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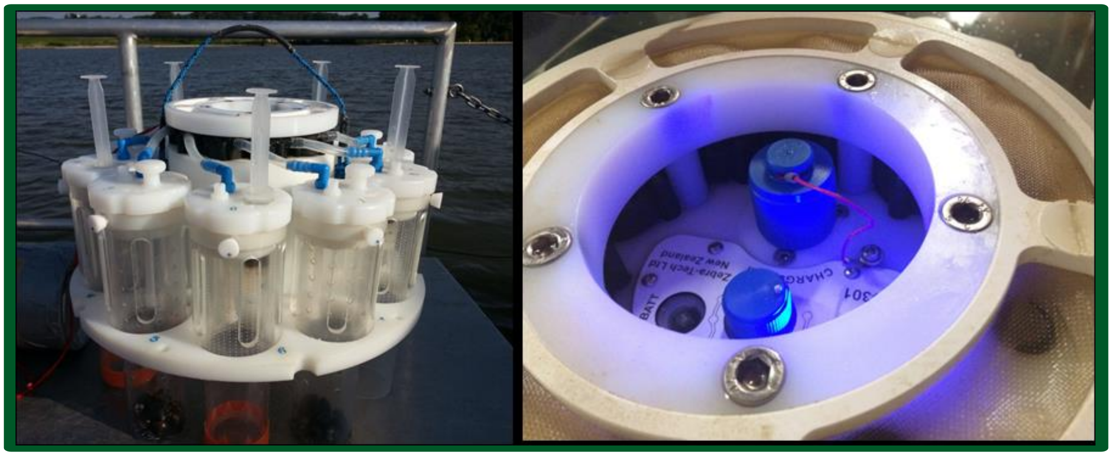

Demonstration and Commercialization of the Sediment Ecosystem Assessment Protocol (SEAP)

July 2017

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14. ABSTRACT
This project was designed to demonstrate, commercialize, and promote regulatory awareness and acceptance of the Sediment Ecosystem Assessment Protocol (SEAP), an integrated assessment ecological risk assessment approach developed under Strategic Environmental Research and Development Program (SERDP) Project ER-1550 (Burton et al. 2012; Rosen et al. 2012), that focuses largely on the performance of a field deployed device referred to as the Sediment Ecotoxicity Assessment Ring (SEA Ring).

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ACRONYMS AND ABBREVIATIONS

%	Percent
‰	Per Mille
µm	Micrometer(s)
µg/L	Microgram(s) per Liter
AMEC	AMEC Environment & Infrastructure, Inc.
AMS	Advanced Monitoring System
ASTM	American Society for Testing and Materials
BNC	Bremerton Naval Complex
CC	Chollas Creek
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
cm	Centimeter(s)
COC	Contaminant(s) of Concern
CV	Coefficient of Variations
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DDX	DDT and its degradation products DDD and DDE
DGT	Diffusive gradient(s) in thin film
DO	Dissolved oxygen
DoD	Department of Defense
ERDC	United States Army Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
ETV	Environmental Technology Verification
ft	Feet
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IMF	Intermediate Maintenance Facility
m	Meter(s)
m^3	Cubic Meter(s)
MCB	Marine Corps Base
mL	Milliliter(s)
MLLW	Mean Lower Low Water
MS4	Municipal Separate Stormwater System
NBSD	Naval Base San Diego
NESDI	Navy Environmental Sustainability Development to Integration

NISE	Naval Innovative Science and Engineering
NPDES	National Pollutant Discharge Elimination System
OF	Outfall
OF-F	Outfall Farfield
PAC	Powdered Activated Carbon
PAH	Polycyclic aromatic hydrocarbon(s)
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyl(s)
PDMS	Polydimethylsiloxane
ppt	Parts per Trillion
PSD	Passive sampling device(s)
PSNS	Puget Sound Naval Shipyard
QA/QC	Quality Assurance/Quality Control
SARA	Superfund Amendments and Reauthorization Act
SCCWRP	Southern California Coastal Water Research Project
SCUBA	Self-container Underwater Breathing Apparatus
SD	Standard Deviation
SEA Ring	Sediment Ecotoxicity Assessment Ring
SEAP	Sediment Ecosystem Assessment Protocol
SERDP	Strategic Environmental Research and Development Program
SIO	Scripps Institution of Oceanography
SOP	Standard Operating Procedure
SPAWAR	Space and Naval Warfare Systems Center
SPME	Solid-phase microextraction
SPI	Sediment Profile Imagery
TIE	Toxicity identification evaluation
TOC	Total Organic Carbon
UCSD	University of California San Diego
USEPA	United States Environmental Protection Agency
UXO	Unexploded Ordnance

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This project was supported by the Department of Defense's (DoD's) Environmental Security Technology Certification Program (ESTCP), project ER-201130. Collaborators on this project were: Mr. Gunther Rosen, PI; Dr. Bart Chadwick, Co-PI (Space and Naval Warfare Systems Center [SPAWAR] Pacific); Dr. Allen Burton, Co-PI (University of Michigan, School of Natural Resources & Environment and Cooperative Institute for Limnology & Ecosystems Research); Dr. Marc Greenberg, regulatory partner (United States Environmental Protection Agency [USEPA], Environmental Response Team); Mr. Chris Stransky and Dr. Howard Bailey (AMEC Environment and Infrastructure, Inc. [AMEC], and Nautilus Environmental, LLC., respectively); and Mr. John Radford, industry partner (Zebra-Tech, Ltd).

We gratefully acknowledge technical support from, but not limited to: Molly Colvin, Victoria Kirtay, Joel Guerrero, Brad Davidson, Bob Johnston, Chuck Katz, Ernie Arias, Pat Earley, Rob George (SPAWAR); Renee Dolecal, Nick Hayman, Jacob Munson-Decker (San Diego State University Research Foundation); Adrienne Cibor (Nautilus Environmental), Kelly Tait and Corey Sheredy (AMEC), Guilherme Lotufo and the analytical chemistry laboratory at the United States Army Engineer Research and Development Center (ERDC); Jason Conder (Geosyntec, Inc.); Brian Hester, Jay Word, and staff of the Ramboll Environ Port Gamble Bioassay Laboratory; and laboratory and field support from Dr. Allen Burton's research team (Ms. Anna Harrison, Mr. Kyle Fetters, and Dr. David Costello). Without critical field support provided by Navy divers at Puget Sound Naval Shipyard (PSNS) and Intermediate Maintenance Facility (IMF), and the USEPA Environmental Response Team at Marine Corps Base (MCB) Quantico, these efforts would not have been possible.

Leveraging with multiple Strategic Environmental Research and Development Program (SERDP), ESTCP, Navy Environmental Sustainability Development to Integration (NESDI), direct Navy and Marine Corps support, and internal SPAWAR research programs have been monumental towards completion of this project. This includes, but is not limited to leverage and collaborations associated with ESTCP Project ER-201311 (Chadwick, Kirtay, et al.), ESTCP Project ER-201368 (Chadwick, Kirtay, et al.), SERDP Project ER-2428 (Reible et al.), SERDP Project ER-1550 (Burton et al.), NESDI Project 459 (Rosen et al.), a Naval Innovative Science and Engineering (NISE) Project led by Molly Colvin (SPAWAR) to support the purchase and laboratory demonstration of Version 3 Sediment Ecotoxicity Assessment Rings (SEA Rings), and much appreciated support from Naval Base San Diego (Jessica Palmer and Len Sinfield), PSNS(Ellen Brown, Mark Wicklein, Dwight Leisle), and MCB Quantico (Fred Evans).

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

This project was designed to demonstrate, commercialize, and promote regulatory awareness and acceptance of the Sediment Ecosystem Assessment Protocol (SEAP), an integrated assessment ecological risk assessment approach developed under Strategic Environmental Research and Development Program (SERDP) Project ER-1550 (Burton et al. 2012; Rosen et al. 2012), that focuses largely on the performance of a field deployed device referred to as the Sediment Ecotoxicity Assessment Ring (SEA Ring).

The specific technical objectives of the technology demonstration were to:

1. Refine the prototype SEA Ring to be more robust, user friendly and cost-effective for commercial application, and standardize test and quality control procedures;
2. Generate sufficient pertinent and high-quality data to scientifically validate the SEAP technology, introduce the Department of Defense (DoD) user community to the technology, and promote regulatory acceptance through rigorous demonstrations at select DoD sites located in geographically diverse settings; and
3. Develop cost and performance data to support the commercialization of the technology and establish a pathway for full-scale DoD implementation.

These technical objectives were carried out at three DoD field demonstration sites and performance was assessed using previously developed performance objectives.

TECHNOLOGY DESCRIPTION

SEAP technology integrates *in situ* biological uptake and effects measures with passive sampling devices (PSDs) and physicochemical tools to assess the sediment-water interface, surficial sediment, overlying water, and advective exposure pathways at contaminated sediment sites. Minor modifications also allow for direct application to surface water exposure pathway assessment. The commercially available SEA Ring, developed and refined under this project, consists of a circular carousel capable of housing an array of *in situ* bioassay chambers and PSDs. The SEA Ring represents a valuable alternative over traditional laboratory-based approaches to toxicity and bioaccumulation testing, particularly for scenarios where laboratory testing cannot sufficiently characterize exposure or effects.

DEMONSTRATION RESULTS

Results from a total of eight SEA Ring deployments at three demonstration sites, in addition to third party technology verification under the United States Environmental Protection Agency's (USEPA) Environmental Technology Verification (ETV) program, were used to assess performance. The incorporation of the technology into monitoring at the demonstration sites provided useful data in all cases. The performance objectives of the SEA Ring largely focused on functional aspects of the commercial prototype to assess practicality for deriving high quality data with which to make site management decisions, including those at for gauging sediment remedy effectiveness and assessment of receiving water impacts from stormwater runoff.

Puget Sound Naval Shipyard (Pier 7). At Puget Sound Naval Shipyard (PSNS), SEA Rings were used at 10 stations to monitor bioaccumulation of polychlorinated biphenyls (PCBs) during a baseline event and for three years following application of powdered activated carbon (PAC), using the AquaGate+PAC™ composite aggregate system (leveraged with Environmental Security Technology Certification Program [ESTCP] Project ER-201131). The goal of the PAC was to decrease the bioavailability of PCBs, which was assessed by conducting *in situ* exposures using SEA Rings loaded with the bent-nosed clams (*Macoma nasuta*) and polychaetes (*Nephtys caecoides*) transplanted from clean sites. Pre-and post-remediation bioaccumulation results have shown that the amendment is achieving the desired performance criteria for Project ER-201131 by substantially reducing bioavailability of PCBs at the site, with post amendment site average sum PCB congener concentrations up to 90 percent (%) lower in clams and worms deployed in SEA Rings. Synoptic placement of passive samplers revealed similar reductions in porewater PCB concentrations. Performance objectives for this project were largely achieved, with a few notable challenges, including difficulty with installation and recovery at stations with cobble and/or high degrees of shell hash, and loss of some polychaetes. Contributors to worm loss included factors such as escape and predation, but also challenges with capping chambers during recovery operations. Demonstration of Version 3 SEA Rings with improved pump performance and battery longevity virtually eliminated any water quality concerns.

Marine Corps Base Quantico. At Marine Corps Base (MCB) Quantico, SEA Rings were used for assessing changes in Dichlorodiphenyltrichloroethane (DDT; and DDT breakdown products) bioavailability before and after the placement of a thin layer sediment cap. This demonstration, leveraged with ESTCP Project ER-201368, involved 14-d *in situ* bioaccumulation exposures using the freshwater Blackworm (*Lumbriculus variegatus*) and the Asian clam (*Corbicula fluminea*). Assessment of bioaccumulation potential occurred pre- and post-remediation at 5 locations where the thin layer cap was placed, and at two nearby reference locations. Overall, performance objectives were achieved with good success deploying and retrieving SEA Rings and test organisms. Clam and worm tissue for analysis of DDX, consisting of DDT and its degradation products dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE), was successfully recovered from 100% and 90% of SEA Rings deployed, respectively. As with PSNS, a substantial reduction in tissue concentrations was observed following cap installation. Within SEA Ring replicates, variability was low and similar to that of laboratory exposures, but not unexpectedly, significant differences were observed when comparing *in situ* bioaccumulation from laboratory exposures conducted on intact cores collected during the SEA Ring deployment.

