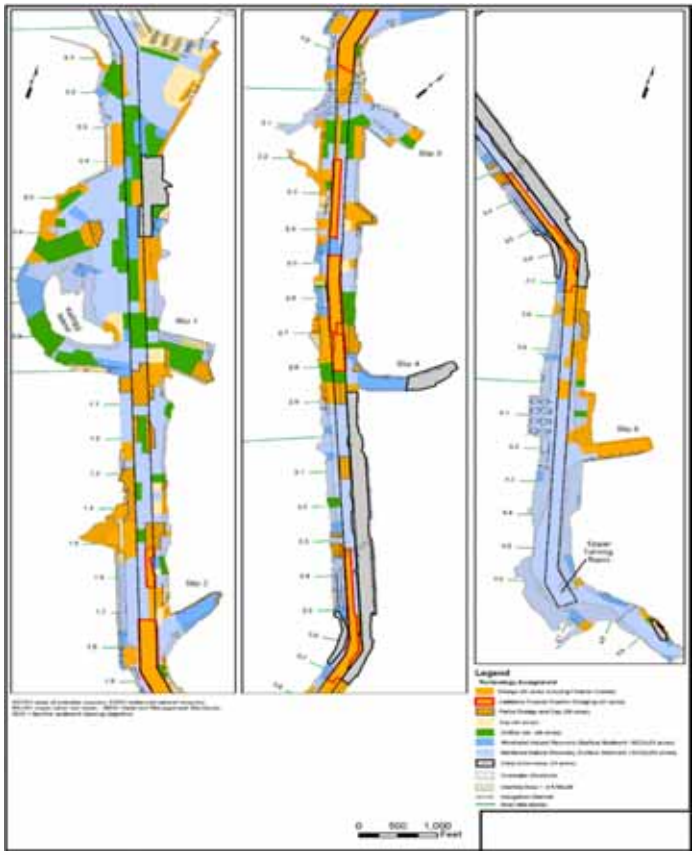
Lower Duwamish Waterway Superfund Site, Seattle, WA
Activated Carbon Pilot Study

www.serdp-estcp.org

Lower Duwamish Waterway Superfund Site, Seattle, WA

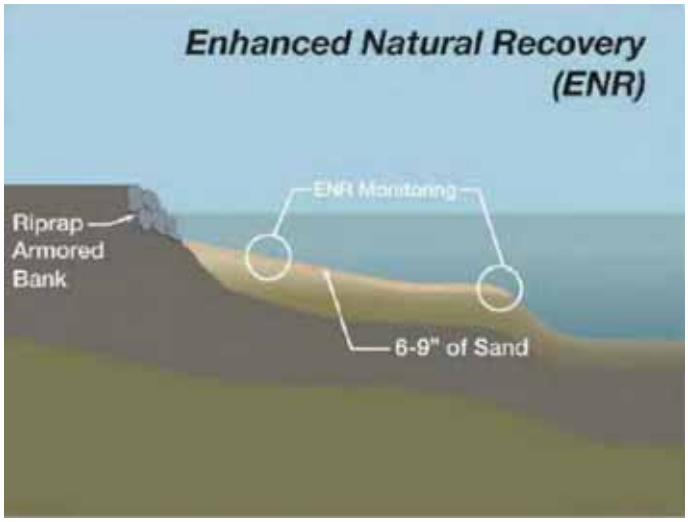
- Decades of industrial activity
- significant pollution of the sediments, water, and aquatic life in the area
- Contaminants of Concern
  - PCBs, PAHs, dioxins/furans, and arsenic
- Record of Decision
  - November 2014
  - actively remediate 156 acres of contaminated sediments
    - dredging, capping, Enhanced Natural Recovery (ENR)
  - 256 acres would be designated for Monitored Natural Recovery
  - $342 million and 7 years of construction

Lower Duwamish Waterway Selected Remedy



Enhanced Natural Recovery (ENR)

- 6 to 9 inches of clean sand atop contaminated sediments
- Reduce contaminant concentrations in the surface substrate
- Accelerate natural processes of sediment deposition
- Applied to areas of relatively low contaminant concentration and minimal scour potential
- Unlike a cap, ENR is not meant to serve as an isolation barrier

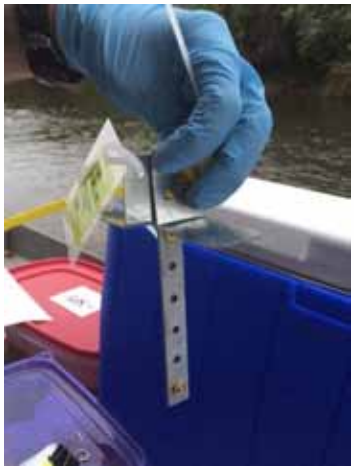


Lower Duwamish Waterway Activated Carbon Pilot Study

- Three one acre plots
  - ½ acre ENR
  - ½ acre ENR+AC
- Scour plot
- Subtidal plot
- Intertidal plot
- Goals of the pilot study are to test placement methods, ability to remain in place over time, and effectiveness at reducing bulk sediment, porewater, and tissue PCB concentrations
- Construction is scheduled to begin in December of 2016

Baseline Sampling with SPMEs

- Contractors placed SPMEs for baseline sampling the week of July 25th
  - Work was performed by AMEC Foster Wheeler, Ramboll Environ, Geosyntec, and Research Support Services
  - SPMEs were obtained from SiREM



www.serdp-estcp.org

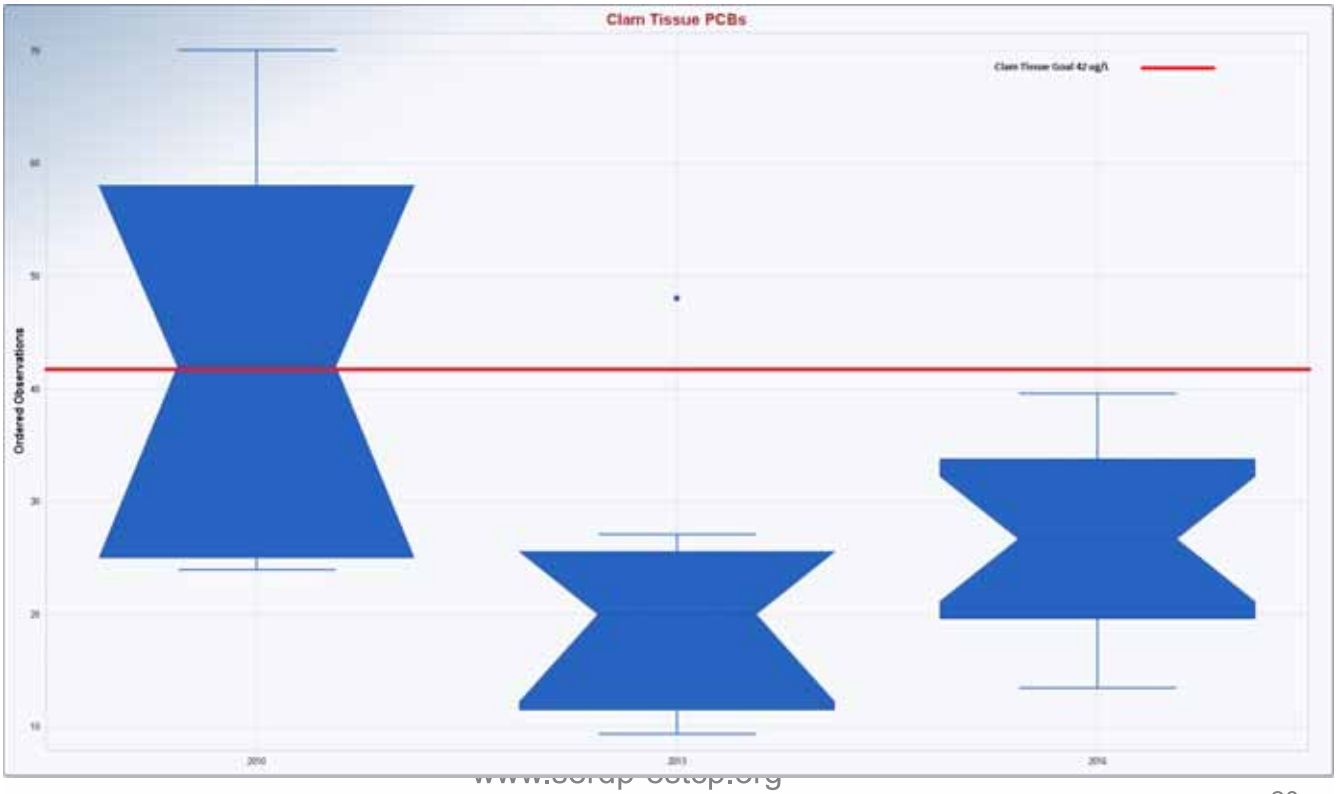
Challenges

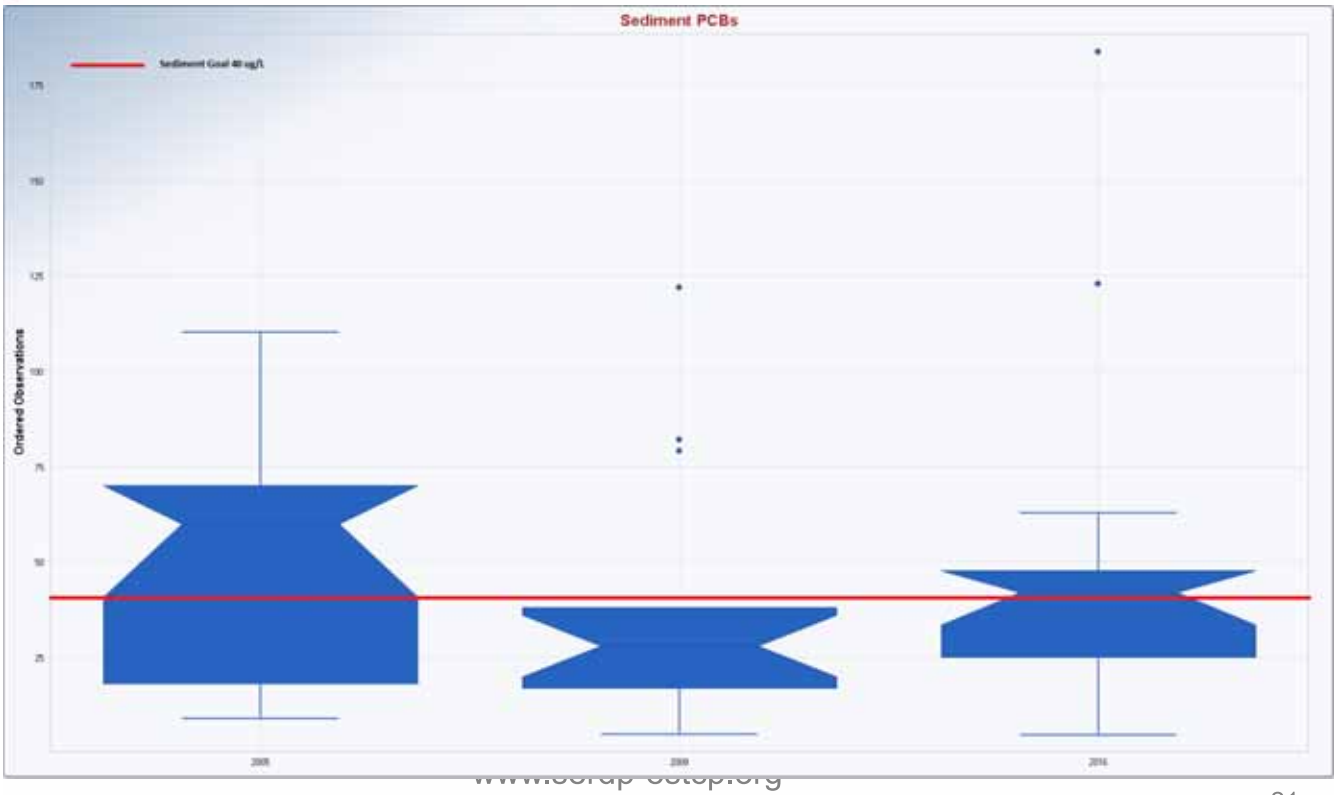
- How to define success?
  - If we see reductions in porewater concentration, what is considered 'enough' to warrant inclusion of activated carbon into the larger remedy?
  - The Record of Decision doesn't establish goals for porewater or tissue concentration, therefore, is it worth it?
- Stakeholder acceptance
  - Concerns over potential toxic impacts to the benthic community
  - Conducting ex-situ toxicity testing as a component of the pilot study

Old Navy Dump/Manchester Annex Site Manchester, Washington

Remedy

- Landfill cap
- Shoreline Protection System
- Thin-sediment cap in intertidal area


Clam Tissue PCBs
Clam Tissue Goal 42 ug/L
Ordered Observations


Sediment PCBs
Sediment Goal 40 ug/L
Ordered Observations

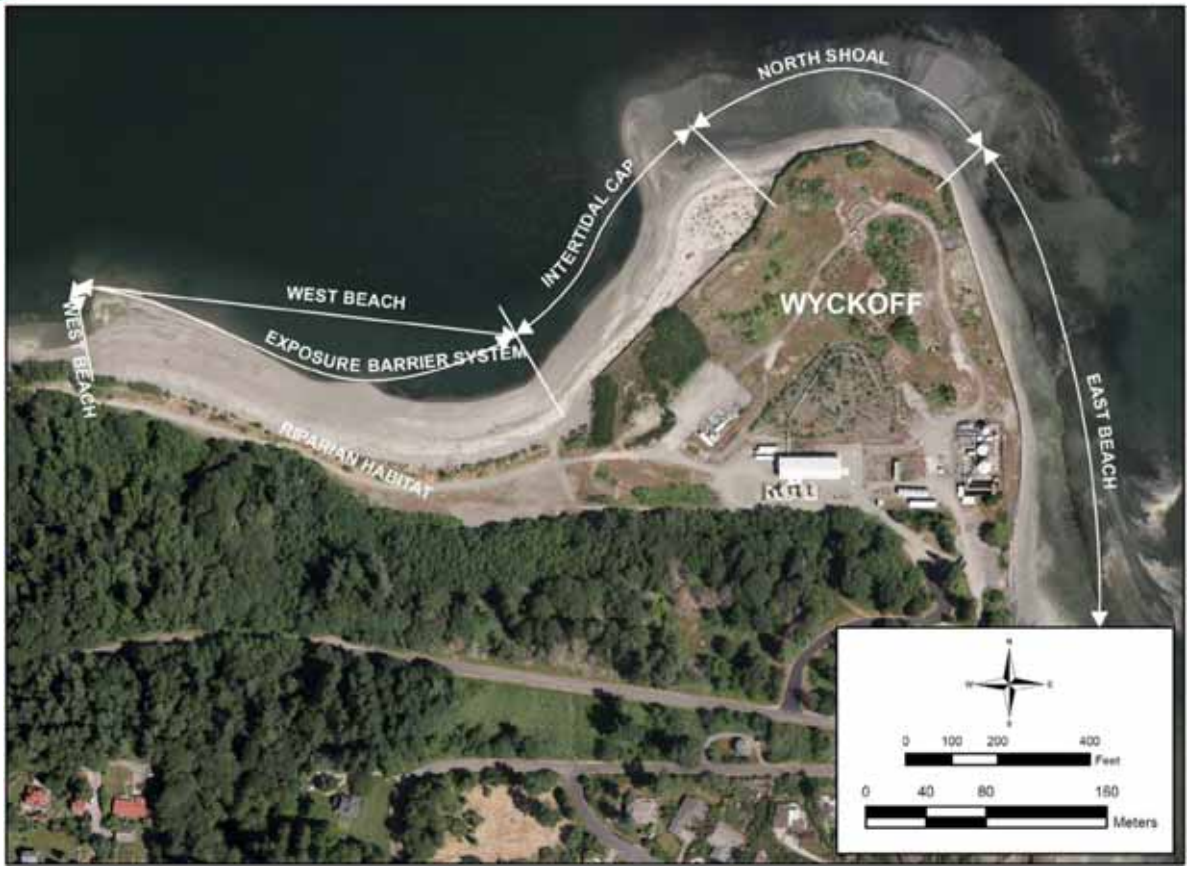
Challenges and Lessons Learned

- Stakeholder interests at the site
- Sediment concentrations continue to exceed ROD cleanup goals based on bulk sediment sampling
- Conceptual Site Model – is it complete?