Naval Base San Diego. A storm water impact assessment in the receiving waters of San Diego Bay was conducted during a series of large storm events occurring between February 28 and March 1, 2014 at Naval Base San Diego (NBSD). At several locations, SEA Rings were placed at two depths, 1- and 3-meters (m) below the surface to assess potential impacts related to vertical stratification of freshwater entering a marine environment. Four marine species were tested: 1) embryo development of the Mediterranean mussel *Mytilus galloprovincialis*; 2) spore germination and growth of giant kelp *Macrocystis pyrifera*; 3) survival of the mysid shrimp *Americamysis bahia*; and 4) survival of the polychaete worm *Neanthes arenaceodentata*. Results of the study found physical conditions in the receiving water to vary dramatically both temporally and spatially among a few of locations due to the dynamics between rainfall periods, salinity stratification, and tides/ currents.

When compared to the far-field reference site at NBSD, limited toxic effects to bivalve embryos and mysid shrimp were apparent *in situ* at a few locations where salinity was not identified as a confounding factor. With the exception of bivalve embryo development, significant effects were observed for all species exposed near the surface (top 1 m) in the Chollas Creek channel, most likely due to extended periods of low salinity. Performance objectives were achieved with good success deploying and retrieving SEA Rings and test organisms at all targeted sites. Incorporation of passive samplers (diffusive gradients in thin films [DGTs]) into the sampling program showed statistically significant relationships between labile metal concentrations and dissolved metal concentrations in composite samples collected from 8 grabs over a 24-hour period, and provided added benefit for toxicity test data interpretation. Stormwater monitoring is inherently challenging, particularly in active industrialized locations such as NBSD. The successful accomplishment of this ambitious demonstration provided confidence in using the SEAP technology for similar future efforts, with lessons learned providing a solid foundation for future use at such sites.

IMPLEMENTATION ISSUES

The ability for a third party to verify the technology with multiple species and sediment and water types under the USEPA's ETV program should instill confidence from regulators and DoD end users to consider this technology in relevant monitoring and regulatory programs. The SEA Ring technology also performed well at all three demonstration sites, providing useful data for assessing the performance of two different sediment remedies and the receiving water impacts associated with stormwater runoff. Regulatory interest was high at all three sites. Implementation is underway in numerous ways, including continued incorporation of the SEA Ring in upcoming monitoring efforts MCB Quantico, incorporation into the assessment of receiving water impacts from stormwater particles under SERDP ER-2428, ongoing use for Area of Biological Significance monitoring requirements at Scripps Institution of Oceanography (SIO), potential inclusion in future southern California Bight monitoring efforts, integration into a recently approved Navy Environmental Sustainability Development to Integration (NESDI) FY17 new start project, and potential incorporation into sediment quality monitoring at PSNS and Intermediate Maintenance Facility (IMF) under direction of Dr. Bob Johnston (Space and Naval Warfare Systems Center [SPAWAR] Pacific/PSNS). Corrective actions for all issues were identified and addressed throughout the project, which led to the development, procurement and demonstration of the commercially available Version 3 SEA Ring (Zebra-Tech, Ltd), which we recommended for end-user consideration.

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1.0 INTRODUCTION

The goal of this project was to demonstrate, commercialize, and promote regulatory acceptance of the Sediment Ecotoxicity Assessment Ring (SEA Ring), an integrative sediment and water quality assessment tool, which was developed under the Strategic Environmental Research and Development Program (SERDP) Project ER-1550. The SEA Ring integrates *in situ* biological uptake and effects measures with passive sampling devices (PSDs) and physicochemical tools to assess the sediment-water interface, surficial sediment, overlying water, and advective exposure pathways at contaminated sediment sites. Minor modifications to the SEA Ring technology also allow for direct application to surface water exposure pathway assessment. The commercially available SEA Ring consists of a circular carousel capable of housing an array of *in situ* bioassay chambers and PSDs. The SEA Ring represents an improvement over traditional laboratory-based approaches to toxicity and bioaccumulation testing, particularly with respect to scenarios where laboratory testing cannot sufficiently characterize exposure or effects.

This project leveraged with multiple other SERDP (ER-1550, ER-1749), Environmental Security Technology Certification Program (ESTCP; ER-201131, ER-0827, ER-201368), and other Department of Defense (DoD) funded demonstration programs including the Navy Environmental Sustainability Development to Integration (NESDI) program (Project #459).

1.1 BACKGROUND

Existing tools for characterizing environmental effects of contaminated sediment, the effectiveness of associated remedies, and point and non-point source impacts of surface water bodies, often rely on unrealistic and disjointed independent lines of evidence for exposure, uptake, and response, potentially resulting in inaccurate sediment or water quality management decisions. This problem is particularly acute for applications where the exposure is sensitive to disturbance, dynamic, or in general cannot be easily recreated in the laboratory. Typical examples include:

- In-place sediment remedies where the in situ interaction of the remedy with the contaminated sediment controls the exposure;
- Metal contamination in sediment which is highly sensitive to redox conditions;
- Groundwater discharge zones where the exposure is only present under field conditions;
- Underwater unexploded ordnance (UXO) where the exposure source cannot be transferred to the laboratory; and
- Stormwater discharge where the exposure is ephemeral and the exposure duration is not consistent with typical static laboratory exposures.

Consequently, there is a need for implementation and acceptance of more environmentally realistic, integrated tools that provide a synoptic assessment of exposure, uptake and response, particularly with respect to gauging the effectiveness of emerging sediment remediation technologies and the accurate assessment of the time varying stressors listed above. While *in situ* assessment technologies have been applied previously in a range of research and applied studies, application in regulatory programs has been limited by their perceived lack of experimental control, and the complexity of their application relative to laboratory methods.

Thus, for these more realistic exposure methods to gain acceptance, there is a need to improve and standardize quality controls, and to simplify field application to a level where the methods can be carried out routinely by personnel from traditional bioassay labs.

1.2 OBJECTIVE OF THE DEMONSTRATION

The technical objectives of the technology demonstration were to:

1. Refine the prototype SEA Ring to be more robust, user friendly and cost-effective for commercial application, and standardize test and quality control procedures;
2. Generate sufficient pertinent and high-quality data to scientifically validate the SEA Ring technology, introduce the DoD user community to the technology, and promote regulatory acceptance through rigorous demonstrations at select DoD sites located in geographically diverse settings; and,
3. Develop cost and performance data to support the commercialization of the technology and establish a pathway for full-scale DoD implementation.

Three demonstration sites were identified and included application for sediment site characterization, sediment remedy effectiveness verification, and sediment and water related impacts from time varying-stressors, specifically stormwater runoff. Sites were selected based on applicability of the technology, site-specific characteristics and historical data, and DoD end user interest and support. Additional criteria towards site selection were based on the desire to maximize demonstration of the technology in a range of conditions (e.g. sediment and surface water, shallow and deep water, freshwater and marine). The demonstration also included a laboratory-based comparative study with third party verification under the USEPA's Environmental Technology Verification (ETV) Program using representative species and field collected sediments to address some performance objectives.

1.2.1 Application 1: Sediment Remedy Effectiveness

The utility of SEA Ring technology towards monitoring the effectiveness of sediment amendments at the Puget Sound Naval Shipyard (PSNS) and Marine Corps Base (MCB) Quantico was assessed by placement of SEA Rings at multiple locations within, and/or adjacent to the location in which a remedy (a reactive amendment or thin layer cap, respectively) was applied. Bioaccumulation and porewater concentrations (derived from passive samplers) of contaminants of concern (COCs), and continuous water quality sensing inside exposure chambers was used in a synoptic manner to assess remedy effectiveness. Concurrent laboratory testing from select stations using standardized methods was used to evaluate performance objectives, on both quantitative and qualitative bases. Controls and reference stations were incorporated into the study design.

Variability within SEA Rings was compared with variability associated with laboratory testing using intact cores. At both Quantico and PSNS, performance objectives were used to make comparisons between SEA Ring and standard laboratory treatment results and between site samples and control sediments in both regimes. Two geographically relevant benthic invertebrate species were employed at both demonstration sites. The PSDs selected for both sites involved two different approaches using Polydimethylsiloxane (PDMS) coated solid-phase microextraction (SPME) fibers.

1.2.2 Application 2: Stormwater Effects Assessment

This assessment took place during a storm event to provide a more thorough understanding of the physical and chemical dynamics, and potential impacts to biological communities in the receiving waters in San Diego Bay during wet weather. SEA Rings were deployed at multiple locations at two depths at each location during the storm event. Stations included a permitted stormwater outfall on Naval Base San Diego (NBSD), two stations within the Chollas Creek entrance to San Diego Bay adjacent to NBSD, a waterway with historical occurrences of stormwater toxicity, and two reference stations. Four marine species were placed in each SEA Ring and exposed for the duration of the storm to evaluate organisms of different sensitivity and to measure acute and chronic, sub-lethal endpoints.

Water quality sondes and HOBO loggers were attached to SEA Rings at all sites to measure the real-time water quality that the organisms will be exposed to such as salinity, and temperature. This provided valuable data to determine if any effects observed were due to parameters outside the organisms’ tolerance range rather than sediment or stormwater-associated contaminants. Multiple stormwater grab samples were collected at each station and submitted to the analytical lab to measure for common contaminants. Diffusive gradients in thin films (DGTs), integrative passive samplers for measuring labile metals, were also deployed. Standard laboratory beaker tests were conducted with stormwater samples for comparison of results obtained through traditional lab toxicity test methods to *in situ* studies using the SEA Ring.

1.3 REGULATORY DRIVERS

PSNS and MCB Quantico (Sediment Remedy Effectiveness). The remedies at the PSNS(Pier 7) and Quantico Embayment are being conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). Implementation of the CERCLA remediation process is outlined in Title 40 of the Code of Federal Regulations (40 CFR) Part 300, National Oil and Hazardous Substance Contingency Plan. Sediment quality assessment of the specific remedy performance is required under these regulations.

Naval Base San Diego (Stormwater Effects Assessment). A National Pollutant Discharge Elimination System (NPDES) Permit (R9-2008-0061, Order CA0109169) outlines waste discharge requirements for NBSD. Under the Permit, stormwater monitoring for chemistry and toxicity is required at end of pipe locations (grab samples during the first-flush). The SEA Ring demonstration at NBSD was used to help evaluate whether traditional end-of-pipe monitoring is truly representative of potential receiving water impacts.

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2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The SEA Ring (U.S. Patent No. 8,011,239) is an integrated, versatile, field tested, toxicity and bioavailability assessment device. The patented (first generation) version was derived from an integration of existing and emerging peer-reviewed technologies developed by SERDP and other environmental research programs, with initial demonstration of proof of concept field testing during SERDP ER-1550 (Burton et al., 2012, Rosen et al., 2012). The device was designed to assess exposure and effects assessment within the water column, sediment-water interface, and/or surficial sediment (**Error! Reference source not found.**). Small sediment dwelling organisms can be introduced into surficial sediment toxicity exposure chambers *in situ* post placement through the organism delivery port built into the cap with a modified 30 milliliter (mL) plastic syringe that will hold the pre-loaded test species. The syringe is capped with a silicone stopper to retain the organisms until desired release by a diver or trigger system operated from the surface. For larger organisms, a 0.5 inch flexible titanium mesh is integrated into the bottom of the exposure chamber opening, allowing organisms to be pre-loaded without the use of the syringe mechanism (Figure 2.2).