Wyckoff/Eagle Harbor Superfund Site Bainbridge Island, Washington

East Harbor (OU1) Remedy

- **Subtidal Area**
  - Sediment Caps
- **Intertidal Areas**
  - Monitored Natural Recovery for East Beach and North Shoal
  - Intertidal Cap
  - Exposure Barrier System on the West Beach



Recent Investigations

- **2011 Monitoring**
  - Used typical bulk sediment collection methodologies to assess cap stability and contaminant isolation
  - Results showed that the intertidal and subtidal caps are intact and operating and functioning as intended, except within the area of the ferry navigation lane
- **2013 Remotely Operated Vehicle Survey**
- **2016 Feasibility Study**
  - Used TarGOST to identify locations of NAPL in the East Beach and North Shoal intertidal areas

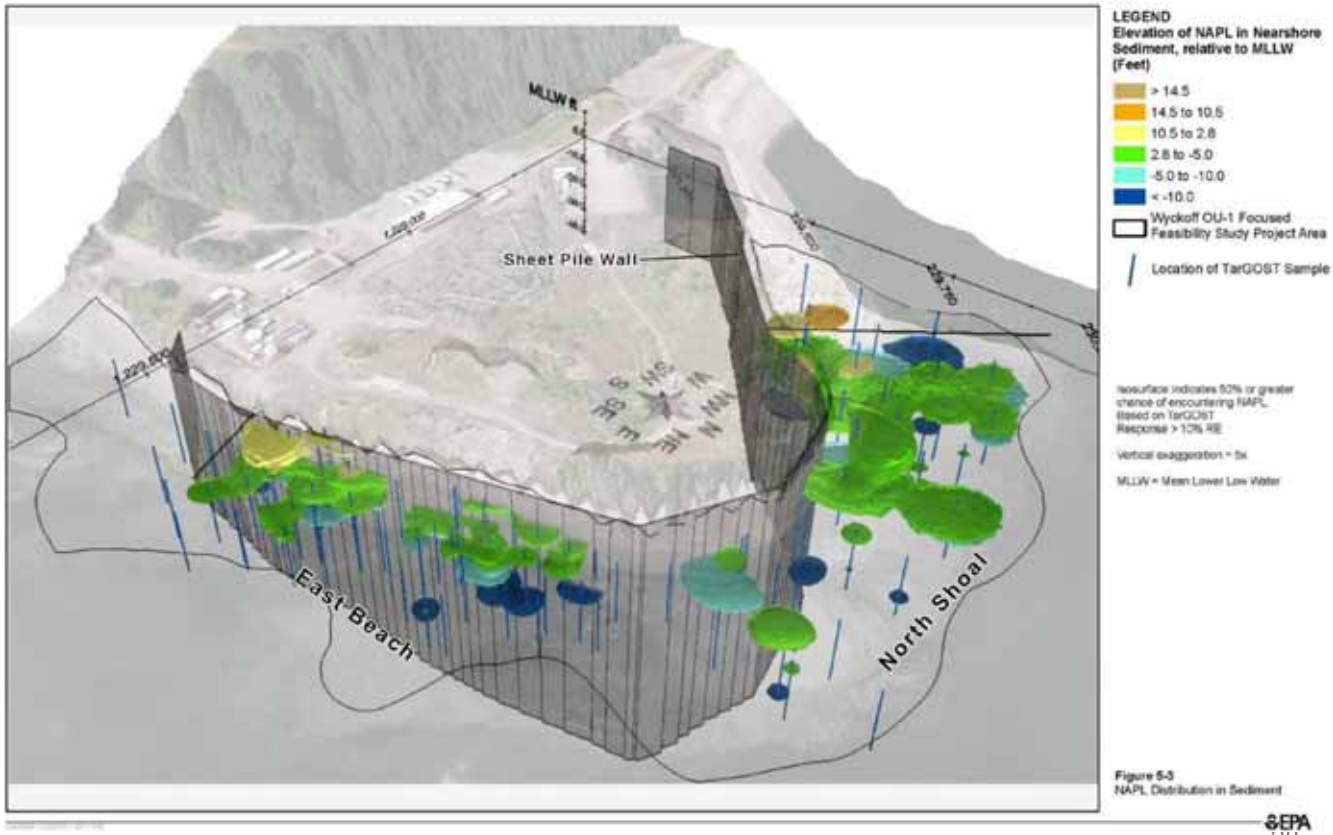


Figure 5-3
NAPL Distribution in Sediment

Current Status

- **Proposed Plan issued in April 2016**
- **Preferred Alternative for the Nearshore: Partial Excavation and Capping**
  - Excavation up to a depth of 30 inches
  - Excavated areas would be backfilled with a reactive layer, a demarcation layer, and clean gravelly sand
  - Caps would be 40 ft x 40 ft and overlap slightly to cover the larger beach areas.

Challenges and Remedial Design Considerations

- Ferry use impacting the subtidal cap
- Public use of the intertidal areas
- Proposed Plan proposes sediment PRGs for carcinogenic PAHs for the top 2 feet of beach sediment
  - Remedial design for reactive layer
  - Potential NAPL and groundwater upwelling
- Future monitoring

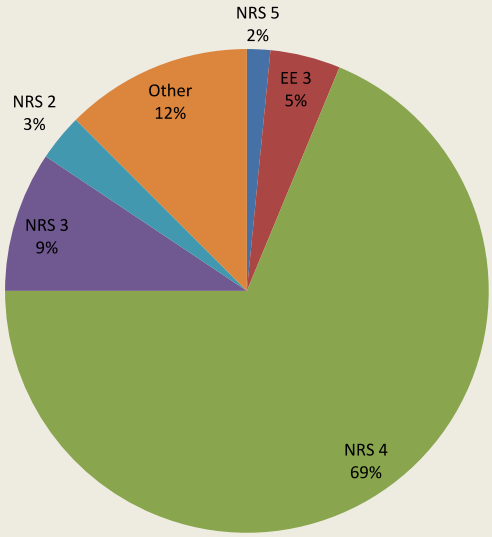
Oregon DEQ

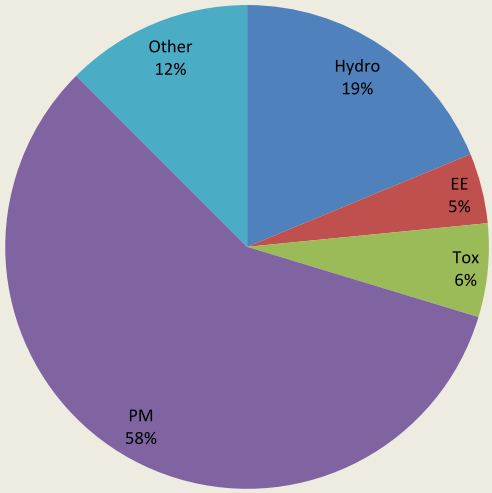
Top Challenges at Oregon Sediment Sites

•*Kevin Parrett, PhD, Manager NW Region Cleanup Program*
•*Sarah Greenfield, PE, Project Engineer/Project Manager*

Current Staff Makeup:

Dominated by senior level (NRS 4) project managers



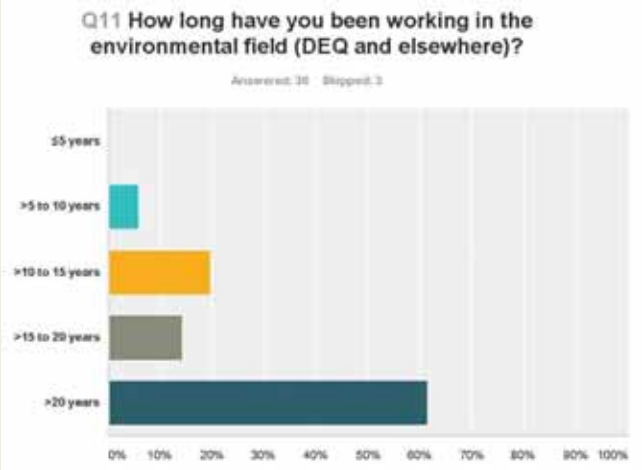


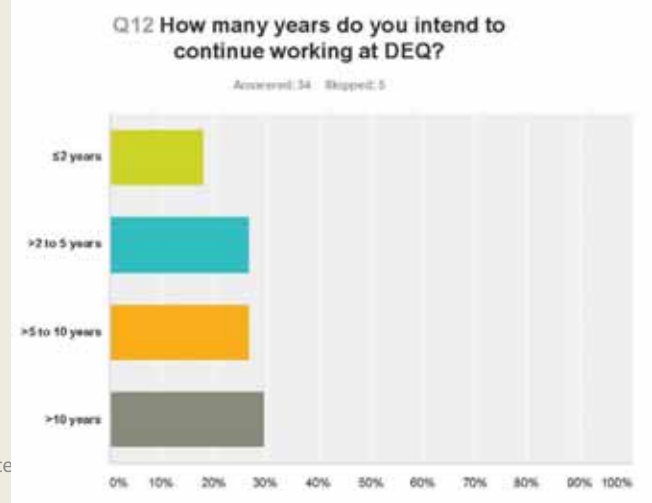
Authorized Positions	
NRS 5	1
EE 3	3
NRS 4	44
NRS 3	6
NRS 2	2
Other	8
Total	64

Authorized Positions	
Hydro	12
EE	3
Tox	4
PM	37
Other	8
Total	64

DEQ Staff Survey - 2015:

Anticipate 44% Turnover within 5 Years

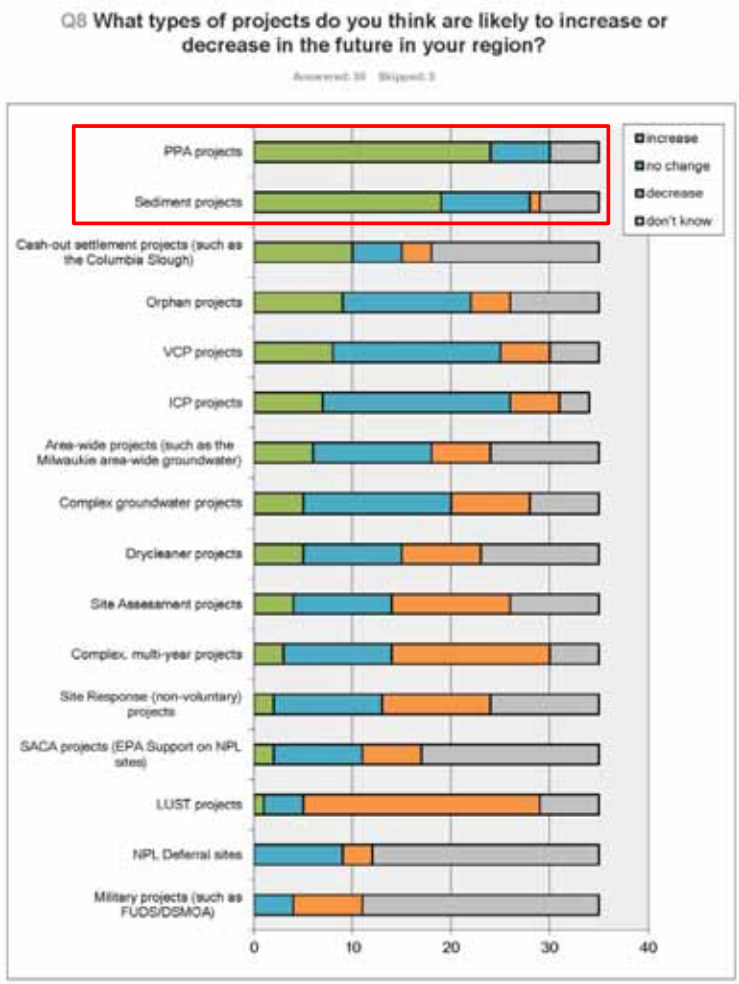




Staff Survey:

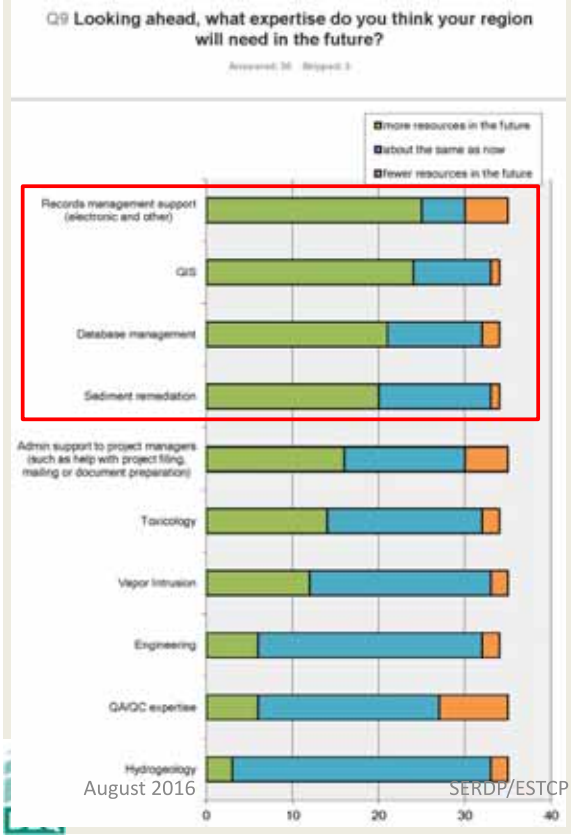
Future shift to PPAs, sediment, settlements, VCP

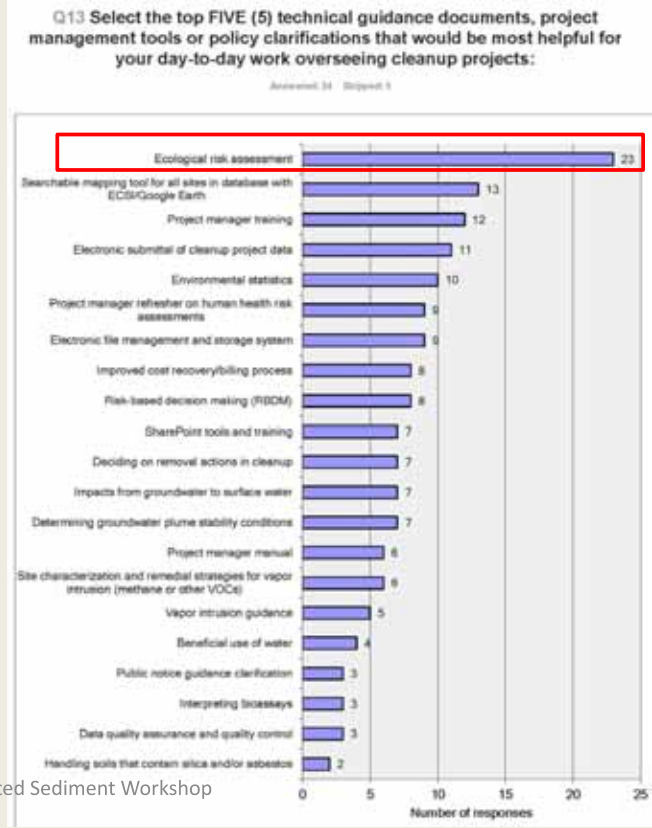
Substantial reduction in site response and LUST



Staff Survey:

Future Areas of Expertise and Guidance

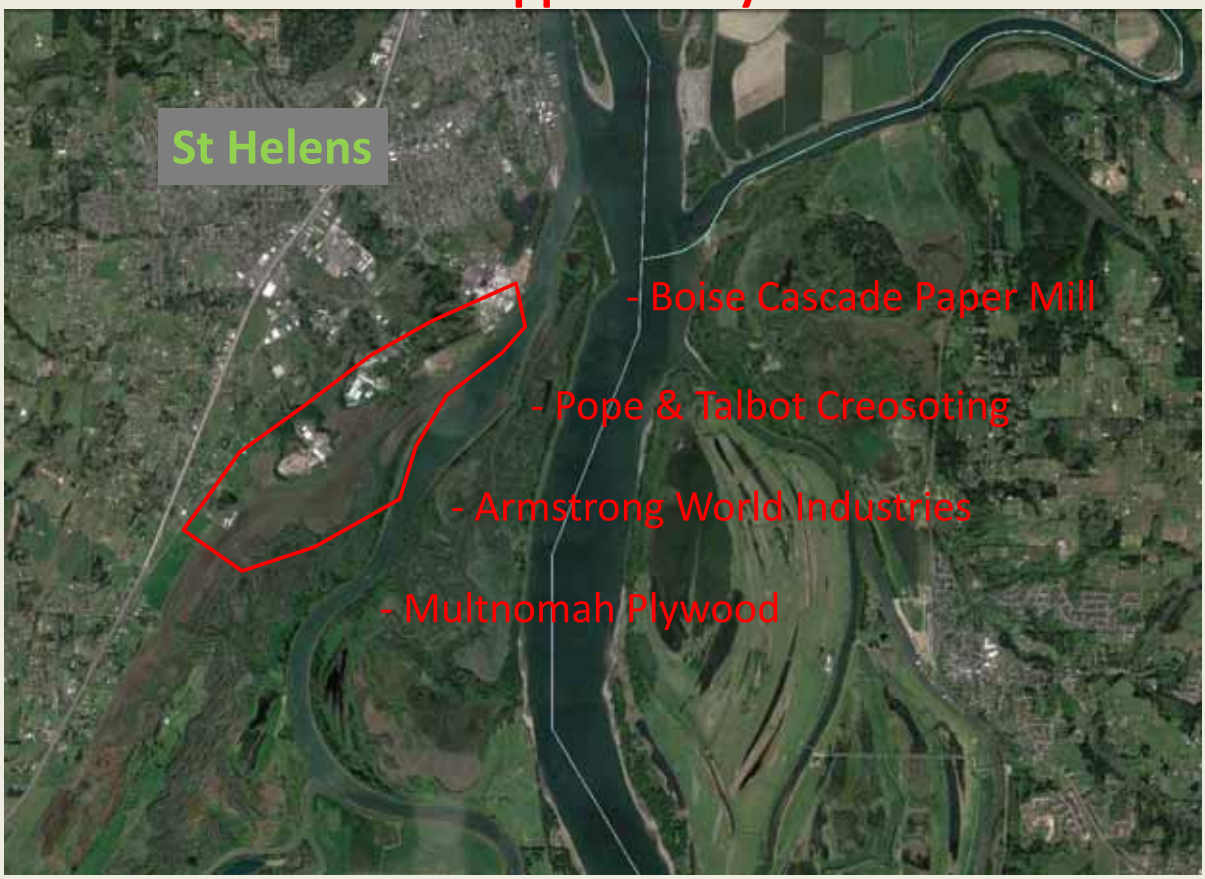




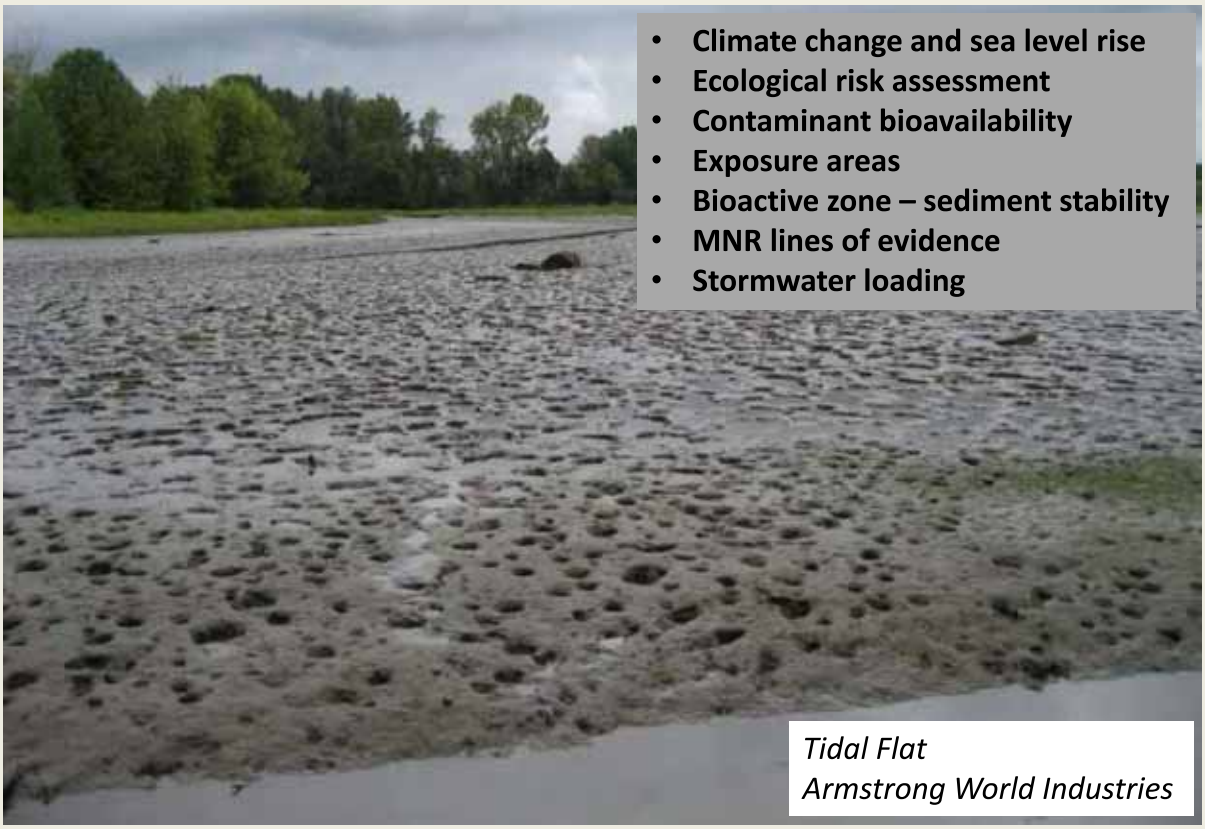
Columbia Slough

Astoria Marine

Scappoose Bay



Common Issues



- **Climate change and sea level rise**
- **Ecological risk assessment**
- **Contaminant bioavailability**
- **Exposure areas**
- **Bioactive zone – sediment stability**
- **MNR lines of evidence**
- **Stormwater loading**

Tidal Flat
Armstrong World Industries

~ The End ~

Native Wapato - Armstrong World Industries

Supplemental

Astoria Marine

Armstrong World Industries

RPM Perspective on Sediment Restoration

August 2016
Kimberly Markillie, NAVFAC Pacific

Presentation Outline

Topic 1: Data Needs to Guide Selection of a Restoration Alternative

Topic 2: Science and Demonstration Needs for In-Situ Remedy Selection

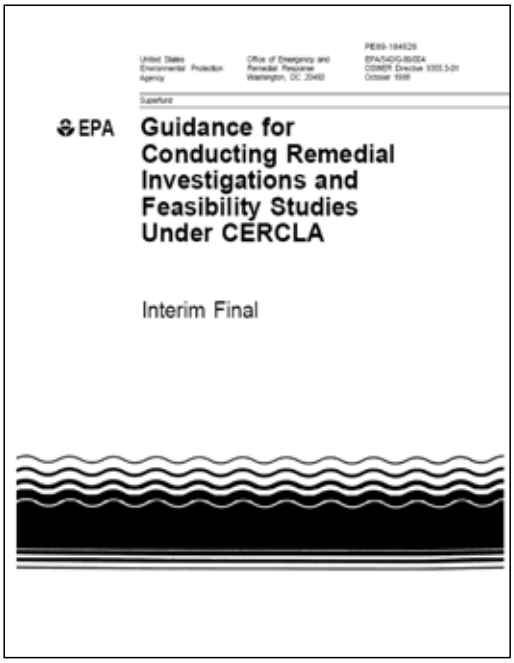
Topic 3: Engineering and Cost Considerations for Sediment Restoration

TOPIC 1: Data Needs to Guide Selection of a Restoration Alternative

1. Superfund CERCLA Process
2. Active Harbor Conditions
3. Munitions Issues
4. Remedy Resilience
5. Performance Metrics for Monitoring Tools

Superfund CERCLA RI Process – Old and New Challenges

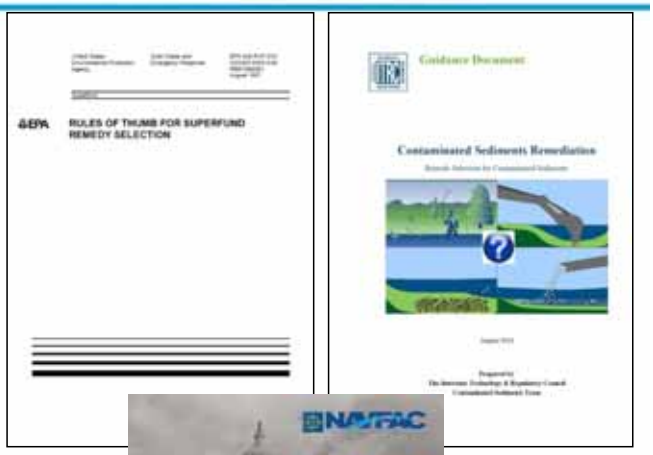
- Challenges
  - Storm water discharges
  - Non-point sources
  - Resuspension
  - Emerging Contaminants
    - G-RAM
    - PFASs
  - Risk assessments for emerging contaminants

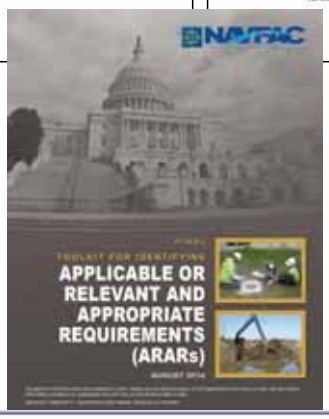

EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA

Interim Final

Superfund CERCLA FS Process – Old and New Challenges

- Challenges
  - Coordination between maintenance dredging and environmental cleanup actions
  - Tools and technologies to measure remedy effectiveness (e.g., fish, porewater, and sediment)
  - Methods to integrate bioavailability-based remedies into remedial action
  - Development of porewater PRGs





Active Harbor Conditions

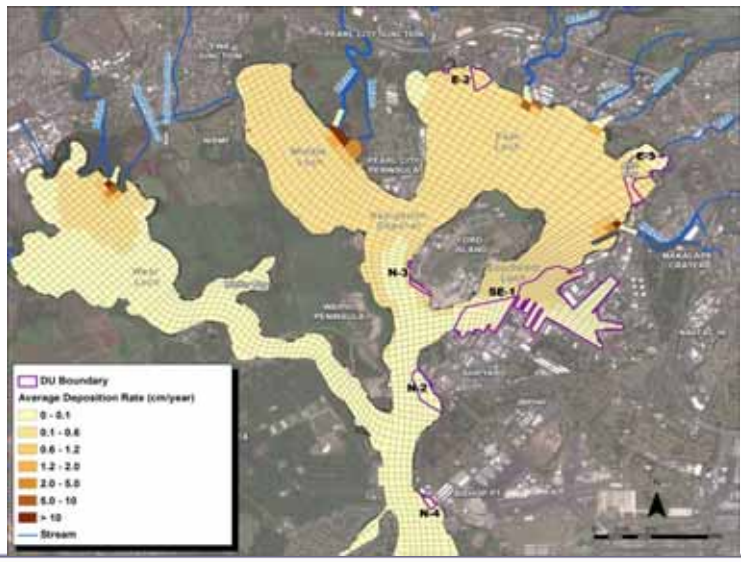
- **Better understanding of remedy performance in active and dynamic harbor conditions including:**
  - **Piers**
  - **Quays**
  - **Wharves**
  - **Slopes**
  - **Ship draft clearance**
  - **Maintenance dredging**
  - **Prop wash**

Munitions Issues

- **Incorporate munitions logistics**
  - Support minimal interaction with and avoidance of munitions
  - Guidance for munitions handling, processing, and exposure
- **Additional Requirements**
  - ESS
  - Exclusion Zone
  - Shielded machinery
  - Time for screening for MEC

Remedy Resilience

- Factors influencing remedy resilience during remediation alternative selection:
  - Current and future site condition
  - Sediment dynamics (i.e., prop wash, resuspension, clean sediment inputs)
  - On-going sources
  - Short and long term benefit



Performance Metrics for Monitoring Tools

- Better linkage of performance metrics to monitoring tools.
  - Biota Tissue vs. Sediment (e.g., BSAF)
  - Biota Tissue vs. Porewater (e.g., food-web modeling)
  - Biota Tissue/Sediment/ Porewater vs. Passive sampling tools (e.g., SPME)

TOPIC 2: Science and Demonstration Needs for In-Situ Remedial Selection

1. Basic Science and Fundamentals of In-Situ
2. Regulatory Standard Challenges - AC
3. Better Tools to Select, Design, Develop and Assess Performance
4. Activated Carbon Amendment (case study from Pearl Harbor Under-Pier Areas)

Basic Science and Fundamentals of In-Situ

- Challenges
  - Complex Environmental Conditions
  - Lack of Experience
  - Lack of Regulatory standards

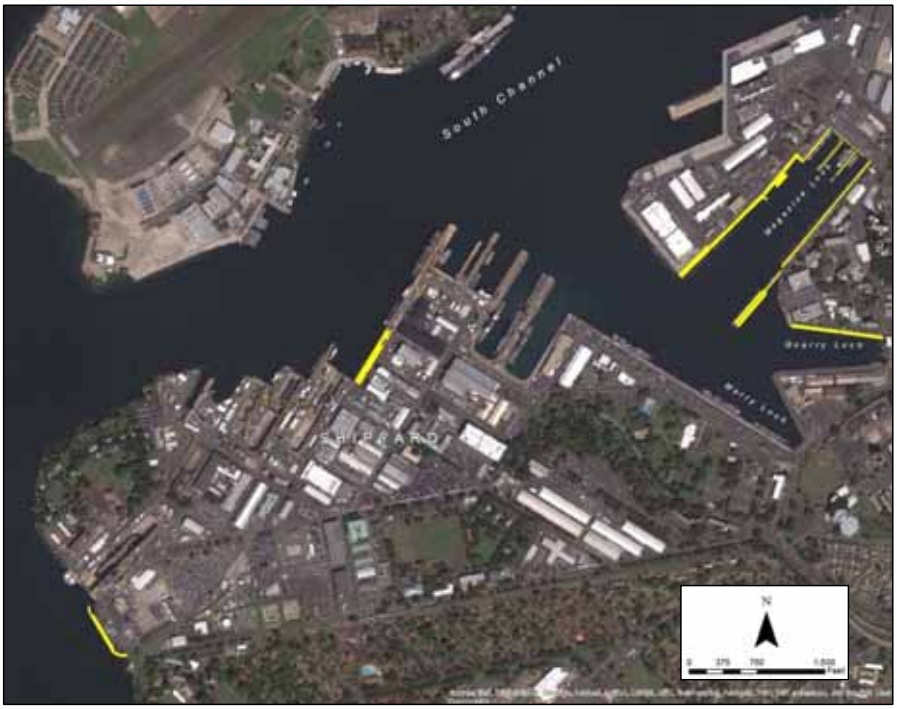
Regulatory Standard Challenges – Activated Carbon

- Currently no "credit" for in-situ treatment under sediment remediation
- No EPA or local regulatory standards for porewater
- Relationship between porewater and biota is not well understood

Better Tools to Select, Design, Develop and Assess Performance

- Bench-scale pilot studies
- Methods to integrate bioavailability-based on in-situ remedies
- Evaluation under a wider range of environments and conditions with site-specific sediments
- Low-cost tools for assessing remedy performance in-situ post implementation

Case Study of AC Amendment – Pearl Harbor Under-Pier Areas

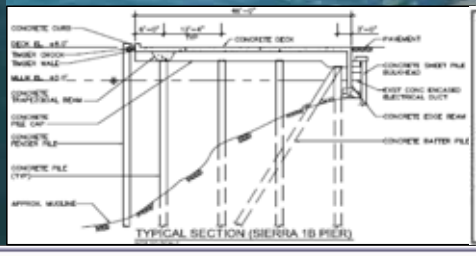


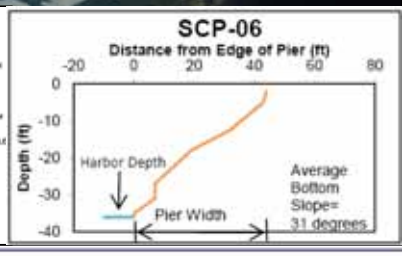
PROJECT DESCRIPTION:

1. Location/Material Selection
2. Amendment Material Placement and Verification
3. Performance Monitoring
   - 6-month monitoring (August 17–21, 2015)
   - 18-month monitoring (October 2016)

Under Pier Sierra 1B – Rationale

- Both PCBs and mercury present in surface sediments
- Moderate slope from bulkhead to pier face (25–30 degrees)
- Soft sediment present under majority of pier with limited rubble / rock debris
- Pier in an active submarine berthing and repair area with common tugboat and sub movements





Over-Water Broadcast Placement

AquaGate + PAC

- Consistent/steady material stream
- Limited dust
- Good broadcast distance

Over-Water Broadcast Placement

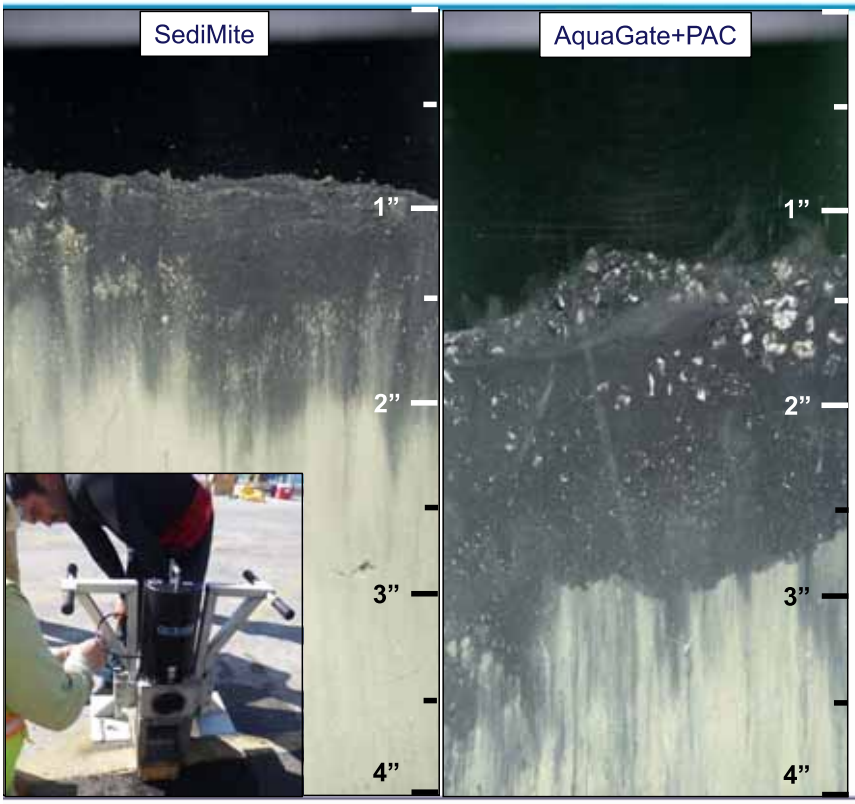
SediMite

- Dust and water mist from compressed air placement technique
- Additional dust suppression needed for confined area
  - Dust created an explosive atmosphere without suppression

Challenges for Monitoring Effectiveness

- Porewater (SPME and DGT)
- Sediment chemistry
- Bioassay testing
- Sediment profile imaging (SPI)
- Monitoring duration

Results – Sediment Profile Imaging



- SPI conducted at 26 locations throughout the Test Plots
- All SPI locations displayed presence of SediMite and AquaGate+PAC
- Some over-application observed
- Native sediment layer observed in all SPI locations

Six-Month (August 17–21, 2015) Sampling Results: Bulk Sediment and Porewater Chemistry

- **Bulk Sediment Chemistry**
  - Increased PCBs sediment concentration in both test plots
  - Higher percent increase with SediMite
- **Sediment Porewater Chemistry**
  - Decreased porewater PCBs concentration in both test plots
  - Higher percent decrease with AquaGate+PAC

Average Change in Sediment PCB Concentration	
Activated Carbon Amendment Type	Total NOAA-18 PCBs % Change
SediMite	192
AquaGate+PAC	70

Average Change in Porewater PCB Concentration	
Activated Carbon Amendment Type	Total NOAA-18 PCBs % Change
SediMite	-36
AquaGate+PAC	-71

TOPIC 3: Engineering and Cost Considerations for Sediment Restoration

- Engineering Challenges
- Hybrid Remedies (i.e., combination of remediation technologies)
- Long-Term Monitoring for Biota

Engineering Challenges

- Integrating maintenance dredging with the remedy footprint
- Managing contaminated sediments under piers
- Controlling ongoing sources: drainage canals / ditches, storm drain outfalls
- Better understanding of MNR processes
- Better tools to select, design, develop and assess performance for hybrid remedies

Hybrid Remedy

Focused Dredging with ENR, AC, and MNR (20 years)

- Achieve RAOs within 20 years
- AC treatment reduces risk to fish during recovery period
- Less construction-related impact to the environment
- Relatively cost-efficient ($47million)
- Engineering is more complex
- Fully compliance CERCLA nine criteria

Dredge Area
ENR and AC
ENR
MNR and AC
MNR
No Remediation Required
Under-Pier AC
Under-Pier MNR
Under-Pier No Remediation Required

Long-Term Monitoring for Biota

- Establish the long-term monitoring program early in the process
- Baseline monitoring
- Pre-construction monitoring
- Post-construction monitoring
- Regular interval (i.e., five-year) long-term monitoring
- Collect collocated sediment and fish tissue samples

Questions?

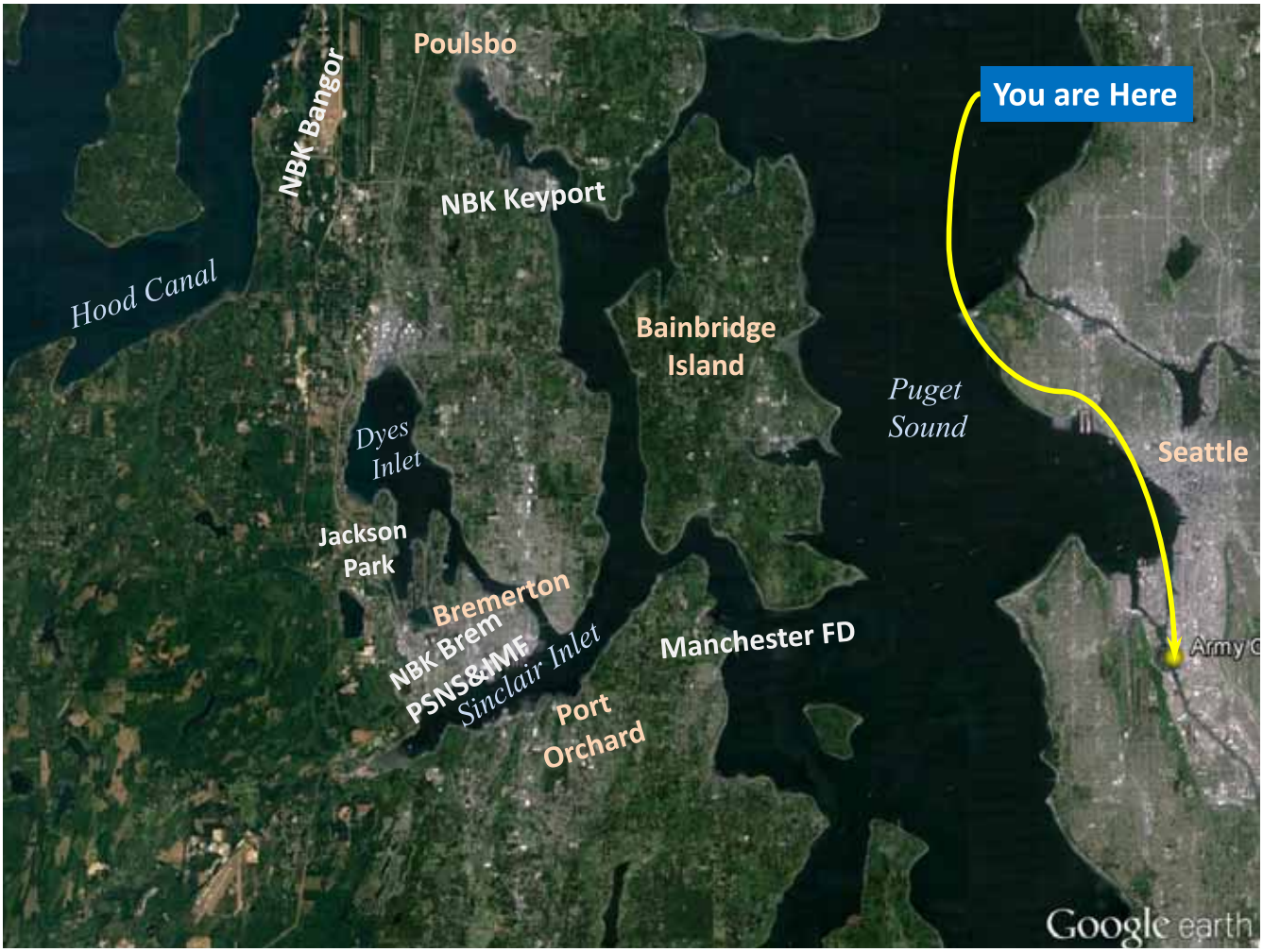
Recontamination Potential for Remediated Sediment Sites

Dr. Bob Johnston, Space and Naval Systems Center Pacific

Introduction/Background
Watershed Based Management
- Pressures and Drivers on the Landscape
- Why is Storm Water Runoff a Problem?

Runoff from Above and Below
Redistribution of Contaminated Sediment
21st Century Contaminants of Concern
Integrating Environmental Quality Goals
Challenges and Opportunities

This presentation reflects the personal views of the author and does not suggest or reflect the official policy, practices, programs, or doctrine of the U.S. Navy, SERDP/ESTCP, or any other governmental agency.

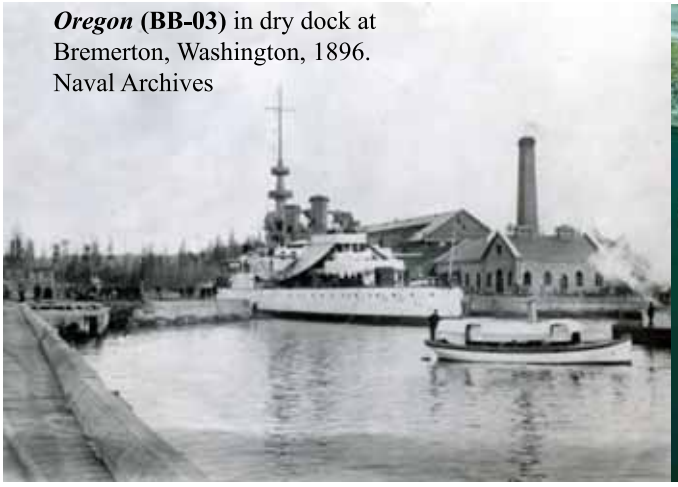


Two Main Sources of Impact

- Historical releases of pollutants
  - Past practices (Point Sources)
  - Legacy residual contamination
- Watershed Development
  - Loss of natural habitat
  - Increases in runoff from landscape
  - More Nonpoint Source Pollution

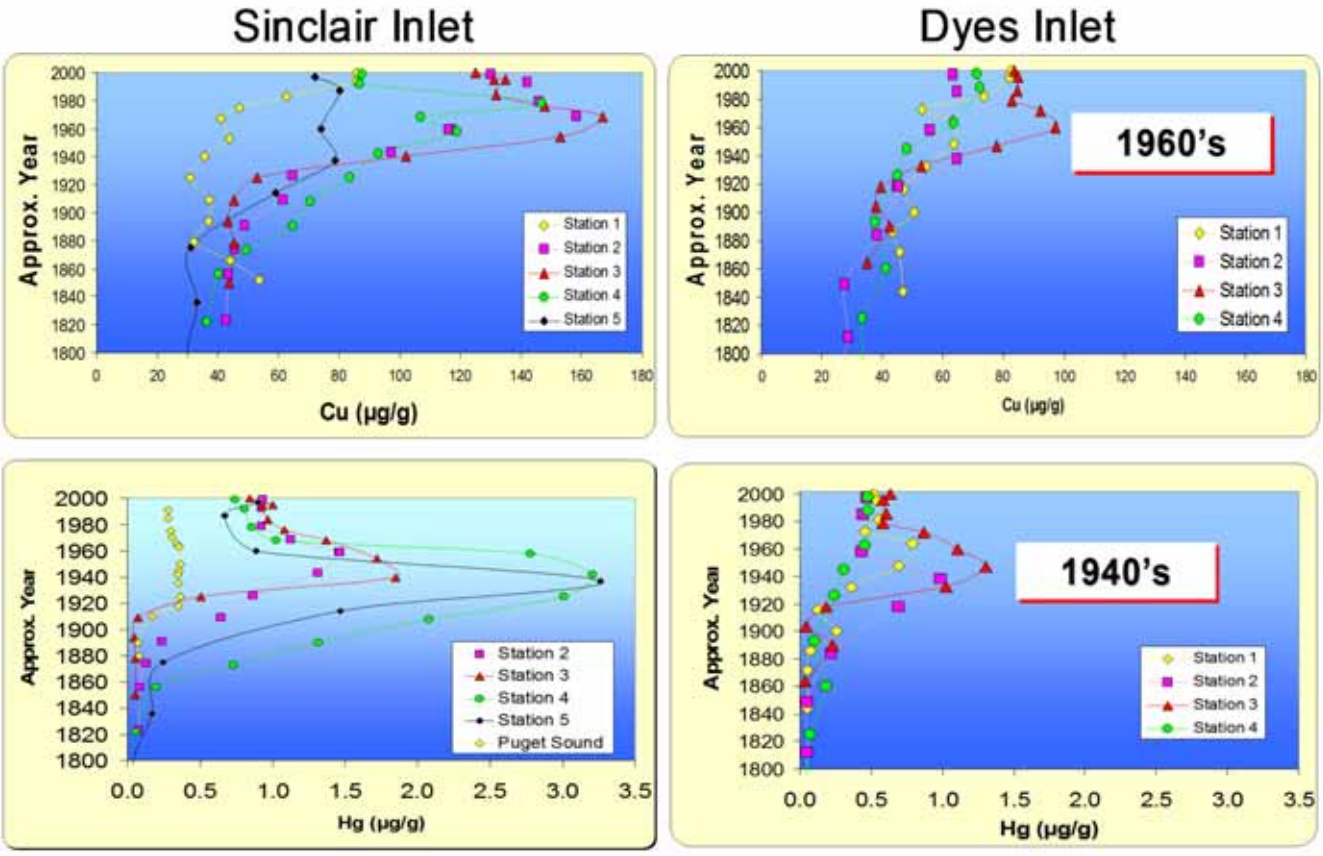
Image U.S. Geological Survey

PSNS & IMF (Bremerton)

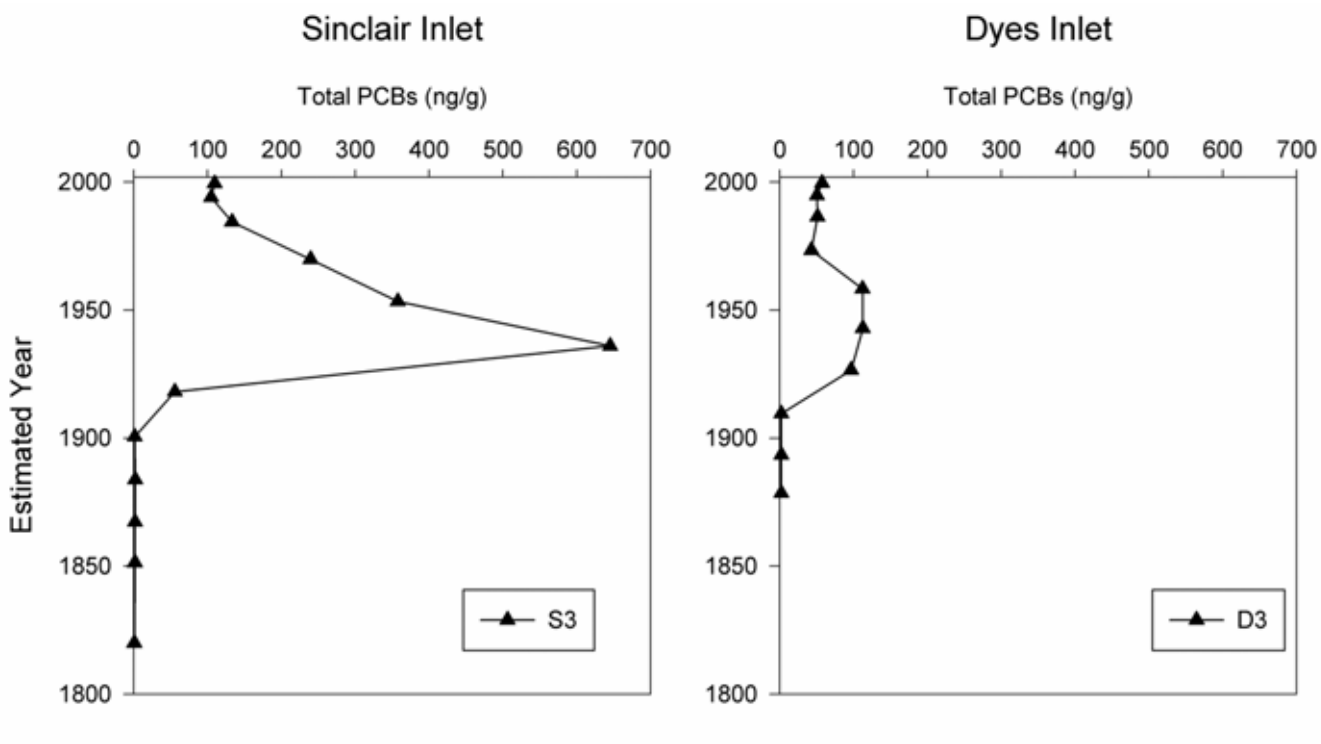


- Established in 1891.
- 179 acres of heavy industrial area (100% impervious surface)
- Old Infrastructure
- No buffer between work and water,
- Located on an "Impaired Water Body"