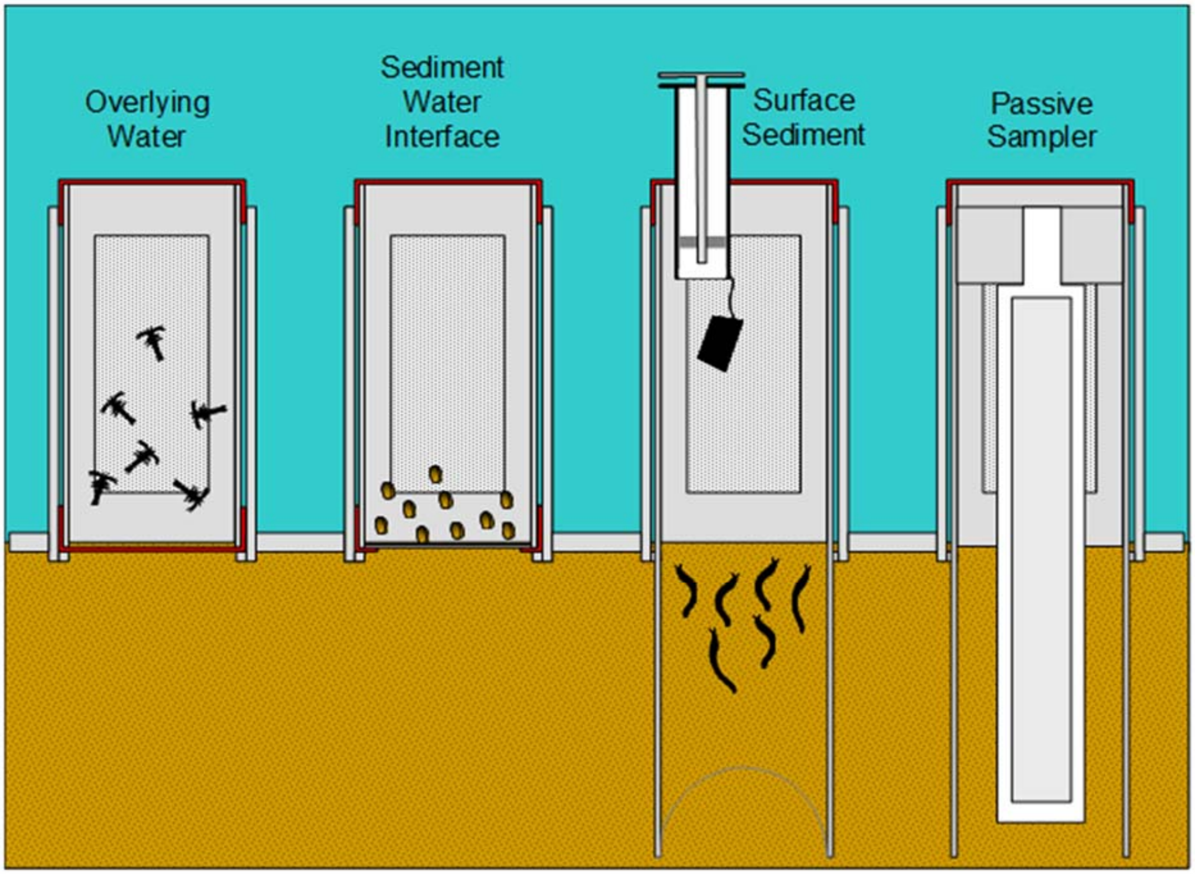


Figure 2.1. Conceptual Diagram of Different Exposure Options Possible with the SEA Ring System.

Version 2 and Version 3 SEA Rings (Figure 2.3) were developed and validated under this project, to bridge the gap between laboratory and classical *in situ* bioassays by providing enhanced control over the exposure by means of a highly standardized system that includes controlled pumping, improved water quality maintenance, continuous water quality measurements, and the ability to integrate other measures such as passive sampling, all of which can be used towards improving the characterization of exposure and effects while maximizing certainty with data interpretation. These advanced designs are more user friendly, more autonomous, and are commercially available from Zebra-Tech, Ltd (http://www.zebra-tech.co.nz/). The technology history is provided in Table 2.1-1.

Figure 2.2. Smaller Organisms (e.g. Polychaetes and Amphipods) Are Delivered by Preloaded Syringes while Larger Organisms (e.g. Clams) Are Placed into Chambers Prior to Deployment.

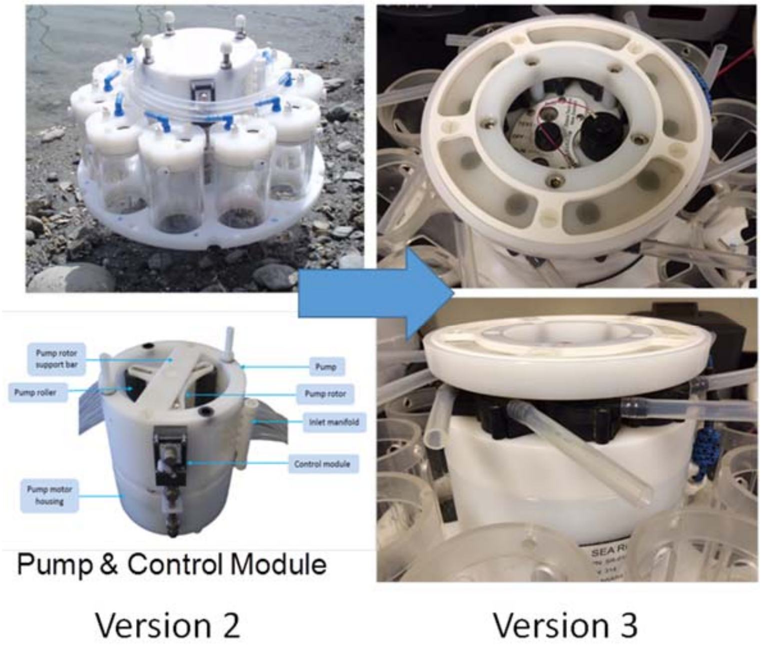


Figure 2.3. Second (left) and Third (right) Generation SEA Rings Acquired and Demonstrated During this Project.

Version 3 is commercially available from Zebra-Tech, Ltd.

Table 2.1-1.Technology Development and Demonstration History.

Development Phase	Time Frame	Project(s)	References
Literature review and laboratory assessment (SERDP ER-1550) to optimize range of standard test organisms and endpoints	2008-2009	SERDP ER-1550	Burton et al. 2011 Burton et al. 2012 Rosen et al. 2009a Rosen et al. 2012
Proof of concept demonstrations of Version 1 device at NBSD, Naval Air Station Pensacola, and Chollas Creek in San Diego Bay	2007-2009	SERDP ER-1550	Rosen et al. 2009b Burton et al. 2012 Rosen et al. 2012
Demonstration of Version 1 device at MCB Quantico to support baseline characterization	2009	ESTCP ER-0827	Chadwick et al. 2009
Delivery and Testing of Second Generation SEA Ring (Version 2)	2011	ESTCP ER-201130 NESDI #459	SEA Ring Operation Manual (Appendix C)
USEPA ETV Testing	2012-2013	NESDI #459 ESTCP ER-201130	McKernan et al. 2014
Site 1 (PSNS) Demonstration	2012-2015	ESTCP ER-201130 ESTCP ER-201131 NESDI #459	Kirtay et al. (2016); This Report
Site 2 (Quantico) Demonstration	2012-2015	ESTCP ER-201130 ESTCP ER-201131 NESDI #459	This Report
Site 3 (NBSD) Demonstration	2014	ESTCP ER-201130 NESDI #459	This Report; Stransky et al. (in prep)
Delivery and Demonstration of Version 3 device	2015-2016	SSC Pacific Naval Innovative Science and Engineering (NISE), ESTCP ER-201130	This Report
Demonstration of Version 3 at Paleta Creek	2016	SERDP ER-2428	Reible et al. (2016)

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The development, use, advantages, and disadvantages of *in situ* bioassays have been reported extensively in the peer-reviewed literature (e.g. Burton et al. 1996, Pereira et al. 2000, Sibley et al. 1999, Chappie and Burton 2000, Geffard et al. 2001, Kater et al. 2001, Anderson et al. 2004, Phillips et al. 2004, Burton et al. 2005, Crane et al. 2007, Liber et al. 2007, Rosen et al. 2009). Our experience with the Version 3 SEA Rings largely echo the advantages and limitations in the literature, but with the added advantages as pointed out below.

ADVANTAGES

- Provide greater realism by exposing test organisms to actual concentrations/conditions
- Take into account spatial and temporal variability of contaminant exposure
- Better assessment of effects from volatile or time-varying contaminants/stressors
- Integrate multiple stressors, both natural and anthropogenic
- Minimize changes in sediment by reducing sampling and manipulation

- Increase ability to interpret organism response when combined with laboratory studies
- Site-specific placing to identify toxic sources
- Minimize sample collection and shipping costs
- Sample holding time concerns are eliminated

LIMITATIONS

- Reduced control of natural non-treatment factors (e.g., water quality, indirect effects)
- Challenges with caging test organisms (e.g., flow restrictions, escape from chambers)
- Issues associated with feeding for some species
- Transportation and acclimation challenges during cage deployment
- Physical disturbance of test chambers
- Predation and competition
- Risk of equipment loss (e.g., weather, vandalism)

3.0 PERFORMANCE OBJECTIVES

Performance Objectives for this demonstration were divided into quantitative objectives (objectives that were measured against a standard or set criteria to demonstrate success) and qualitative objectives (objectives that require a particular quality during use of the technology or in the end result). Table 2.2-1 outlines the performance objectives, success criteria, and brief results for evaluating performance.

Table 2.2-1. Performance Objectives for the Demonstration of the SEA Ring Technology.

	Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1	Water quality maintenance	Within chamber and ambient dissolved oxygen (DO), salinity, pH, temp, and/or ammonia (NH_3)	SEA Ring chamber ± 50% of ambient conditions	Met in most cases. Water quality met criteria in the ETV study and in situ demonstrations using Version 3 SEA Rings. In some cases, DO was reduced to <50% of ambient inside the chambers of Version 2 SEA Rings when pump units stopped pumping prior to recovery, or in sediments with particularly high oxygen demand.
2	Pumping rate	Water exchange rate within all 10 exposure chambers on a SEA Ring	Volume exchange rate varies by <50% across chambers; minimum 6 volume turnovers per day	Met. Flow rate varied 3-9% within a SEA Ring (inclusive of both Version 2 and Version 3 pump designs). A minimum of 14 turnovers per day was achieved across all demonstrations, which increased by up to an order of magnitude (~140 turnovers per day) with introduction of more efficient pumps in the Version 3 unit.
3	Sediment/organism recovery	Recovery rate of sediment and/or organisms across chambers/Rings	Recover sediment and/or organisms 80% of the time (e.g. 4 out of 5 replicates)	Met. Successful recovery of organisms averaged 80-100% for 6 species, except for one species, (*Nephtys caecoides*) which averaged 60% in the field.
4	Control performance	Survival or sublethal effects data in SEA Ring and laboratory tests	No statistical difference and <25% difference between beaker and lab tested SEA Ring control samples (ETV)	Met. No statistical difference and difference between SEA Ring and lab beaker control in ETV testing ranged from 0 to 11% for five species (and six toxicity test endpoints).
5	Completion rate (Completeness)	Percentage of SEA Ring chambers recovered with useful data	≥80% recovery rate of SEA Ring chambers providing useful data	Met. For site demonstrations, SEA Rings were deployed at a total of 69 stations, 66 (96%) of which provided useful data. Of the eight species used in the site demonstrations, seven provided >80% recovery rates, while the polychaete (N. caecoides) resulted in 60% average recovery.