Sediment Core Profiles

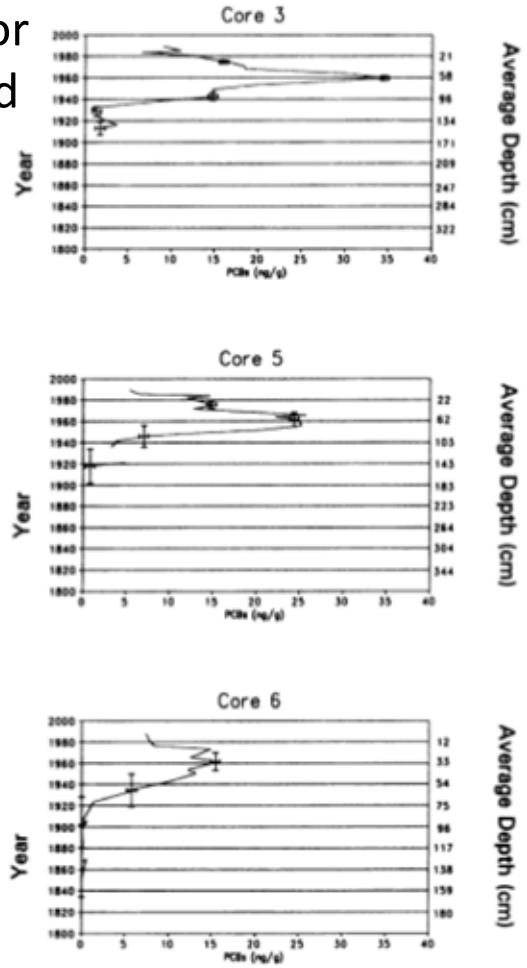


(Crecelius et al. 2003)

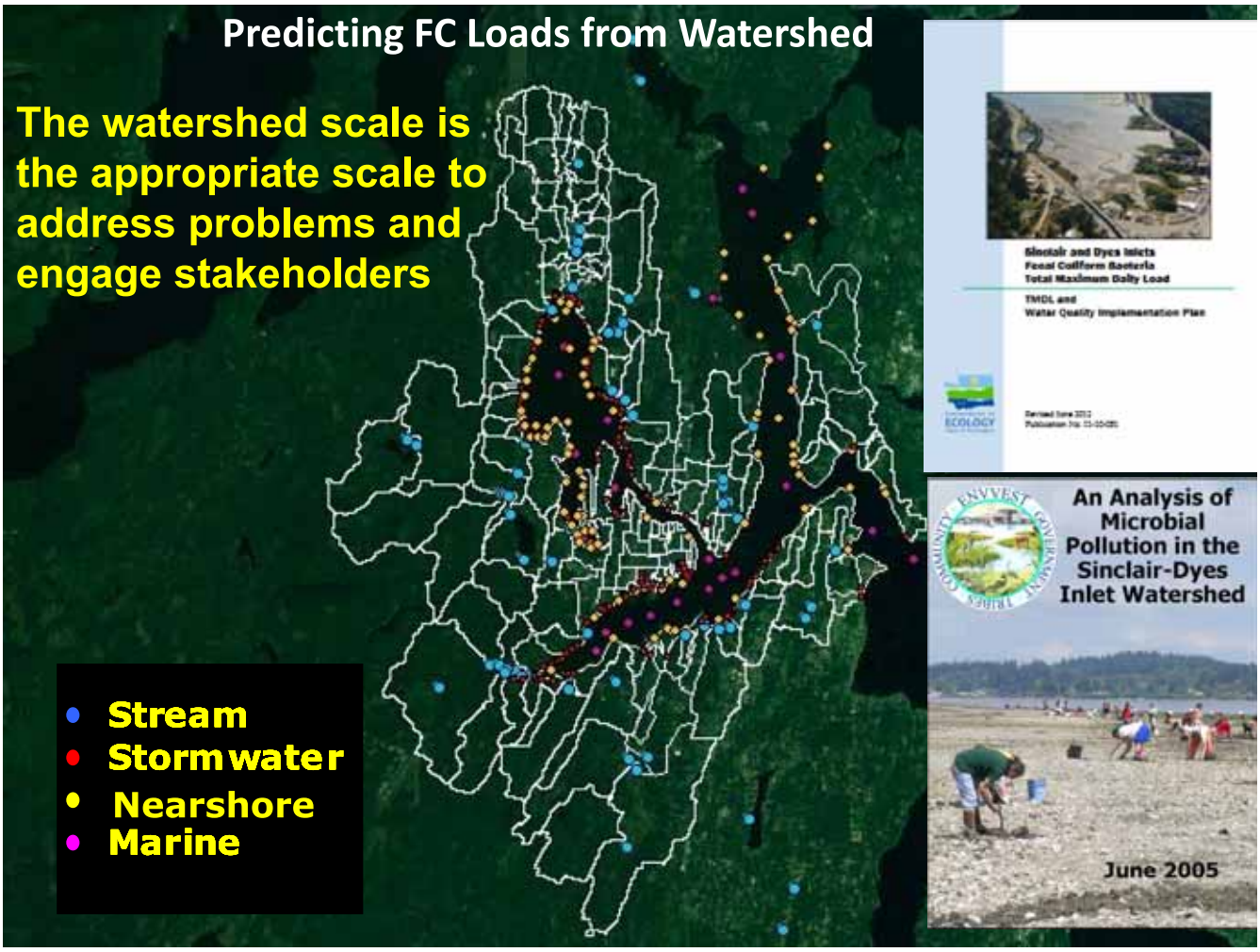


(Brandenberger, Crecelius, Johnston 2008)

PCB Core Profiles for central Puget Sound

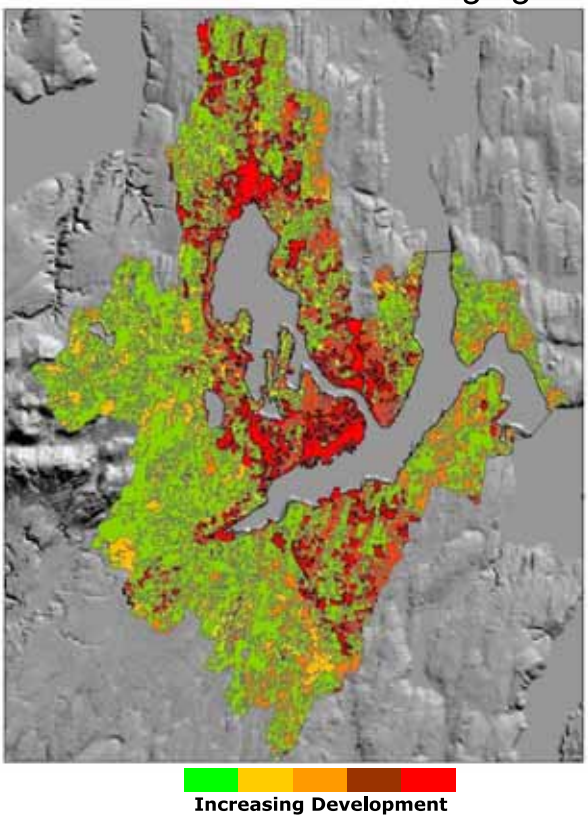


(Lefkovitz, Cullinan, Crecelius 1997)

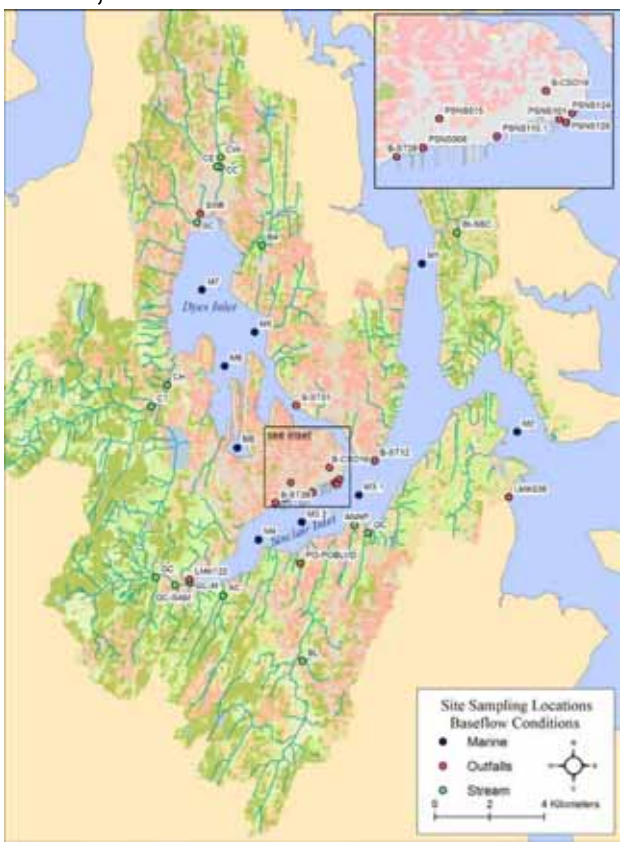


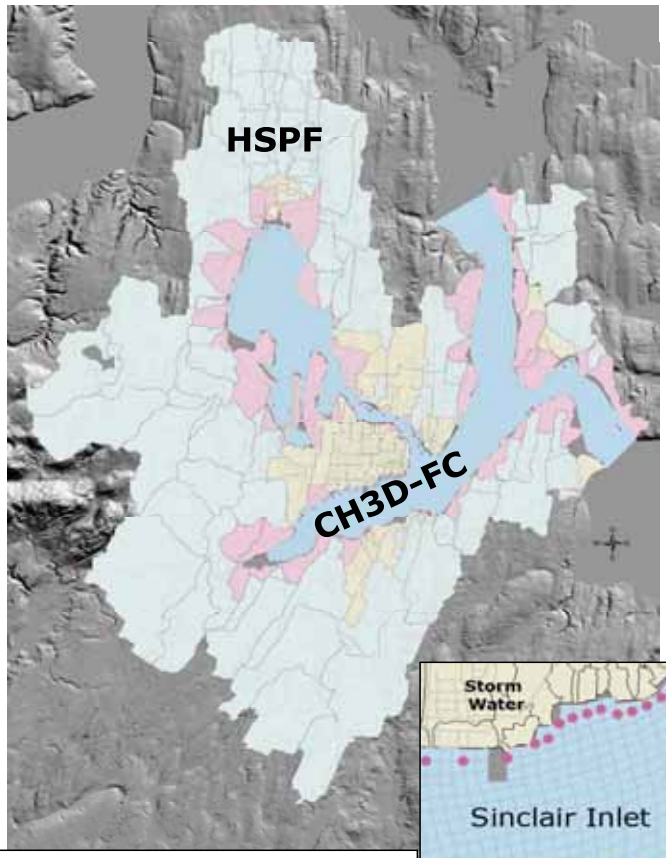
Landscape Chromatography

Sampled: n = 16:68 Streams and 18:87 Stormwater Outfalls ranging from 2 to 9,634 acres



Total Impervious Area (TIA)

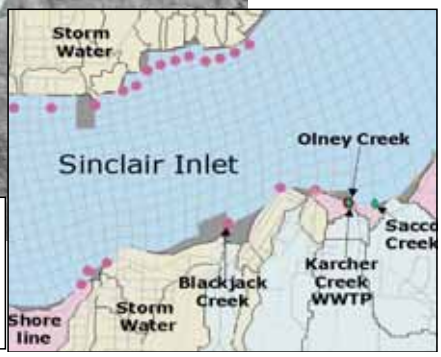




Integrated Modeling

The integrated watershed (HSPF) and receiving water (CH3D-FC) models all inputs.

Current Configuration:
39 Streams
50 Stormwater Outfalls
44 Shoreline Drainages
4 Treatment Plants
---
137 Separate Inputs



Inputs
- Stream
- Storm water
- Shoreline runoff
- Wastewater Treatment Plant (WWTP)

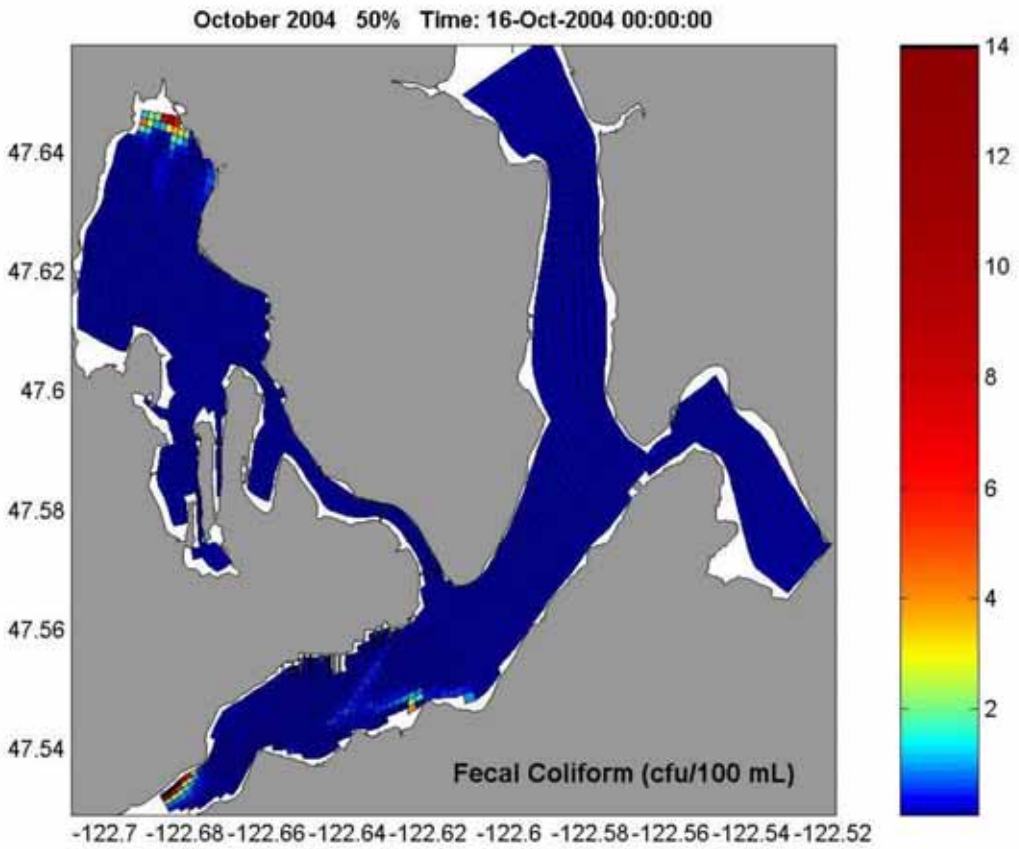
Simulation of Oct 2004 Storm Event

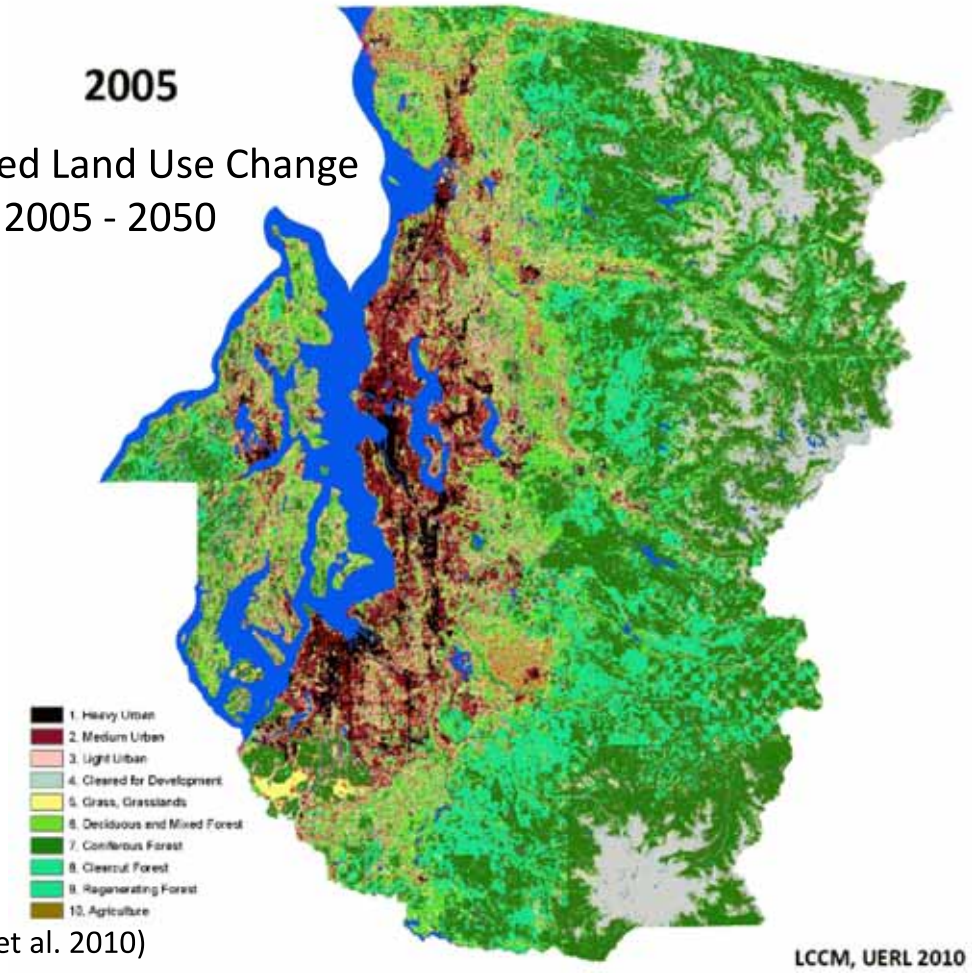
Color scale shows build up of contamination near creek mouths and nearshore areas with limited flushing

Upset condition occurred at Port Orchard treatment plant (19 Oct 24 1000)

Effect of upset evident throughout Inlets

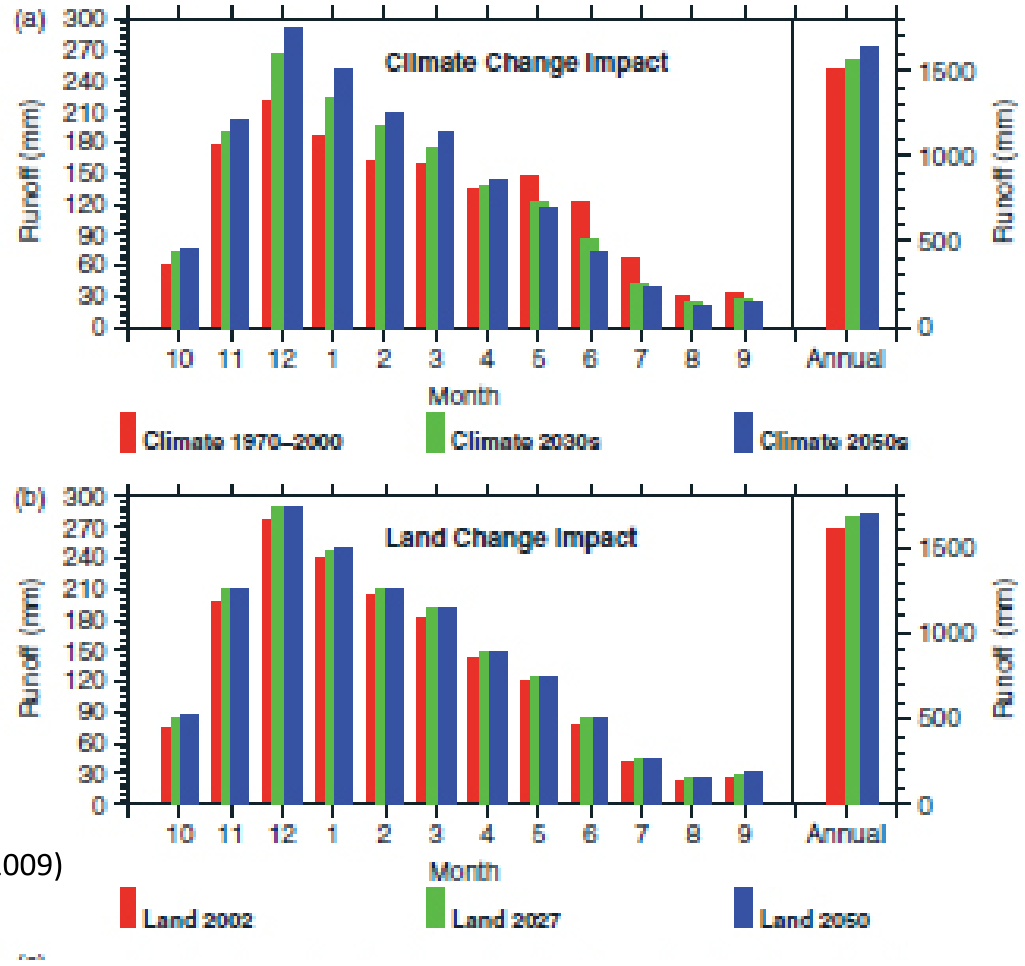
Short term effect as contamination is reduced by dispersion, mixing, and die off of harmful bacteria



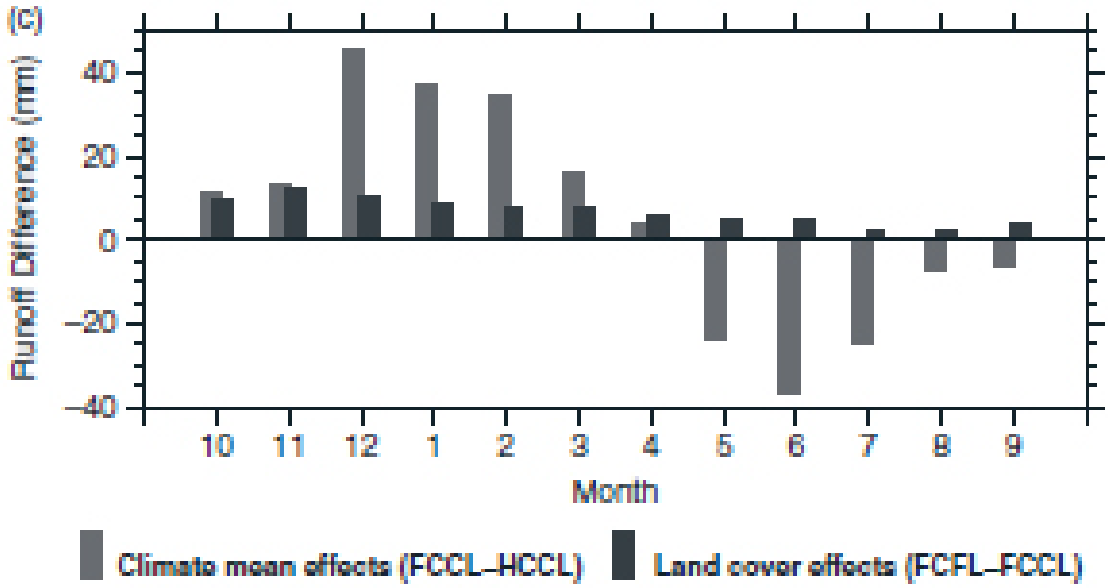


Simulated Land Use Change
2005 - 2050

(Alberti et al. 2010)



(Cuo et al. 2009)



(Cuo et al. 2009)

https://www.youtube.com/watch?v=1JDsFJJJHSY

Park in Manchester cleans the environment

BY: Chris Henry
Kitsap Sun POSTED: 9:31 PM, Aug 15, 2015 UPDATED: 9:44 PM, Aug 15, 2015

MANCHESTER — It's a park; it's a water treatment facility. It's both. Manchester Stormwater Park, recently completed, is operated by Kitsap County, and enjoyed by Manchester residents and visitors.

Copyright 2015 Journal Media Group. All rights reserved. This material may not be published, broadcast, rewritten, or redistributed.

Chris May, director for the county's stormwater division, (top left) and Kitsap County engineer Jon Brand look over the new spiral rain garden. It is the centerpiece of the new Manchester Stormwater Park. (LARRY STEAGALL / KITSAP SUN)

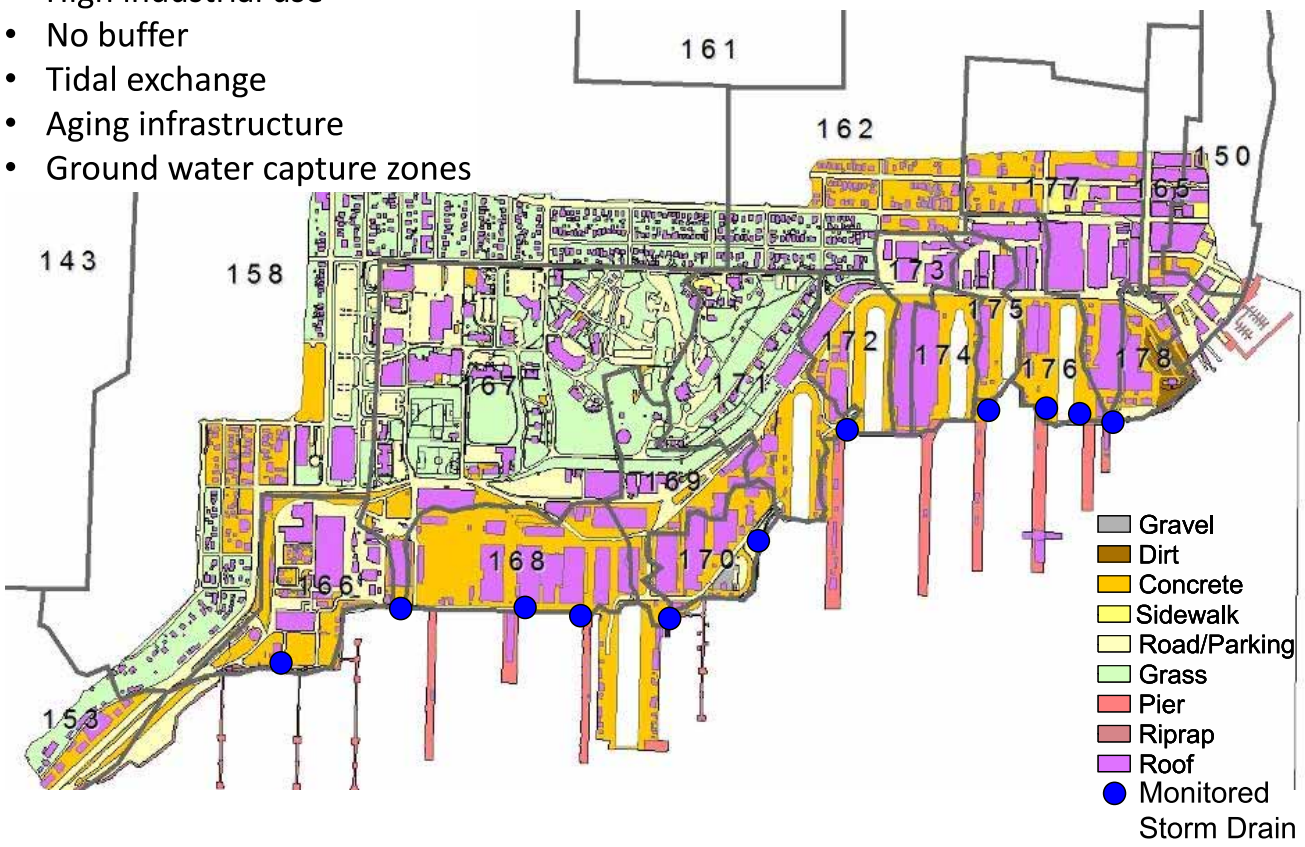
Park in Manchester cleans the environment

Manchester Stormwater Park

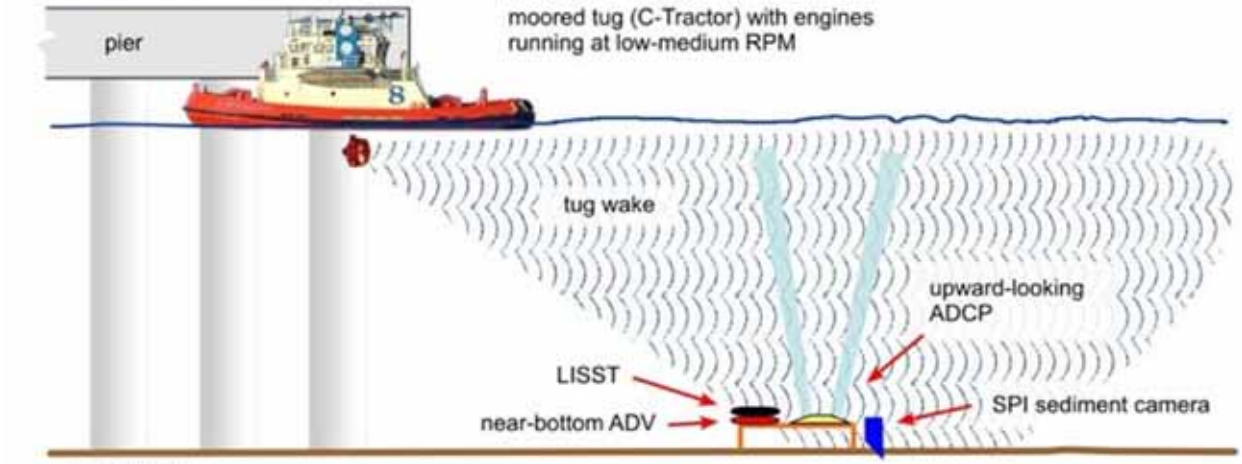
http://kitsap.paladinpanoramic.com/project/2231/44030

NBK Bremerton Stormwater Drainage Basins

- High industrial use
- No buffer
- Tidal exchange
- Aging infrastructure
- Ground water capture zones



Redistribution of Contaminated Sediment by Prop Wash



(Wang et al. 2014)

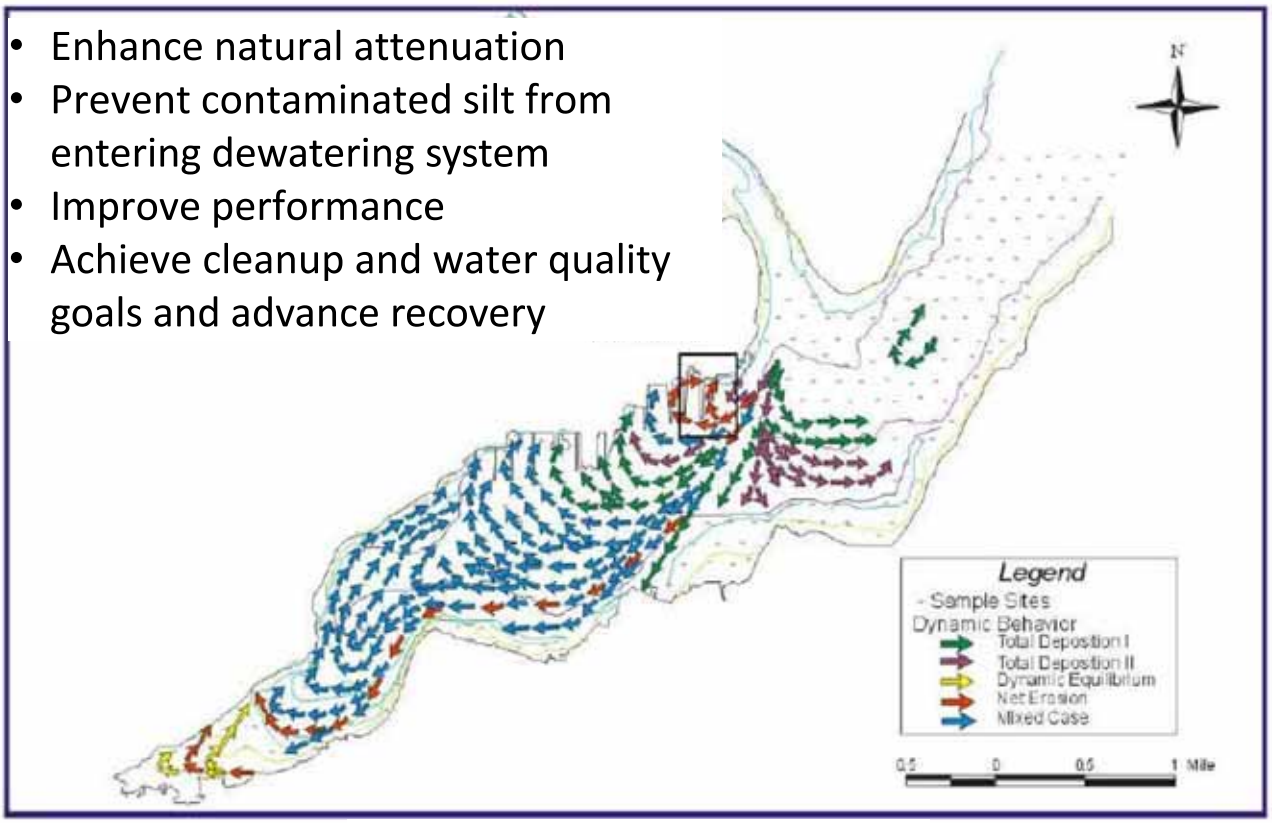
Figure 38. Sediment profile image at the Bravo site at the start (left) and end (right) of the experiment. Scale: width of each image = 14.5 cm.

(Wang et al. 2014)

Figure 41. Height of sediment and amount of suspended sediment in water column as a function of time during Bravo experiment.

How to Manage Contaminated Silts

- Enhance natural attenuation
- Prevent contaminated silt from entering dewatering system
- Improve performance
- Achieve cleanup and water quality goals and advance recovery



Sediment Trend Analysis (McLaren 1998)

SECTIONS Search... KitsapSun 48° SUBSCRIPTION

LOCAL NEWS

Feb., 25, 2016

Fish near Bremerton exposed to heavy drug doses

Drugs in Wastewater

Nanograms per liter found in wastewater from Bremerton and Tacoma.