Table 3-1. Performance Objectives for the Demonstration of the SEA Ring Technology (Continued)

	Performance Objective	Data Requirements	Success Criteria	Results
6	Successful identification of confounding factors	Continuous water quality measurements (DO, salinity, temperature, and pH) in select SEA Rings. NH_3 measurements at test initiation and termination. Sediment grain size.	>90% completion success for proposed water and sediment quality measurements	Met. Critical parameters were documented on a site-specific basis and used to interpret organism recoveries/toxicity in 100% of deployments and SEA Rings deployed.
7	Contaminant uptake	Concurrent assessment of laboratory beaker and SEA Ring tissue concentrations	No statistical difference and <25% difference between SEA Ring and laboratory uptake in controlled lab (ETV) exposures	Met, for two of three species used in the ETV study. Amphipod bioaccumulation was not statistically different but averaged 44% higher in the laboratory tests compared with the SEA Ring study. High variability among replicates both in lab and SEA Ring was likely associated with observed amphipod rejection of the polychlorinated biphenyl (PCB) contaminated sediment during first few days of the exposures.
Qualitative Performance Objectives				
8	Ease of operator use	Information from commercial partners and end users	Positive feedback from commercial partners/users	Met. USEPA and Navy divers quickly understood operation and use of the technology. Review of diver videos and feedback indicated that deployment and recovery operations were challenging at stations with cobble, high shell hash, or other obstructions, while fine grained sediments were easy for such efforts. AMEC Environment & Infrastructure, Inc. (AMEC) and Nautilus commercial partners have routine success using the technology in other monitoring programs.
9	Integration of passive samplers	Inclusion of relevant passive samplers in SEA Ring deployments	Successful integration and recovery of passive samplers	Met. SPME or DGTs were successfully integrated for all events and sites, and provided added value to assessments.
10	Diverless deployment and recovery	Accurate depth and spatial placement of SEA Rings; feedback from divers on improved ease or elimination of capping of open-bottomed sediment chambers	Verification that SEA Rings remained in place where initially anchored[1]; positive diver feedback	Partially met. Deployment of SEA Rings was completed successfully without the use of divers for the demonstration at NBSD. For the PSNS and MCB Quantico demonstrations, divers were integrated in to the field design. Promising sediment capture devices were evaluated for different sediment types, but require further optimization for a completely diverless system.
11	Cost-benefit	Lab and SEA Ring costs and overall comparison of value between methods	Value of improved certainty of ecological risk relative to actual cost of technology	Met. Costs, outlined in the Cost Analysis section of this report, are comparable to laboratory based testing, and we believe benefits of improved accuracy, and better management decisions, warrants implementation of this technology for various applications.

4.0 SITE DESCRIPTION

4.1 SITE LOCATIONS

4.1.1 Puget Sound Naval Shipyard

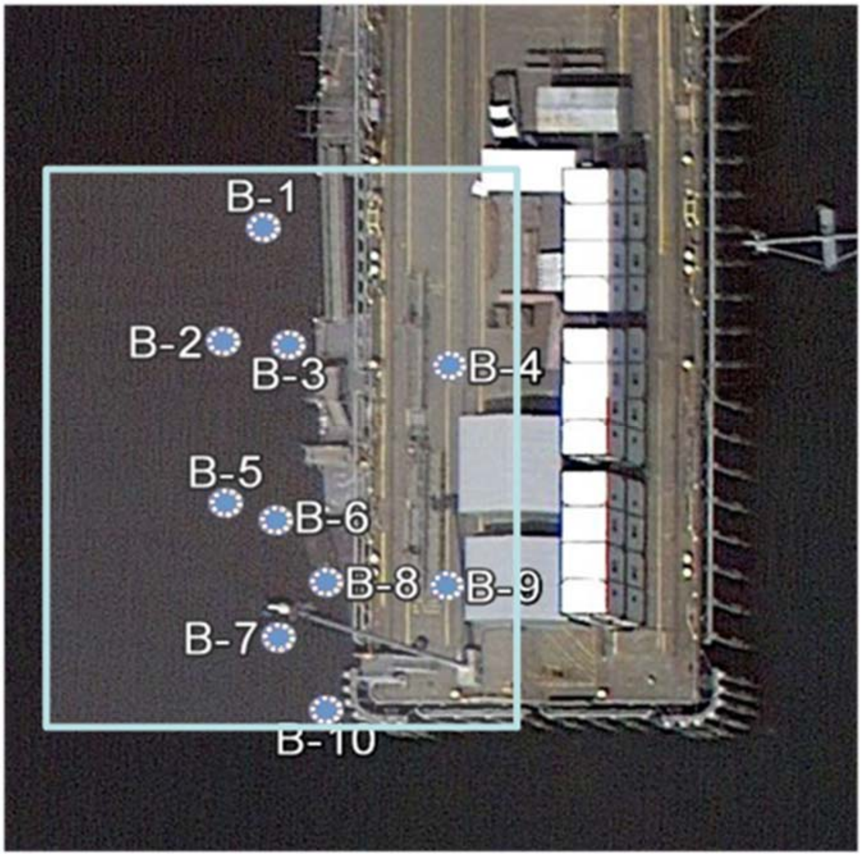


Figure 4.1. PSNS Pre- and Post-amendment Assessment Locations using the SEA Ring Technology.

Blue square is targeted outline of reactive amendment placement.

One of the sites selected for demonstration of the SEA Ring technology was Pier 7 at the PSNS and Intermediate Maintenance Facility (IMF), part of the Bremerton Naval Complex (BNC; Bremerton, WA). PSNS has six dry docks, eight piers and moorings, and numerous industrial shops to support the industrial operations. The specific location for the field demonstration was identified as the southwest corner of Pier 7, located at the Shipyard's eastern end (Figure 4.1), where both PCBs and mercury (which is co-located with the PCBs) were listed as COCs.

4.1.2 Marine Corps Base Quantico

Quantico Embayment is a semi-circular inlet of the Potomac River (Figure 4.2). Its surface area is approximately 190 acres. Within the southern half of the bay, and approximately 500 feet (ft) from the shoreline, is a 12-acre private island called Chopawamsic Island.

A broad shelf between 3 to 5 ft depth is located northeast of the island, and a historical river channel left a small depression approximately 16-20 ft deep west of the island. In general, the water depths of the bay range from tidal level along the shoreline to 5 to 6 ft where the bay meets the Potomac River.

Figure 4.2. Sampling locations for MCB Quantico site. The area in green represents where a thin-layer sand cap was installed in April 2014.

Cap area encompasses sediment with surface sediment DDX concentrations greater than or equal to 200 micrograms per kilogram.

4.1.3 Naval Base San Diego

NBSD (Figure 4.3) was selected as the site to assess the time-varying stressor of contaminated stormwater discharge to a receiving environment. The base borders southeast San Diego Bay. Toxicity and chemistry of wet weather runoff have been routinely measured in outfalls and receiving water off NBSD for compliance with NPDES storm water discharge permits. The north end of the site borders Chollas Creek, drains from a highly urbanized watershed adjacent and through Navy property to San Diego Bay, and has a history of storm water toxicity (Katz et al. 2006). The placement of SEA Rings at multiple sites with possible varying degrees of contamination, along with concurrent laboratory tests, was important to demonstrate whether the organisms exposed to a sample in the SEA Ring have the potential to exhibit effects similar to those exposed to the same site water in the laboratory.

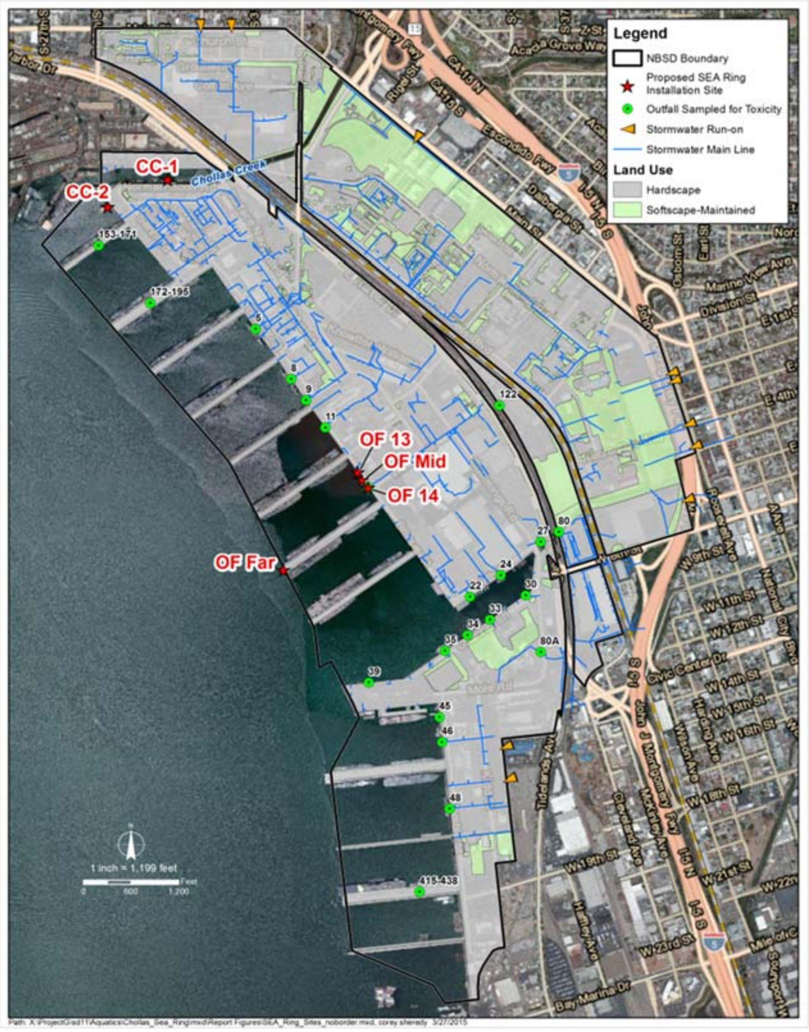


Figure 4.3. NBSD - SEA Ring Installation Sites.

CC = Chollas Creek, OF = Outfall. Space and Naval Warfare Systems Center (SPAWAR) Reference Site not shown.

4.2 SITE GEOLOGY/HYDROLOGY

4.2.1 Puget Sound Naval Shipyard

Nearshore sediments along the north shore of Sinclair Inlet and in the central inlet are dominated by silt and clay, while those along the south shore are predominantly sandy. Coarser sediments are only present in intertidal areas affected by significant wave action (e.g., Ross Point). The implications of the depositional nature of the inlet are for contaminated sediments to remain resident in the inlet for long periods. Tidal currents and winds are the primary sources of water circulation in Sinclair Inlet. Weak tidal currents move water in and out of the inlet with a maximum velocity of 0.2 to 0.3 knots. Analysis of tidal currents in 1994 indicated residual current speeds of less than 0.2 knots (10 centimeters [cm] per second) for more than 90% of the time, regardless of site location, water depth, or season. Residual current speeds higher than 0.2 knots were rare, and speeds higher than 0.4 knots occurred less than 0.5% of the time.

Surface currents generally flow out of the inlet, although surface current flow into the inlet has been observed during summer months. Near-bottom currents primarily flow into the inlet, regardless of season. Currents are generally not capable of resuspending bottom sediments.

4.2.2 Marine Corps Base Quantico

This location is defined predominantly as a freshwater system, with minimal tidal influence (between 0.3 meter [m] to 0.7 m tidal range). Surface water salinity at this site ranges from between 0.5 to 3 practical salinity units, with the higher salinity occurring during lower river flow conditions in the late summer and early fall. Sediment is typically fine-grained, with greater than 55% silt and clay (Battelle and Neptune 2004). More coarse-grained sediment is located along the shoreline and adjacent to outfalls, and finer-grained sediment (with greater than 80% silt and clay) is located in outer areas of the embayment (Battelle et al., 2007). Based on the grain size distribution and evidence of low flow velocities within the embayment, it is assumed that this site is depositional in nature.

4.2.3 Naval Base San Diego

San Diego Bay is 15 miles long and varies from 0.2 to 3.6 miles in width. It is 17 square miles or about 11,000 acres in area at mean lower low water (MLLW; Wang et al. 1998). A sand spit, deposited by a northward-bound eddy of the coastal current on the west, separates the bay from the sea. Historically, the transported sand was laid down from deposition emanating from the Tijuana River. However, since the damming of the river in 1937, the sand supply has been cut off and northern beaches have undergone severe erosion (Peeling 1975). Zuniga Jetty, which runs parallel to Point Loma at the bay's inlet, was built to control erosion near the inlet, changing the bay's hydrodynamic characteristics by diverting both northward-bound sediment and currents (Wang et al. 1998). Rugged Point Loma hooks around the north side of the bay, cutting off the ancient floodplain of the San Diego River, which throughout its evolution alternatively drained into San Diego or Mission Bays. With a water volume of about 230,000 cubic meters (m3) (Peeling 1975), the bay's depth ranges from 59 feet (ft) (18 m) near the mouth to less than 3 ft (1 m) at the south end. It has an average depth of 21 ft (6.5 m) measured from mean sea level (Wang et al. 1998).

Freshwater contribution to the bay comes primarily from the Otay and Sweetwater Rivers and secondarily from several creeks: Telegraph Canyon (south of Sweetwater River Basin), Chollas Creek (north end of Naval Depot south of National Steel and Shipbuilding Company), Switzer Creek (near Tenth Avenue Marine Terminal), Paleta Creek (7th Street Channel, south of Naval Repair Base), and Paradise Creek (south of Paleta), as well as some minor drainage groups. Freshwater input is now limited to surface runoff from urban areas (e.g. the over 200 storm drains and intermittent flows from several rivers and creeks after storms). For about nine months of the year, the bay receives no significant amount of fresh water.

4.3 CONTAMINANT DISTRIBUTION

4.3.1 Puget Sound Naval Shipyard

Pier 7 lies within an area known as Operable Unit B Marine that was previously subject to a Superfund sediment cleanup (USEPA 2000). The primary components of the remedial action included dredging, disposal in a pit excavated in the sea floor in Sinclair Inlet, capping of contaminated sediments in a small area at the southwest end of the naval complex and placement of a thin layer of clean sediment to promote recovery of sediments (enhanced natural recovery) in the area around the cap, stabilization of a section of shoreline in the center of the naval complex and allowing for the ongoing processes of sediment natural recovery to continue to decrease the residual contamination throughout the area over a period of 10 years (US Navy 2008).

The areas within Operable UnitB Marine found to have the highest PCB levels were identified for dredging. The highest levels of PCBs were found mostly in areas along the shoreline or adjacent to the moorings and piers (e.g., Pier 7) of the BNC. A limited amount of additional dredging was included in the remedial action based on a combination of elevated mercury levels and moderately-elevated levels of PCBs. A more comprehensive description of the site is provided in the Final Technical Report for ESTCP Project ER-201131 (Kirtay et al., 2016).

4.3.2 Marine Corps Base Quantico

The Quantico Embayment and adjacent habitats, including the Southern Wetlands, have historically received numerous potential contaminants from several sources. These sources include the Site 4 Old Landfill, the Former Pesticide Control Building, the Mainside Sewage Treatment Plant, and the active Marine Corps Air Facility Quantico.

In addition, a number of historical and current stormwater outfalls had or have discharge points draining to the Quantico Embayment. Prior to the separation of the storm and sanitary sewer systems at MCB Quantico, these outfalls may have been a source of chemical constituents to the embayment from various operations (e.g., maintenance facilities, floor drains, wash racks). Six outfalls are currently regulated under NPDES permits, and drain directly into the Southern Wetlands and/or Quantico Embayment. Of these, two outfalls discharge non-contact cooling water and steam condensate, and one discharges steam condensate only. NPDES permitted outfalls within MCB are not expected to be a significant current source of potential contamination; non-NPDES permitted outfalls are also not expected to be continuing sources of potential contamination as they only drain storm runoff from buildings and parking lots (Battelle, 2009). Present chemical inputs to Quantico Embayment from Potomac River sources are considered minimal (Battelle and Neptune, 2004).

Although COCs at this site included polycyclic aromatic hydrocarbons (PAHs), metals, chlorinated pesticides, and PCBs in both surface (0 to 10 cm) and subsurface (greater than 10 cm) sediment, the presence and concentration of DDX compounds drove the requirement for site remedy. DDX compounds, consisting of dichlorodiphenyltrichloroethane (DDT) and its degradation products dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE), have generally been measured at the highest concentration levels in the northern portion of the inner portion of the Quantico Embayment adjacent to the northern edge of the Site 4 Old Landfill and adjacent to the potential runoff stream from the Former Pesticide Control Building. Sediment sampling suggests that DDX concentrations both increase with depth in the sediment and are generally highest in the near-shore area, hence the placement of the thin layer cap (Figure 4.2).

4.3.3 Naval Base San Diego

Chemical contaminants that are currently of primary concern in San Diego Bay include various heavy metals and organic (chlorinated pesticides and petroleum hydrocarbon) pollutants. A recent regional monitoring program by the Southern California Coastal Water Research Project (SCCWRP; Bight ‘08) also identified pyrethroids and, to a lesser extent, polybrominated diphenyl ethers (PBDEs) in sediments from San Diego Bay at locations near major urban runoff inputs (Chollas Creek and the Sweetwater River) (Schiff et al., 2011). Better information for the bay is becoming available through more advanced and frequent monitoring programs such as the Regional Harbor Monitoring Program, NPDES permit monitoring by 22 dischargers (including Navy, Port, County, Cities), and the regional Bight Monitoring Program by SCCWRP in 1994, 1998, 2003, 2008, and 2013.

Toxicity and chemistry of wet weather runoff have been routinely measured in outfalls and receiving water off NBSD for compliance with NPDES storm water discharge permits. Copper and zinc frequently exceed benchmark concentrations for the protection of aquatic life in storm water samples from NBSD and have been found to cause acute toxicity to the mysid shrimp *Americamysis bahia* in end-of-pipe storm water samples using Toxicity Identification Evaluation (TIE) procedures (Katz et al. 2006).

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The experimental design was established to evaluate the performance objectives for the SEA Ring technology for a range of applications and field conditions, including fresh and saltwater environments, differing COCs, and varying sediment or water physico-chemical characteristics. A controlled laboratory based ETV including concurrent SEA ring and standard laboratory bioassays was conducted, in addition to demonstrations at the three sites.

5.2 BASELINE CHARACTERIZATION

The purpose of this technology demonstration was to demonstrate an integrative *in situ* based approach that centers on a field deployed technology. Although it did involve both baseline and post-remedy components associated with the two sediment demonstration sites, details of performance of the associated remedies at these sites (PSNS and Quantico MCB) are provided in the final technical reports associated with those projects (ER-201131 and ER-201368, respectively). As baseline and post-remedy characterization activities involved essentially the same approaches and level of effort, their results are presented together.

5.3 LABORATORY STUDY RESULTS

The USEPA ETV Program's Advanced Monitoring System (AMS) conducts third-party performance testing of commercially available technologies that detect or monitor natural species or contaminants in air, water, soil, and sediment. The purpose of ETV is to provide objective and quality assured performance data on environmental technologies so that users, developers, regulators, and consultants can make informed decisions about purchasing and applying these technologies. A summary of important elements of the study are included in this report as they directly address some of the Performance Objectives associated with this technology demonstration. Data and in-depth assessment of the performance is provided in the Final Technical Report for this project (ER-201433), and in greater detail in the ETV final report (McKernan et al. 2014).

The goal of the study was to generate performance data on the SEA Ring for assessing sediment and water column toxicity and bioaccumulation potential, relative to widely accepted standard laboratory methods, in a laboratory-based evaluation. The performance of the SEA Ring compared to USEPA and American Society for Testing and Materials (ASTM) laboratory methods was evaluated utilizing two water column species: Pacific topsmelt (*Atherinops affinis*) and mysid shrimp (*A. bahia*) for aqueous toxicity testing; and three sediment dwelling species, the bent-nosed clam (*Macoma nasuta*), marine amphipod (*Eohaustorius estuarius*), and marine polychaete (*Neanthes arenaceodentata*) for sediment toxicity and bioaccumulation testing. The primary evaluation assessed survival, growth, and bioaccumulation of contaminants in the aquatic and benthic organisms exposed in the SEA Ring compared to responses achieved in the laboratory using standard ASTM and USEPA methods. In performing the verification test, SPAWAR and the third party, Battelle, followed the technical and quality assurance procedures specified in a SEA Ring Verification Quality Assurance Project Plan (Battelle, 2012), and also complied with the data quality requirements in the AMS Center Quality Management Plan (Battelle, 2011). Performance was evaluated based on parameters including repeatability, comparability, intra-unit reproducibility, and operational factors.

5.4 FIELD TESTING

5.4.1 Puget Sound Naval Shipyard

The field program for PSNS consisted of evaluation of SEA Ring technology performance under four events over a 4-year period, including baseline (pre-remedy) conditions and 10, 22, and 34 months post-remedy. Deployments were coordinated and paired with ESTCP Project ER-201131 (Chadwick et al.), which focused on the placement and performance of a reactive amendment (AquaGate™) towards sequestration of sediment-associated PCBs.

The primary components for the field testing included:

1. *In situ* toxicity and bioaccumulation testing with SEA Rings
2. Concurrent real-time monitoring of water quality conditions inside SEA Rings
3. Inclusion of SPME passive samplers in SEA Ring as another measure of bioavailability
4. Sediment collection for laboratory bioaccumulation experiments

In addition to the measurements made as part of this demonstration, leveraging with ER-201131 added the following supporting components and measures, which are fully described in that report (Kirtay et al. 2016):

- Sediment coring, for total organic carbon (TOC) and black carbon assessment
- Sediment Profile Imagery (SPI) survey, for amendment placement/mixing assessment
- SPI survey, for assessment of benthos and mixing via bioturbation
- Benthic community census, for evaluation of ecological conditions
- Resistivity/Friction Sound Probe Sensing, for amendment placement/mixing assessment

5.4.2 Marine Corps Base Quantico

The field program at Quantico Embayment was coordinated with ER-201368. Detailed results that include additional measures to characterize the performance of the thin-layer cap will be provided in that report. For this project, there were four primary components for the field testing at Quantico:

1. *In situ* toxicity and bioaccumulation testing with SEA Rings
2. Concurrent real-time monitoring of water quality conditions inside SEA Rings
3. Inclusion of SPME passive samplers in SEA Ring as another measure of bioavailability
4. Sediment core collection for laboratory bioaccumulation comparison (baseline only)

The 2012 baseline characterization event was conducted 10-24 October 2012. Six sampling locations (Figure 4.2) were evaluated using two organisms, the aquatic oligochaete (*Lumbriculus variegatus*) and the Asian clam (*Corbicula fluminea*). Note that a seventh sampling station (B7) was added for post cap placement monitoring.

5.4.3 Naval Base San Diego

There were four primary components of the field activities for this demonstration:

1. *In situ* toxicity testing (and passive sampling) using the SEA Ring (and DGTs);
2. Concurrent laboratory-based toxicity studies for comparison to the SEA Ring exposure;
3. Analytical chemistry on grab samples, composite samples, and passive samplers;
4. Stormwater plume characterization using real-time water quality sondes

SEA rings were deployed with test organisms the day before a series of strong winter storms with a total of 2.59 inches of precipitation recorded during the field exposures spanning up to 4 days between 27 February and 2 March 2014.

5.5 SAMPLING METHODS

5.5.1 Puget Sound Naval Shipyard and Marine Corps Base Quantico

The sampling methods for both sites evaluating effectiveness of a sediment remedy were generally similar and briefly captured below. More detailed descriptions of the sampling methods are provided in the ER-201433 Final Technical Report and a pictorial overview of the steps are provided in Appendix B of this report.