	Bremerton	Tacoma
Amphetamine	164	67
Caffeine	1,170	152
Cocaine	59	8.5
Codeine	178	290
Cotinine (nicotine byproduct)	340	115
DEET (insect repellant)	684	23
Fluoxetine (Prozac)	57	60
Ibuprofen	1,060	116
Oxycodone	158	231
Metfromin (diabetes drug)	29,300	82,700
Valsartan (high blood pressure)	2,010	3,000

Source: NOAA, UW

Environmental Pollution 213 (2016) 254–267

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Contaminants of emerging concern in a large temperate estuary☆

James P. Meador [a, b, *], Andrew Yeh [b, 1], Graham Young [c, d, 2], Evan P. Gallagher [b, 1]

[a] Ecotoxicology and Environmental Fish Health Program, Northwest Fisheries Science Center, NOAA Fisheries, Seattle, WA, 98112, USA
[b] Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, WA, USA
[c] School of Aquatic and Fisheries Sciences, University of Washington, Seattle, WA, USA
[d] Center for Reproductive Biology, Washington State University, Pullman, WA, USA

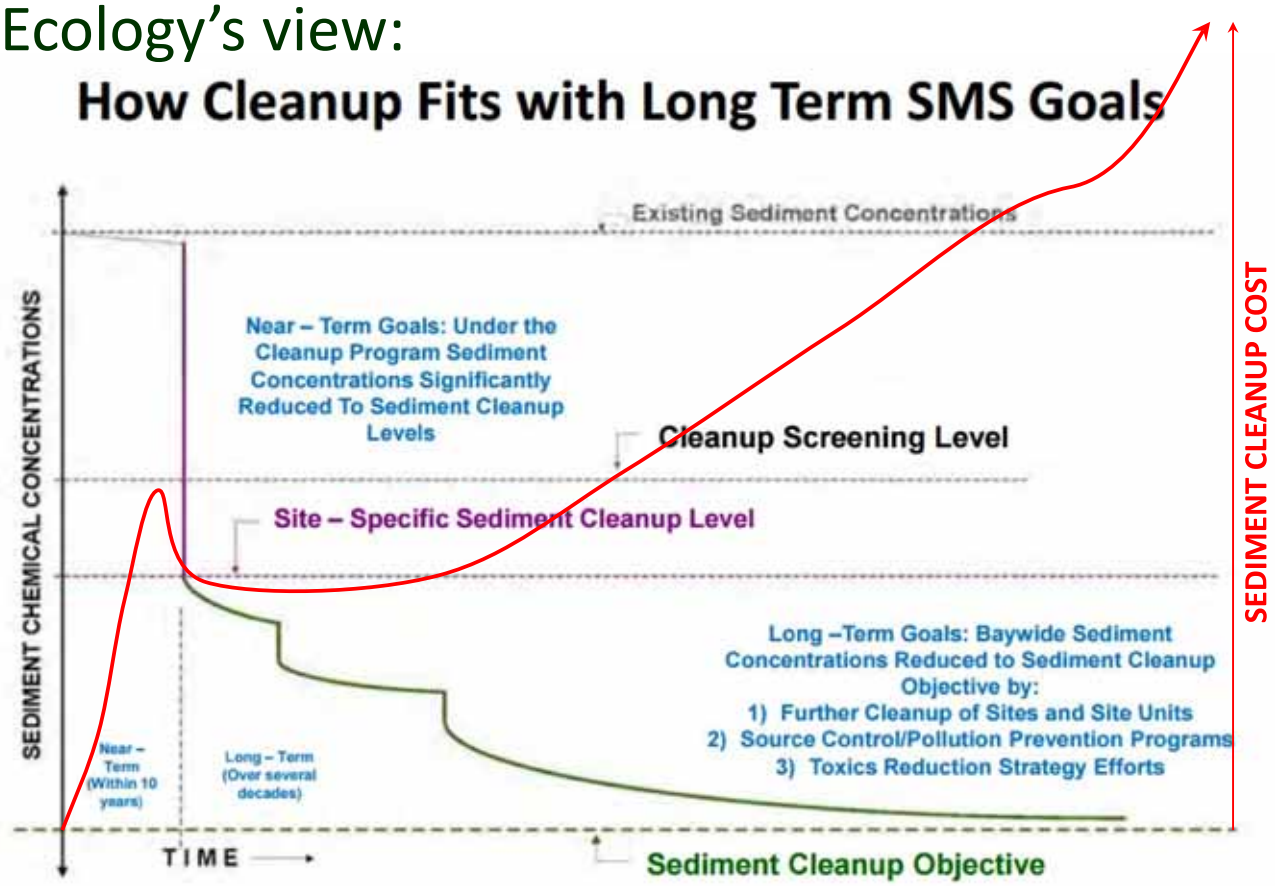
21st Century Contaminants of Concern

- Pharmaceuticals
- Personal Care Products
- Flame Retardants
- Alkylphenols
- Bisphenol A
- Phthalates
- Current use pesticides/herbicides

Integrating Environmental Quality Goals

- Overlap between Cleanup and Compliance at PSNS&IMF
  - If contaminated silt is entrained in Dry Dock drainage systems the silt could contribute to NPDES discharge permit violations
  - Dry Docks function as groundwater capture zones so contaminated groundwater from upland Cleanup sites may enter drainage system and impact NPDES discharges
  - Legacy contamination may effect Sediment Impact Zones at outfalls
- Source Control / Continuous Process Improvement
  - Effectiveness of BMPs and Process Improvement
- Partnering at watershed scale to meet recovery goals
  - Control contaminant loading to assure capacity to receive discharges and meet sediment cleanup objectives
  - Manage shifting baseline

Ecology's view:



(Anderson 2013 Sediment Management Annual Review Meeting)

Opportunities and Challenges

- Monitoring and Modeling Tools
  - Descriptive (*What?*), Explanatory (*Why?*), Predictive (*What if?)*
- Landscape Ecology / Landscape Chromatography
- Return on Investment for Restoration and Retrofit
- Watershed / Regional Management
- Integration of Cleanup, Compliance, and Recovery
- "Designing with the Environment in Mind" (ASME 2011)

References

Ahearn, Dylan, Curtis Hinman, and John Lenth, 2015. BIO RETENTION PERFORMANCE: Pacific Northwest study identifies problems & solutions. The Water Report, Issue #139, Sept 15, 2015

Alberti, M., J Hepinstall, M Marsik, S Coe, R Weeks, and Y Jang, 2010. Modeling Land Cover Change In Central Puget Sound: The LCCM Model. LCCM Research Team, University of Washington, Seattle, WA. http://urbaneco.washington.edu/wp/research/modeling-land-cover-change-in-central-puget-sound-the-lccm-model/

Anderson. I, 2013. Sediment Sites: Now What Do We Do With Them? Presented at 2013 SEDIMENT MANAGEMENT ANNUAL REVIEW MEETING (SMARM), May 1, 2013, Seattle, WA. http://www.nws.usace.army.mil/Portals/27/docs/civilworks/dredging/SMARM%20minutes/SMARM-2013-Minutes-final%20.pdf

Brandenberger J. M., E.A. Crecelius, and R. K. Johnston 2008. Draft Contaminant Mass Balance for Sinclair and Dyes Inlets, Puget Sound, Washington. Prepared for the Puget Sound Naval Shipyard and Intermediate Maintenance Facility Project ENVVEST Bremerton, Washington under Contract DE-AC06-76RLO 1830, Pacific Northwest National Laboratory, Richland, Washington

Baurick, Tristan, 2016. Fish near Bremerton exposed to heavy drug doses. Kitsap Sun 2/25/2016,

Cuo, L., Lettenmaier, D.P., Alberti, M., Richey, J.E. 2009. Effects of a century of land cover and climate change on the hydrology of the Puget Sound basin. Hydrological Processes 23 (6): 907-933

Crecelius, Eric, Robert K. Johnston, Martin Miller, Jill Brandenberger, Jim Leather and Joel Guerrero, 2003. Contaminant Mass Balance for Sinclair and Dyes Inlets, Puget Sound, WA. Paper presented at Georgia Basin Puget Sound Research Conference, Vancouver, BC, Canada April 2, 2003. http://archives.eopugetsound.org/conf/2003GBPS_ResearchConference/PAPERS/ORAL/6e_crece.pdf

Ecology 2009. Puget Sound Shorelines. http://www.ecy.wa.gov/programs/sea/pugetsound/tour/geology.html

Henry, Chris, 2015. Park in Manchester cleans the environment. Kitsap Sun POSTED: 9:31 PM, Aug 15, 2015 UPDATED: 9:44 PM, Aug 15, 2015

Johnston, R.K., Wang, P.F., Loy, E.C., Blake, A.C., Richter, K.E., Brand, M.C, Skahill, B.E., May, C.W., Cullinan, V., Choi, W., Whitney, V.S., Leisle, D.E., and Beckwith, B. 2009. "An Integrated Watershed and Receiving Water Model for Fecal Coliform Fate and Transport in Sinclair and Dyes Inlets, Puget Sound, WA." Space and Naval Warfare Systems Center, Technical Report 1977, Dec. 2, 2009. http://www.mesodat.org/Public/TR1977/

Lawrence, S., M. Roberts, Karol Erickson, and R.K. Johnston, 2012. Sinclair and Dyes Inlets Fecal Coliform Bacteria Total Maximum Daily Load: TMDL and Water Quality Improvement Plan. April 2012, revised June 2012. Washington State Department of Ecology, Northwest Regional Office, Bellevue, WA, Publication No. 11-10-051. https://fortress.wa.gov/ecy/publications/summarypages/1110051.html

Lefkovitz, L. F.; Cullinan, V. I.; Crecelius, E. A. Historical Trends in the Accumulation of Chemicals in Puget Sound; National Oceanic and Atmospheric Administration: Silver Spring, MD, 1997. https://babel.hathitrust.org/cgi/pt?id=uc1.31822009438524;page=root;seq=73;view=image;size=100;orient=0

May, Chris, Tim Beachy, Phil Struck, David Dinkuhn, Norman Olson, and Michelle Perdue, 2016. Manchester's Stormwater Park: Retrofits to help the Puget Sound's Water Quality. Stormwater May 2016. http://digital.stormh20.com/publication/?i=297444#{"issue_id":297444,"view":"articleBrowser","article_id":"2452693"} http://kitsap.paladinpanoramic.com/project/2231/44030

May, C.W. Dana Woodruff, Valerie Cullinan, Nathan Evans, Lohna O'Rourke, Lee Miller, Robert K. Johnston, P.F. Wang, Heather Halkola, K.E. Richter, B. Davidson, Victoria Whitney, and Joseph Wright, 2005. An analysis of microbial pollution in the Sinclair-Dyes Inlet Watershed. Washington Department of Ecology, Report No. 05-03-042, 428pp + Appendices. http://www.ecy.wa.gov/biblio/0503042.html

Meador, James P., Andrew Yeh, Graham Young, Evan P. Gallagher, 2016. Contaminants of emerging concern in a large temperate estuary. Environmental Pollution, Volume 213, June 2016, Pages 254–267. doi:10.1016/j.envpol.2016.01.088 http://www.sciencedirect.com/science/article/pii/S0269749116300884

Nature Conservancy in Washington and Washington State University, 2016. Solving Stormwater. YouTube https://www.youtube.com/watch?v=1JDsFJJJHSY

Thilmany, J., 2010. Designing with the Environment in Mind [Adapted from "Green Decisions" by Jean Thilmany, Associate Editor, Mechanical Engineering, March 2010.] https://www.asme.org/engineering-topics/articles/environmental-engineering/designing-with-the-environment-in-mind

Wang, Pei-Fang, Richter, K ; Rivera-Duarte, I D ; Davidson, B ; Wild, B ; Barua, R ; Liao, Q ; Germano, J ; Markillie, K ; Gailani, J 2014, "Evaluation of Resuspension from Propeller Wash in Pearl Harbor and San Diego Bay", SPACE AND NAVAL WARFARE SYSTEMS CENTER PACIFIC SAN DIEGO CA Technical Report 2036, pp 156. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA606641

CONTAMINATED SEDIMENT WORKSHOP
SUSTAINABILITY CONSIDERATIONS IN SEDIMENT MANAGEMENT

Victor S Magar, PhD, PE

August 9, 2016

RAMBOLL ENVIRON

SERDP DOD • EPA • DOE

ESTCP

Policy & Guidance
(Sustainability in Remedy Implementation)

Sustainability and the CERCLA Process

Tools to Quantify Sustainability

EPA SUSTAINABILITY GOALS

Green remediation reduces the demand placed on the environment during cleanup actions….promotes incorporation of state-of-the-art methods for:

- Conserving water
- Improving water quality
- Increasing energy efficiency
- Managing and minimizing toxics
- Managing and minimizing waste
- Reducing emission of criteria air pollutants and greenhouse gases (GHGs)

Figure 2. Best management practices of green remediation balance core elements of a cleanup project.

USEPA Technology Primer (2008): Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites, USEPA 542-R-08-002

SUSTAINABLE REMEDIATION FORUM (SURF)

Mission: Incorporate sustainable concepts throughout the remedial action process while continuing to provide long-term protection…and achieving public and regulatory acceptance

Sustainable remediation: a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources

- Minimize or eliminate energy consumption
- Reduce or eliminate releases to the environment
- Harness or mimic a natural process
- Reuse or recycle land or otherwise undesirable materials
- Encourage use of technologies that permanently destroy contaminants

CASE STUDY

ONONDAGA LAKE, HONEYWELL

HONEYWELL GREEN PRACTICES SUCCESSES
CLEAN DIESEL

Biodiesel usage replaces **3 million gallons** of standard diesel fuel, GHG emissions reduced by **6,500 $MtCO_2e$**

Biodiesel Usage at Onondaga Lake

HONEYWELL GREEN PRACTICES
SUSTAINABLE REMEDIATION

Green electric booster pumps

Powered by renewable energy; GHG emissions reduced by 18,000 $MtCO_2e$

Onondaga Lake remedial design and construction

Hydraulic dredging over mechanical; GHG emissions reduced by 52,000 $MtCO_2e$ (9,500 cars for one year)

Materials processing reuse and recycle in Syracuse, NY

6MM CY minimally processed local borrow materials; reduced GHG emissions

Recycling sediment pipeline

Recycled 37,000 lbs. used HDPE pipeline and 2,500 lbs. steel

HONEYWELL GREEN PRACTICES SUCCESSES
MATERIAL REUSE, REDUCTION AND RECYCLING

Alternative cover provides biomass

Initial GHG reduction of 27,500 $MtCO_2e$ compared to conventional cover (5,000 cars for one year); thereafter, will sequester 4,700 $MtCO_2e$ annually

Material reuse at Syracuse Visitor's Center

Using reclaimed lumber for observation decking and flooring

Onondaga Lake Conservation Corps

Hundreds of community volunteers have become environmental stewards of Onondaga Lake since 2012

Solar panels provide Camillus, NY pump station electricity

50 kW PV system with Honeywell components; GHG emissions reduced by 10 $MtCO_2e/yr$

HONEYWELL GREEN PRACTICES
WETLAND RESTORATION – MORE THAN 90 ACRES

Geddes Brook restored wetlands

Channel grade wetland and structures

Nine Mile Creek riparian areas

Riparian edge and connected wetlands

Onondaga Lake western shoreline restored wetlands

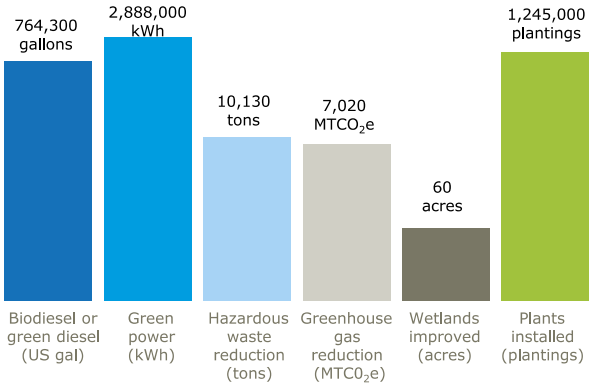
Perched and connected wetlands

Onondaga Lake

Shoreline wetlands at mouth of Nine Mile Creek

SYRACUSE, NY HONEYWELL SITE
CUMULATIVE SUSTAINABILITY METRICS - 2015 TO DATE

Over **400 hours volunteered** in 2016 for community service



RAMBOLL ENVIRON SERDP ESTCP

Policy & Guidance
(Sustainability in Remedy Implementation)

Sustainability and the CERCLA Process

Tools to Quantify Sustainability

RAMBOLL ENVIRON SERDP ESTCP

WHEN TO EVALUATE SUSTAINABILITY

- Site characterization
- Feasibility study and remedy evaluation
- Remedy selection
- Remedy design
- Remedy implementation

Sustainability needs to be considered throughout the life of the project

SUSTAINABILITY AND THE CERCLA PROCESS

Overall protection of HH and environment

Long-Term Effectiveness (Permanence)

Long-term risk reduction

Degree of certainty that alternative will prove successful

Degree of remedy permanence

Short-Term Effectiveness

Extent of environmental disturbance during remediation

Energy requirements/green engineering

Potential short-term environmental impacts

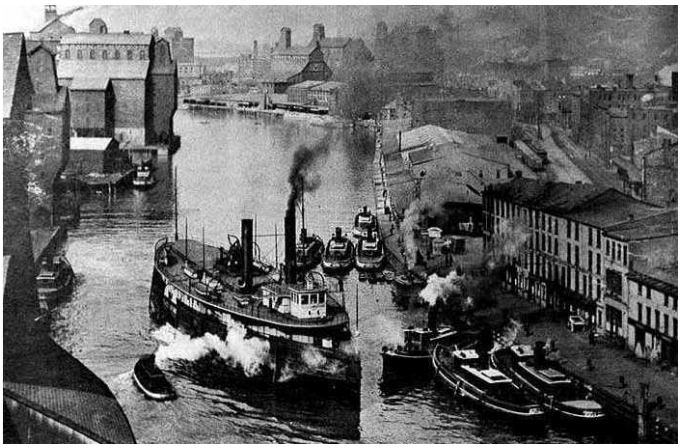
ALTERNATIVE RISK MANAGEMENT APPROACHES

Cost Sharing	1
Working with Nature	2
Adaptive management	3
Post-remediation risk evaluations	4

BUFFALO RIVER

1. Reduce human exposures to sediment contaminants
2. Reduce wildlife exposures to sediment contaminants
3. Improve the quality of future dredged sediments
4. Protect and restore habitat and support wildlife

Buffalo Harbor – Foot of Main Street, 1890's

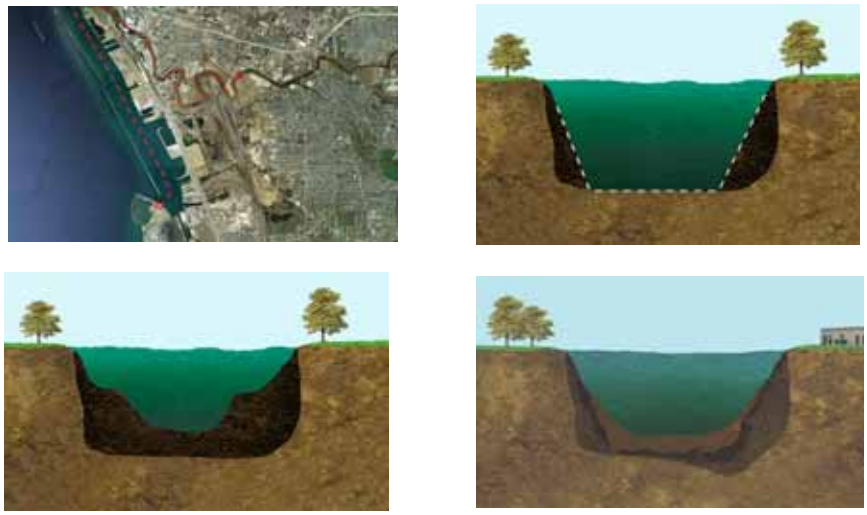


PAH TOXICITY UNIT (TU) VERTICAL PROFILES

MNR to address stable, buried deposits

Remedy based on surface exposures

DREDGING, DISPOSAL AND NATURAL RECOVERY



Cost-effective dredging

Post-removal MNR to achieve long-term Remedial Goals

Cost-effective CDF disposal at local CDF

HABITAT RESTORATION INCORPORATED INTO REMEDY DESIGN

BUFFALO RIVER LESSONS LEARNED

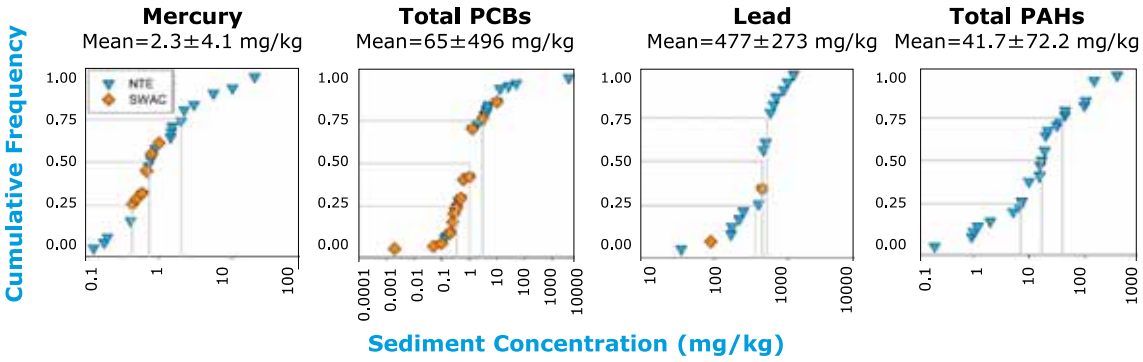
- Risk analysis focused on surficial deposits
- Removal action worked with MNR processes
  - Left buried contamination in place
  - Relied on post-removal natural deposition
- Disposal in local CDF for non-TSCA waste
  - Improved CDF to prevent dissolved chemical migration into Lake Erie
  - Substantially reduced energy use (no dewatering, limited transportation, minimal processing)
  - CDF already used for contaminated sediment
- Restoration projects addressed mitigation with remediation

ALTERNATIVE RISK MANAGEMENT APPROACHES

1. Cost Sharing
2. Working with Nature
3. Adaptive management
4. Post-remediation risk evaluations

RAMBOLL ENVIRON SERDP ESTCP

SEDIMENT PRG AND REMEDIATION GOAL INFORMATION FOR PCBS, PAHS, LEAD AND MERCURY



Notes: Gray lines indicate quartile values for each chemical
Total PCB values reflect remediation goals developed for total PCBs, Aroclors 1248 and 1254.
mg/kg = milligrams per kilogram; StDev = standard deviation

RAMBOLL ENVIRON SERDP ESTCP

Policy & Guidance
(Sustainability in Remedy Implementation)

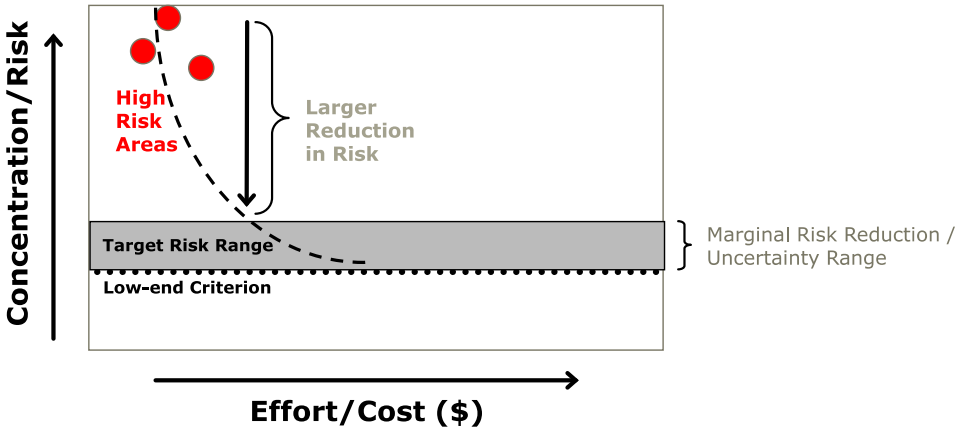
Sustainability and the CERCLA Process

Tools to Quantify Sustainability

SUSTAINABILITY TOOLS

- Energy (CO_2) modelling/monitoring
- Ecosystem services
- Net Environmental Benefits Analysis (NEBA) or Net Ecosystem Services Analysis (NESA)
- Working with Nature (USACE) https://ewn.el.erdc.dren.mil/

BALANCING THE RISK/BENEFIT OF CLEANUP



EVOLUTION OF ECOSYSTEM SERVICES IN REMEDIATION

Discussion, Approaches and Presentations

- ACES 2008, 2010, 2012
- DTSC Green Remediation Symposium (2009)
- Ecosystem Services Conference (Dec, 2008/2010)
- EPA HQ (OSWER, PARMS), Multiple 2004-Present
- EPA National Brownfield Conferences (2005, 06, 08)
- ITRC Mining Task Force (2008)
- EPA ERAF (Feb 2007): Eco-Risk Assessors
- EPA Region 5 (Oct 2008): RPM Project
- EPA Region 10 (Feb 2007): RPM's
- EPA Region 9 and BTAG (May 2007): RPM's
- Sediment Management Work Group (2007)
- SuRF: Sustainable Remediation Forum (2007)
- EPA Region 6 Site Revitalization Summit (2006)
- SETAC and ITRC Short Course 2006
- EPA Region 5 (2005): Select RPMs
- EPA Region 4 (2004); Regional Administrator
- and Staff (Eco-Risk and RPM's)
- Environmental Management Paper (2004)

EVOLUTION OF ECOSYSTEM SERVICES IN REMEDIATION

SELECT METRICS TO MEASURE SERVICES

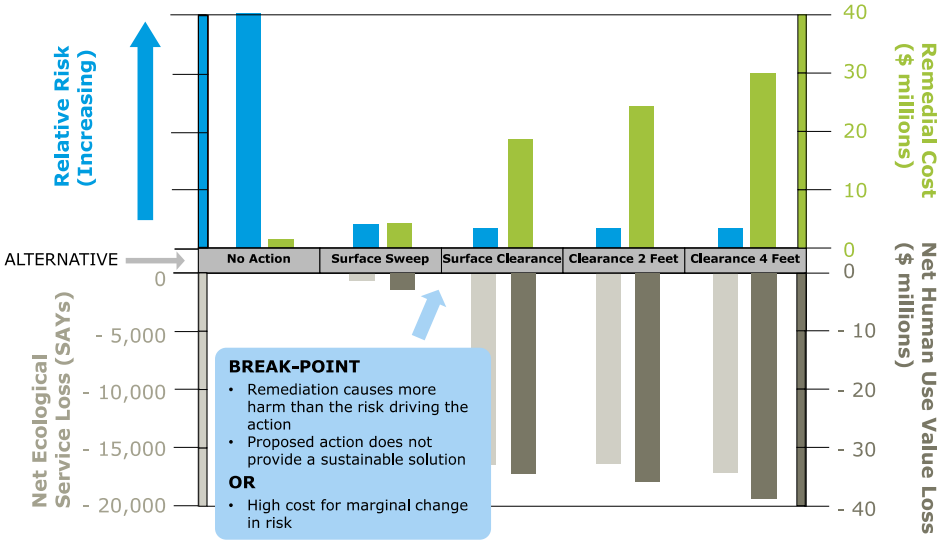
- Identify specific metrics or a combination of metrics
  - Too many services exist to practically measure them all
  - Typically, one or more metrics act as surrogates that represent all services
- Example ecological service metrics
  - Fish Density (fish/hectare, fish/km, etc.)
  - Benthic Density (# / m^2)
  - Vegetation Density (shoots / m^2)
- Example human use service metrics
  (Measured as visitor days by activity)
  - Bicycling, hiking, bird watching, etc.
  - Note: visitor days can be converted to dollars ($)
  - Fish consumption

CASE STUDY 1: SOIL REMEDIATION

- Camp Bonneville, WA
- 2,000+ acres, old growth forest Stands
- Lead and MEC Issues
- Engineering Evaluation/Cost Analysis (EE/CA)
- Needed an approach to compare the cost, benefit and risk associated with remedial alternatives

RAMBOLL ENVIRON SERDP ESTCP

CASE STUDY 1: ECOSYSTEM SERVICES ANALYSIS



RAMBOLL ENVIRON SERDP ESTCP

SEDIMENT MANAGEMENT AREAS

81 acres (48 acres)

Low-End RGO Range

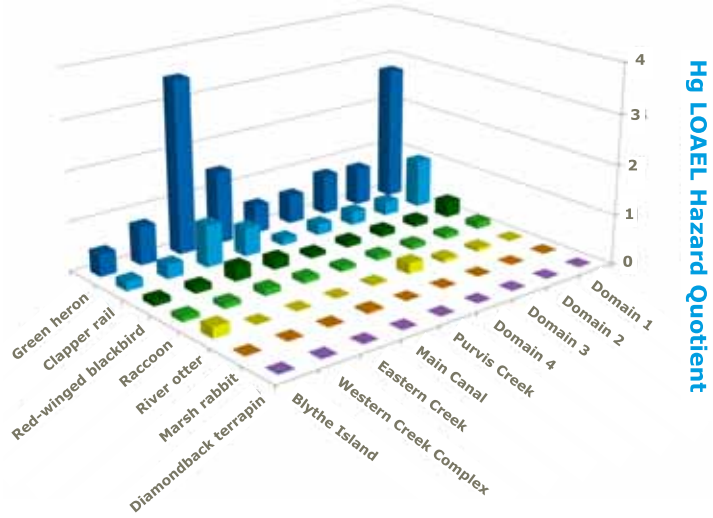
18 acres

Upper-End RGO Range

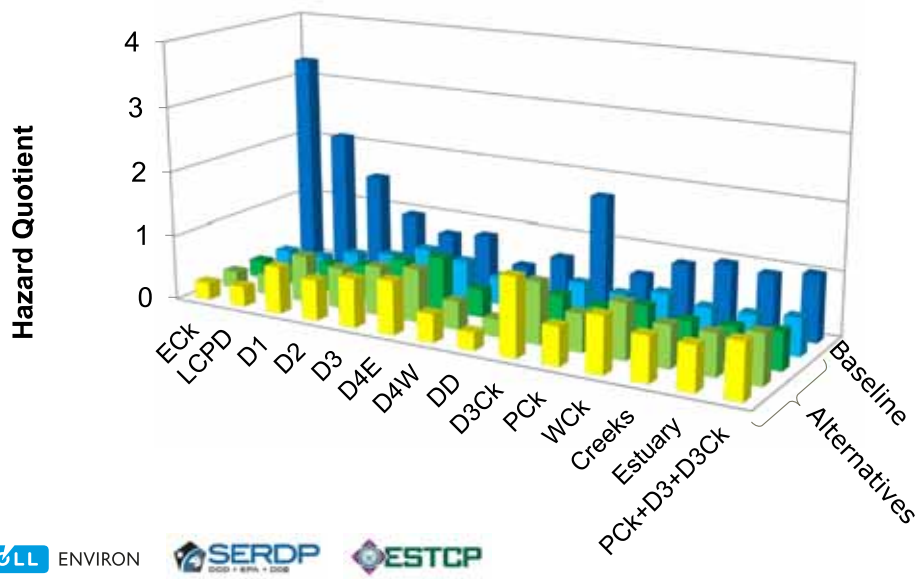
24 acres

Intermediate RGO Range

BASELINE ECOLOGICAL RISK ASSESSMENT FINDINGS FOR MAMMALS AND BIRDS

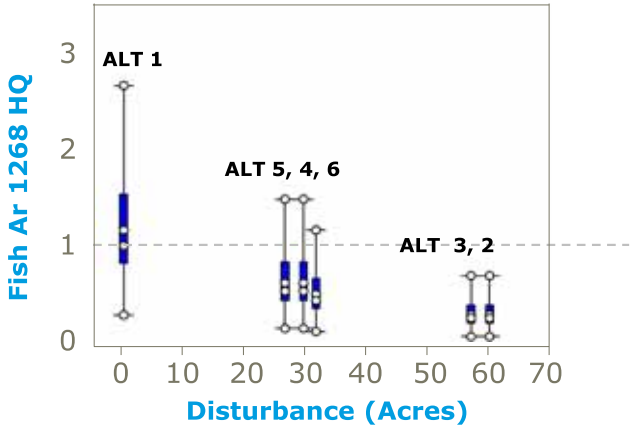


GREEN HERON MERCURY RISK REDUCTION



RAMBOLL ENVIRON SERDP ESTCP

REMEDY ALTERNATIVE COMPARISON FOR FINFISH
AREA OF DISTURBANCE



RAMBOLL ENVIRON SERDP ESTCP

Policy & Guidance (Sustainability in Remedy Implementation)

Current Focus: remedy implementation (energy reduction/efficiency and reuse)

Sustainability and the CERCLA Process

Opportunity: Integrate sustainability into all facets of the RI/FS process

Tools to Quantify Sustainability

Needs: Tools to weigh the benefits of remediation against habitat impacts, social impacts, energy use

THANK YOU

Victor S Magar, PhD, PE
Ramboll Environ
333 W Wacker Dr., Suite 2700
Chicago, IL 60606

vmagar@ramboll.com
Direct 312.288.3840
Mobile 312.731.2419