Preparation. SEA Rings were cleaned following standard operating procedures (SOPs) prior to shipment to the site. Once on site, SEA Ring devices were fully charged and programmed to the desired pumping interval. SEA Rings, test organisms, water quality sondes, and other required equipment were shipped to and stored on site. Test organisms were acclimated to site water conditions on-site (Quantico) or at local laboratory facilities (PSNS), at appropriate temperatures, for a minimum of 24 hours.

Organisms. For PSNS (a marine site), bent-nosed clams (*M. nasuta*) and marine polychaetes (*N. caecoides*) were field-collected from uncontaminated sites by J & G Gunstone Clams, Inc. (Sequim, WA) and Brezina and Associates (Dillon Beach, CA), respectively. For MCB Quantico (a freshwater site), farm-raised aquatic *L. variegatus* and field-collected *C. fluminea* were purchased from California Blackworm Co. and Dr. Harriett Phelps (University of the District of Columbia) or Dr. Jennifer Bouldin (Arkansas State University), respectively.

Deployment. On deployment day, clams were directly loaded into exposure chambers with coarse (1/2” flexible titanium) mesh fastened to the bottom. Worms were loaded into the 30 mL syringes embedded in the SEA Ring chamber cap for later release into the open bottomed sediment chambers following placement at the site. SEA Rings were held in 17 gallon plastic Chemtainers in site water and lowered to the water surface where divers removed them from the container followed by deployment of each unit on the sea floor. Deployment involved pushing the device so that cores were inserted to a depth where the base plate became flush with the sediment surface, embedding test chambers to a depth of approximately 5 inches. SEA Rings were then attached with large zip ties to pre-deployed plastic coated fence stakes to further secure them. A series of cores were also collected and composited for sediment chemistry (i.e., COCs, TOC, grain size, at a minimum) based on goals of projects ER-201131 and ER-201368.

Recovery. Following a 14-day exposure period, SEA Rings were recovered by divers. Following an initial visual assessment of each Ring, the device was gently lifted out of the sediment and polyethylene end caps were immediately affixed to the bottom of each exposure chamber upon removal from the sediment. In some cases, pre-installed core catchers were used instead of capping by divers. Each SEA Ring was then placed into a Chemtainer while under water prior to transfer to the boat crew. Worms and clams were recovered on site using seawater pumped over a 500 micrometer (µm) stainless steel sieve to retain the organisms.

Tissue Preparation and Analysis. Following recovery, worms and clams were purged in clean seawater overnight, and the soft-body portion saved for tissue analysis. Wet tissue weights were assessed on a per-replicate basis for both organism types, then typically composited on a per-station basis, and tissues were frozen and shipped on dry ice to the United States Army Engineer Research and Development Center (ERDC) analytical chemistry laboratory, where extraction and analysis were conducted using modifications of standard methods for small sample sizes (Jones et al. 2006).

Water Quality Characterization. Troll® 9500 probe (In-Situ®, Inc.) or HOBO loggers (Onset Corp) were used to measure DO, temperature, conductivity/salinity, and pH inside and outside a representative SEA Ring chamber at select stations. The loggers were used to verify that: 1) parameters within test chambers remain within organism tolerance ranges; and 2) parameters within the test chambers did not vary more than 50% from ambient conditions. Continuous water quality data were collected at 5-minute intervals.

Porewater Sampling Analysis. SPME passive samplers were deployed directly inside one replicate SEA Ring chamber and immediately adjacent (outside) to the SEA Ring at each station stations to provide a measurement of freely dissolved PCBs or DDX present in porewater of the surface sediment layer (top 15 cm). SPMEs were retrieved after 14 days, extracted with organic solvent, and the extract was analyzed for PCBs following procedures outlined by Yu et al. (2011) and Harwood et al. (2012), and discussed in detail in the final report for ER-201131 and the pending final report for ER-201368.

Concurrent Laboratory Testing. For at least one event for both sites, ten 5" intact cores were collected from all or a subset of the stations and hand delivered to the laboratory for concurrent laboratory exposures using modifications of standard methods (USEPA 1994, ASTM 2000, ASTM 2010), with the primary difference being that intact replicate cores were used instead of homogenization and sieving practices.

5.5.2 Naval Base San Diego

In Situ Toxicity Tests. SEA Rings were installed at three locations centered on two primary outfall locations (OF 13 and OF 14), and two locations within Chollas Creek channel (Figure 4.3).

A SEA Ring located at the far end of Pier 6 at NBSD (OF-Farfield [OF-F]) and the SSC Pacific dock (near the bay mouth) served as comparative "reference" locations at a distance from direct freshwater influences. Sites assessing impacts from Chollas Creek were located directly in the middle of the channel between the security finger piers and bulkhead (CC-1), and just outside the entrance of Chollas Creek to San Diego Bay (CC-2), located between the quay wall and the eastern edge of a large portable Pier (the MHP Pier).

Each SEA Ring housed four test species (mysid shrimp, giant kelp sporophylls, polychaete worms, and mussel embryos). SEA Rings were suspended 1 m below the surface at MLLW all locations, a depth where direct influence of stormwater was anticipated based on prior salinity depth profile measurements during large storm events. At the two Chollas Creek sites, and the site closest to OF 13, an additional SEA Ring was situated at a depth of approximately 3 meters below the water surface (Bottom) to assess any vertical spatial differences related to salinity stratification.

Water Quality Characterization. Characterization of the receiving water at locations monitored for toxicity using the SEA Rings was conducted through the use of a variety of supporting real time and discrete measurements as described below:

- ***SEA Ring Test Chamber Water Quality***. HOBO loggers (Onset Corp) that recorded temperature and DO were placed inside a single test chamber on two of the SEA Rings to verify that these parameters remained within organism tolerance ranges within test the chambers, and did not differ by more than 50% from ambient conditions. All continuous water quality data within and outside SEA Ring test chambers was collected at 10-minute intervals.
- ***Ambient Water Quality Monitoring.*** HOBO loggers and sondes were mounted to the external frame of each SEA Ring to monitor ambient salinity and temperature conditions at each SEA Ring unit. These measurements were collected concurrent with multiple grab samples at each site prior to and during the storm event, as well as at 48- and 96-hour time points. These field measures provided valuable information to assess the dynamic water quality conditions to which test organism were exposed *in situ*, and also to determine if any effects observed were due to parameters outside the organisms' physiological tolerance, rather than sediment or stormwater-associated contaminants.
- ***Diffusive Gradients in Thin-films.*** DGTs were incorporated for *in situ* determinations of labile metal species (INAP, 2002). Two DGT passive samplers were deployed concurrently with each SEA Ring at each of the 9 stations, DGTs were retrieved after a 48 hour exposure, and underwent an acid-extraction of the resin layer followed by metal analysis of the extract via Inductively Coupled Plasma Mass Spectrometry (ICP-MS).
- ***Collection of Grab Samples for Laboratory Analysis and Toxicity Testing.*** For comparison to the SEA Ring exposures for stormwater monitoring, discrete water samples were collected at the same locations and depths where SEA Rings were deployed for laboratory toxicity assessment and chemical analyses. Water samples from open sites were collected by a team of two people using a Niskin bottle. Samples from the stormwater outfalls, OF 13 and OF 14, were collected from the man-hole access cover using a peristaltic pump, and transferred into high-density polyethylene Cubitainers®. Three temporally distinct sample types were collected: 1) Pre-storm samples; 2) First-flush grab samples (Grab 1 and/or Grab 2); and 3) time-weighted 24-hour composite samples consisting of up to eight grab samples collected over the 24-hour period. The 8 grab samples from each station were composited.
- ***Chemical Analysis of Grab and Composite Samples.*** First-flush grab samples from the receiving water at each SEA Ring location, OF 13 and OF 14, as well as an event-wide receiving water composite sample were submitted to analytical laboratories (Weck and SPAWAR Pacific) for analysis of a select suite of COCs (trace metals and PAHs) and physical characteristics including dissolved organic carbon and total suspended solids as described further in Section 5.6.3.

5.6 SAMPLING RESULTS

Key sampling results summarizing organism recoveries, bioaccumulation and passive sampling data, toxicity, control performance, variability among replicates in *in situ* and laboratory testing, and water quality maintenance, are provided in this section.

5.6.1 Puget Sound Naval Shipyard

The results of the AquaGate study at BNC Pier 7 are extensively reported in the Final Technical Report for ER-201131 (Kirtay et al. 2016). Results shown here include a brief overview of the performance of the remedy for easy reference, but in general results provided here address the performance objectives associated with this project and not the performance of the remedy site.

Overall Performance at Site. The overarching result of ER-201131 was a significant and persistent reduction of PCB bioavailability (compared with pre-remedy conditions) following placement of the reactive amendment at Pier 7 (Figure 5.1). The reduction in concentrations of total PCBs in *M. nasuta* tissue from baseline to the 33-month event was 88% on average. The reduction in concentrations of total PCBs in *N. caecoides* tissue from baseline to the 33-month event was 97% on average. The reduction in concentrations of total PCBs in sediment porewater from baseline to the 33-month event was 81% on average.

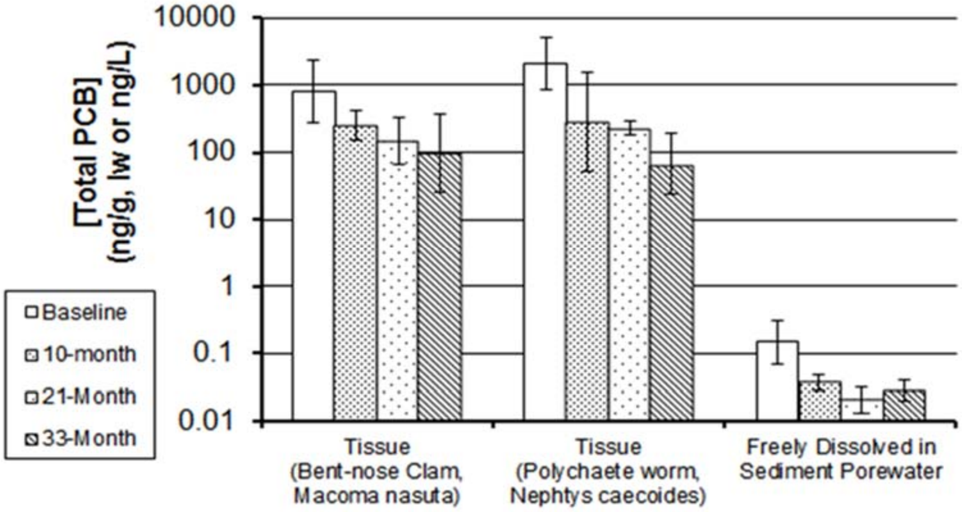


Figure 5.1. Summary of Reduction in Concentrations of Total PCBs in Tissue and Sediment Porewater.

Results are shown as mean ± 95% confidence level. From ER-201131 Final Technical Report (Kirtay et al. 2016).

Sediment/Organism Recovery. For the four PSNS deployments, *M. nasuta* numbers recovered alive averaged 72%, while sufficient tissue mass was recovered for composite tissue analysis 93% of the time (37 out of 40 units). Improvements in the recovery of *M. nasuta* were observed in events following the 2012 baseline event after integration of lessons learned (e.g. extended battery life and ultimately a more efficient pumping system).

N. caecoides recovery was acceptable in terms of tissue mass required for analysis for 24 out of 40 (60%) SEA Rings deployed over the four sampling events, considerably less than that for the freshwater oligochaete (*L. variegatus*) at Quantico. The number of stations providing sufficient tissue mass for analysis was relatively consistent across the 4 events, ranging from 5 to 7 of 10 stations. Reasons for loss of some organisms include escape, predation, toxicity, water quality issues, and deployment or recovery challenges (e.g., cobble and shell hash).

Water Quality Maintenance. Example water quality measurements from the PSNS site are shown in Figure 5.2, and include continuously logged data representing conditions both inside and outside individual SEA Ring chambers. Conditions inside the SEA Ring chamber were generally similar to those outside. In some cases, rental datasondes had technical issues functioning partway through the deployment. The use of Hobo loggers using modified SEA Ring chamber caps was much more successful for monitoring water quality than flow cells with Troll 9500 sondes.

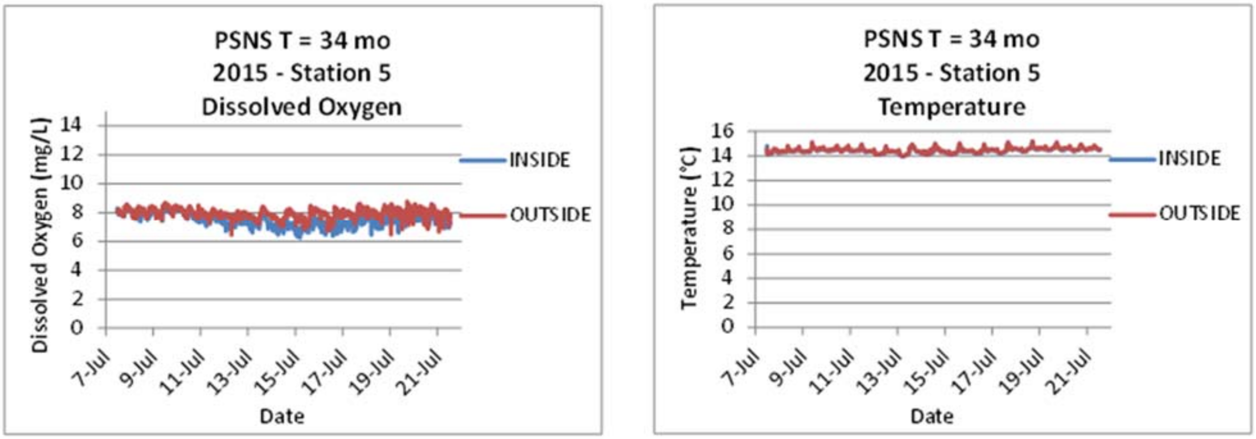


Figure 5.2. DO and Temperature Data from T=34 Month (2015) Post-remedy Deployment at PSNS (Station 5) Inside and Outside SEA Ring Chambers.

Tissue Uptake and Porewater Comparison. Total PCB concentrations in tissues and in porewater (SPME) are tabulated in the Final Report, while a more detailed compilation of all tissue and passive sampling data are reported in Kirtay et al. (2016).

A positive relationship was observed between tissue and porewater concentration for both species when all data points (n=37 and n= 23 for *M. nasuta* and *N. caecoides*, respectively) for which both tissue and porewater data were available. For *M. nasuta*, the relationship was relatively weak (r^2= 0.050) and was not statistically significant (p=0.184). For *N. caecoides*, the relationship was stronger (r^2 = 0.276) and was statistically significant (p=0.010). When the data were averaged across the entire site and expressed on a per event basis, the relationship became much stronger, with r^2 values of 0.651 and 0.917, for *M. nasuta* (p= 0.193) and *N. caecoides* (p=0.043), respectively. It is conceivable that the stronger relationship observed for *N. caecoides* is associated with their preference to deposit feed at a subsurface level (as compared to the surface deposit feeding clam), thus being more closely in contact with the top several inches of the sediment.

5.6.2 Marine Corps Base Quantico

Overall Performance at Site. The overarching result of ER-201368 (after two post-cap installation monitoring events) was a significant and persistent reduction of DDX bioavailability (compared with 2012 baseline conditions) in the surficial sediment layer, following placement of the thin-layer cap at the site (Figure 5.3).

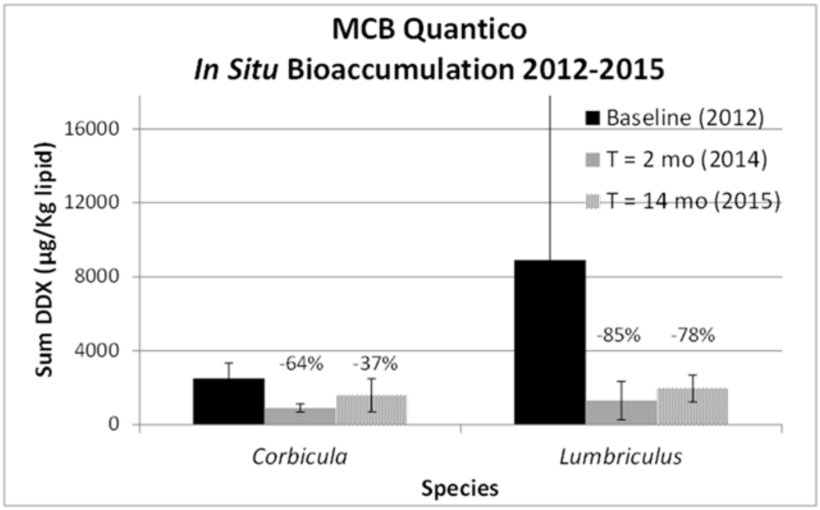


Figure 5.3. Mean (± Standard Deviation [SD]) 14-day Bioaccumulation by *C. fluminea* and *L. variegatus* from Composite Samples from Three SEA Ring Deployments at MCB Quantico between 2012 and 2015.

Values above bars are mean sum DDX % reduction from baseline.

Incorporation of Passive Sampling Devices (SPME). Porewater concentrations were estimated using *ex situ* methods under ER-201368 (data pending final report) and *in situ* (paired with SEA Rings) using SPME provided by Texas Tech University (Dr. Danny Reible). Modified Henry samplers housing 30 or 60 cm lengths of PDMS coated SPME fibers were deployed with SEA Rings at each station for all three events. The SPME samplers were deployed and recovered by divers concurrent with the SEA Ring deployment, and positioned within a few inches away from the SEA Ring base plate approximately equidistant apart (on opposite sides of the SEA Ring). Due to some differences in the approach used among different sampling events and the in--progress status for ER-201368, it is anticipated that these data will be incorporated into that Final Report.

Overview of SEA Ring Pump Performance. Version 2 SEA Rings were deployed during the 2012 Baseline and first post remedy event (T=2 months; 2014), while Version 3 units were deployed during the second post remedy event (T=14 months; 2015). SEA Rings were successfully deployed and recovered for all events, except for a duplicate unit deployed at Station Q3 in 2014, which was lost. Pump rates were calculated as averaging 107 ± 6.7 mL/chamber/minute (<5% difference) for the first two events (Version 2 SEA Ring), which equated to 17 or 40 water exchanges within a given chamber per day, depending on whether or not an external battery pack was present, the latter of which allowed for a more aggressive pumping regime. For the third event (Version 3), pump rates averaged 3,240 mL/chamber/minute (324 mL/chamber/6 seconds), equating to 140 or more turnovers per day. Variation among individual pumps on a SEA Ring unit was <9%.

Sediment/Organism Recovery. Detailed data associated with the Quantico demonstration are provided below and in Appendix E. *C. fluminea* were recovered from 100% of SEA Rings (Figure 5.4), providing sufficient tissue mass for analysis. Sufficient *L. variegatus* tissue mass was recovered from 19 out of 21 (90%) of units deployed over the three events, with one unit being lost and plungers accidentally not depressed by divers to release worms for the other (Figure 5.4).

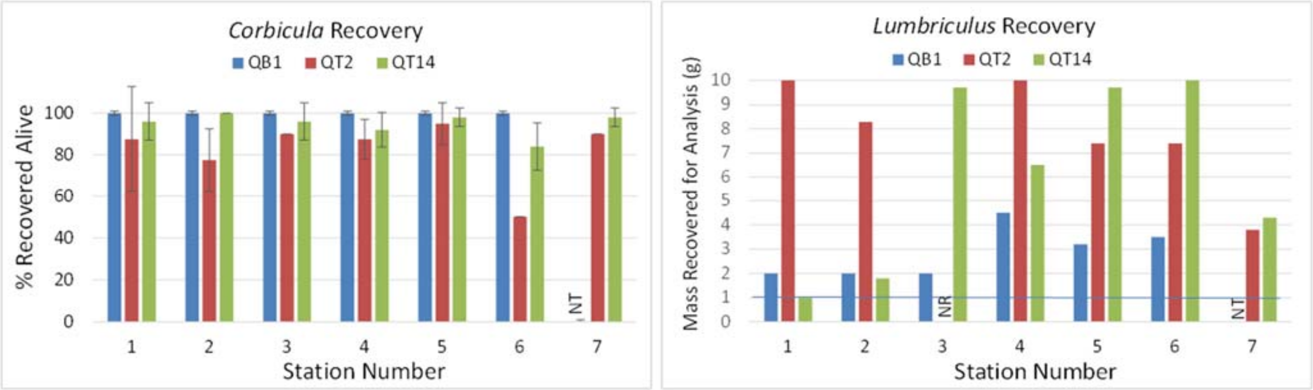


Figure 5.4. Percentage of Asian Clams (*C. fluminea*; left) Recovered Alive, and Mass of blackworms (*L. vareigatus*; right) Submitted for Tissue Analysis, from Three Sampling Events at MCB Quantico.

Blue line in right figure represents mass required for analytical requirements. NT = not tested for the 2012 Baseline event (QB1).

Replicate Comparison Between In Situ and Laboratory. For the 2012 Baseline event, three of the five SEA Ring cores associated with each species were processed as individual replicates for comparisons of within station variability for both *in situ* and laboratory based exposures. As with all other events, a subsample from each of the five replicates (or number of replicates containing live organisms at the end of the exposure) was also composited for determination of a single composite sample on a station by station basis.

Sum DDX concentrations, sSDs, and coefficients of variations (CVs) associated with 6 stations (*in situ*) and 4 stations (laboratory) are shown for both species evaluated in Figure 5.5. For *L. variegatus*, the same trend of decreasing uptake in the order of station Q1>Q3>Q5>Q6 was observed both *in situ* and in the laboratory, although the magnitude of uptake was greater in the laboratory. For *C. fluminea*, uptake was marginally higher than the time zero samples *in situ* in the proposed cap area, and lowest for the reference site (Q6), but all site samples were lower than the time zero sample after 14-d in the laboratory exposure.

The CV for *L. variegatus* averaged 30.5% and 37.8% for laboratory and *in situ* exposures, respectively. The CVs for *C. fluminea* averaged 28.8% and 19.9% for laboratory and *in situ* exposures, respectively. T-tests (α=0.05) comparing laboratory and *in situ* CVs resulted in p-values of 0.383 and 0.211, for *L. variegatus* and *C. fluminea*, respectively, indicating no significant differences in replicate variability between the SEA Ring and laboratory exposures.

Comparison of *in situ* and laboratory composite sample bioaccumulation data (see Final Technical Report) showed a positive relationship among stations observed (r^2= 0.922 and 0.753, for *L. variegatus* and *C. fluminea*, respectively), with lowest uptake both *in situ* and in the lab for the reference location (Q6). However, the magnitude of uptake differed by as much as a factor of four, with higher DDX concentrations observed in the laboratory for *L. variegatus*, but higher *in situ* for *C. fluminea*. Differences are likely associated with site-specific factors (e.g. food sources, suspended solids, water quality, time-varying contaminant and physical stressors) that differed in the field while conditions were held constant in the laboratory. The different trends observed for each species may be due to species-specific behavioral factors. For example, *C. fluminea* tends to filter feed from the sediment surface and may have had less direct contact with porewater in the field, while *L. variegatus* tends to deposit feed.

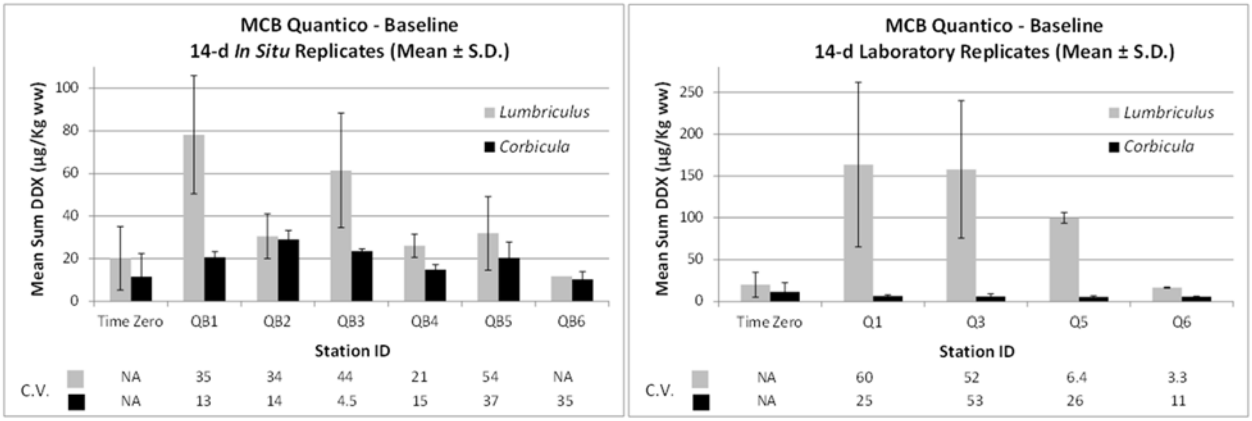


Figure 5.5. Comparsion of 14-day Bioaccumulation by *L. variegatus* (top) and *C. fluminea* (bottom) from *in situ* (top) and Laboratory (bottom) Exposures from Replicate (n=3) Analysis of Select Cores from MCB Quantico 2012 Baseline Event.

C.V. = Coefficient of variation.

5.6.3 Naval Base San Diego

Environmental Exposure Conditions. SEA rings were deployed with test organisms the day before a series of strong winter storms with a total of 2.47 inches of precipitation recorded during the exposures between 27 February and 3 March 2014. Light rain with a total of 0.12 inches was recorded during the day on 27 February prior to deploying the test organisms, however, little runoff was observed during this timeframe. Organisms were then exposed to ambient conditions for approximately 12-15 hours prior the start of rainfall from the main storm front arriving early on 28 February. Rainfall was sporadic and very heavy at times over the next 4 days (Figure 5.6).

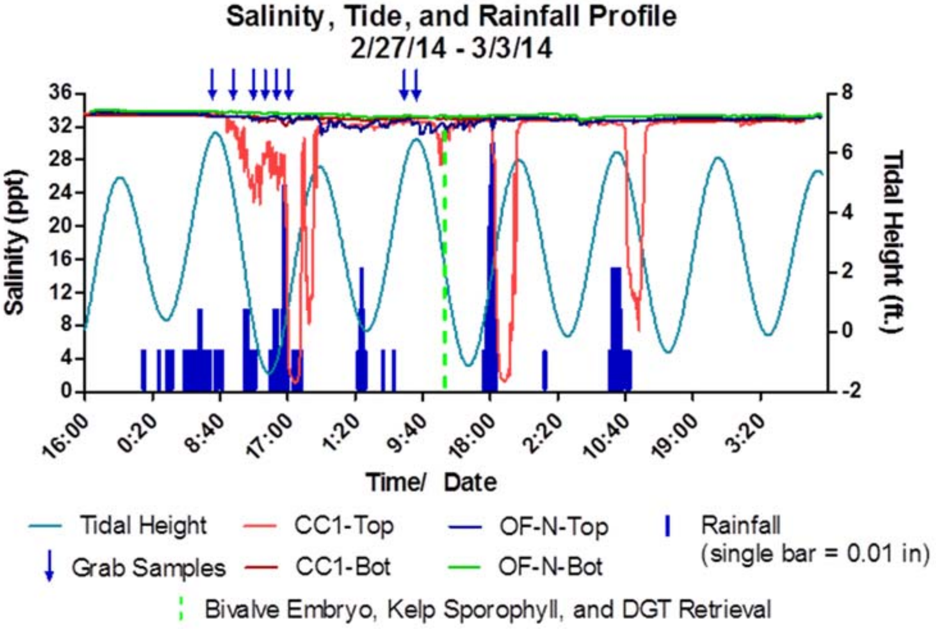


Figure 5.6. Profiles of Salinity, Tide and Precipitation as Measured at CC1-T & B and OF-N-T & B.

Test organisms were added to the SEA Rings between 14:30 and 17:30 on 27 February 2014 at the beginning of the x-axis on this figure.

SEA Ring Deployment, Recovery, and Performance. Deployment and recovery of the SEA Rings and test organisms was successful at all 9 targeted locations. This demonstration proved the SEA Ring as a valid implementable tool for stormwater assessment as shown with the predecessor passive version used for compliance monitoring off Scripps Institution of Oceanography (SIO) over the past 5 years (AMEC 2010-2014a, b).

In Situ Toxicity Results. A summary of results for all *in situ* toxicity tests relative to the far-field reference station (OF-F) is shown in Table 5.6-1. Notably, all toxicity tests met applicable laboratory-based control performance criteria in SEA Rings placed *in situ* at reference locations (e.g., SPAWAR Pier and OF-F) expected to be minimally impacted by runoff. This observation provides additional confidence that SEA Rings performed well and provided an environment conducive of sustaining healthy organism throughout the exposure periods.

General trends were similar among the four species though some notable differences were also observed. The greatest effects to survival of *A. bahia* and *N. arenaceodentata*, and germination of spores from *M. pyrifera* occurred in the SEA Ring most directly influenced by stormwater runoff at the surface in the Chollas Creek channel (CC1-T). Effects for these three species ranged from only 32% to 55% of the reference location (OF-F). *M. galloprovincialis* embryos showed no effect in the top SEA Ring at this location, but did show a slight statistically significant effect (84% of OF-F) in the bottom SEA Ring (CC1-B). *A. bahia* and *M. pyrifera* also showed significant adverse responses in the top SEA Rings at Site CC-2 and nearest the outfalls (OF-N), though to a lesser degree, ranging from 67% to 90% relative to OF-F.

M. galloprovincialis embryos also showed a significant effect at OF-N-T (78% of OF-F), and was the only species to show an effect at Site OF-M-T with a similar response (76% of OF-F). No sites were observed to be significantly lower from OF-F for the kelp spore growth endpoint.

Table 5.6-1. *In Situ* SEA Ring Toxicity Test Results Relative to Results from Reference Site OF-F.

Site	Species/ Endpoint Results Shown as % of OF-F				
	M. galloprovincialis **Embryo Development**	***A. bahia*** **Survival**	***N. arenaceo-dentata*** **Survival**	***M. pyrifera*** **Germination**	***M. pyrifera*** **Growth**
SSC-Ref	109	92	90	102	105
CC-1-T	100	**55**	**35**	**32**	103
CC-1-B	**82**	87	100	92	110
CC-2-T	91	**90**	90	**76**	94
CC-2-B	99	103	100	93	100
OF-N-T	**78**	**67**	95	**77**	108
OF-N-B	92	100	100	97	102
OF-M-T	**76**	105	95	90	100

*Values in **bold** are significantly reduced from the respective reference site (OF-F for Grab and Composite Samples (USEPA TST, 2010, EPA 833-R-10-003).

Values > 100 indicate a greater response in the SEA Ring site relative to that observed at OF-F.

The freshwater doses experienced at the CC1-T SEA Ring were likely sufficient to cause the observed responses at this location. A study by Weston (2011) found that a reduced salinity to 10 parts per trillion (ppt) or less for a period of 6 hours affected survival of *A. bahia* with few to no survivors following exposure to 6 ppt for the same timeframe. Given that *A. bahia* is known to tolerate brackish salinities, it is highly likely that exclusively marine *M. pyrifera* and *N. arenaceodentata* would also be affected by the pulses of freshwater observed at CC-1-T, and possibly CC-2-T. Direct transfer of *N. arenaceodentata* from saline to salinities of 15-20 ppt have been shown to have significant effects on mortality and growth (Dillon et al. 1993). Though published salinity tolerance data does not appear to exist for kelp, kelp spores degrade quickly when exposed to reductions in salinity (Stransky, pers. observations). Salinity tolerance studies recently conducted for the City of San Diego have found that the marine kelp shrimp *Holmesimysis costata* is very sensitive to brief reductions in salinity, resulting in 0% acute survival following exposure to a salinity of 20 ppt for only 30 minutes (AMEC 2015). The sensitivity of bivalve embryos (*M. galloprovincialis*) depends on when the developing embryos are dosed. The embryos are sensitive to a moderate reduction in salinity between 22 and 25 ppt if dosed for a period of 2-3 hours soon after cell division, but are insensitive at salinities down to 15 ppt for up to 3 hours if dosed approximately 20 hours post cell division (AMEC 2015). A high proportion of normal embryos exposed to the reduced salinity at CC1-T suggest that they had surpassed a developmental stage where they were particularly sensitive to salinity decreases. Indeed, bivalve embryos were approximately 16-18 hours post initial cell division by the time the first noticeable freshwater influence occurred in the Chollas Creek channel.

With the exception of those results for CC1-T, significant effects observed at other locations among all three species was limited to less than a 33% difference from that observed at OF-F. Test organisms in SEA Rings at CC-2-T and OF-N-T may have been effected by the restricted flow created by these two units being plumbed backwards, which resulted in air space remaining in some of these test chambers. This could have presented a physical stressor on the test organisms associated with the turbulence during the storm and resulting sloshing in the chambers. *In situ* video footage documented this issue during the study.

The potential cause for observed effects to bivalve embryos in properly operating SEA Rings at Sites CC-1-B and OF-M-T is uncertain, though effects were limited with a difference of 18% and 24%, respectively, relative to embryo development at OF-F.

Laboratory-Based Toxicity Results. Laboratory-based tests were performed as a part of the demonstration at NBSD to:

1. Provide a standard for Quality Assurance/Quality Control (QA/QC) by which to assess test organism sensitivity and performance under controlled laboratory conditions to a reference toxicant test and field collected samples; and
2. Compare general patterns and conclusions derived from standard discrete sampling and composite preparations to that determined using the *in situ* methods with the SEA Rings.

Effects were not observed with any species tested in grab and composite samples from the receiving water with the exception of a single grab sample (Grab 2) collected at Site CC2-T using bivalve embryos. Despite a statistically significant difference in this one sample, the effect was limited: 12% and 16% reduction from the laboratory control and the OF-F Grab 1 sample, respectively. The overall lack of laboratory-based effects observed in the receiving water during storm events is consistent with the limited effects observed in a prior large stormwater assessment project conducted by SPAWAR in San Diego Bay (Katz et al., 2006).

In contrast to receiving water samples, tests of salinity-adjusted undiluted stormwater from OF 13 and OF 14 caused substantial impairment to *M. galloprovincialis* embryos (<10% normal development). However, no acute survival effects were observed to *A. bahia* or *N. arenaceodentata* exposed to the salinity-adjusted stormwater grab samples. The results observed for bivalve embryos were consistent with those observed in prior studies with more than 50% of samples resulting in chronic effects to marine invertebrates (Katz et al., 2006 and AMEC 2006-2014 Wet Weather Monitoring Reports for University of California San Diego [UCSD] SIO).

Analytical Chemistry: Receiving Water. Measured concentrations of dissolved copper during the stormwater demonstration ranged 3.7 to 11 micrograms per liter (μg/L) among all receiving water samples tested (individual grabs and 24-hour composites) in the Chollas Creek channel and off NBSD. The greatest concentration was noted during collection of the first grab sample at the innermost location in the Chollas Creek channel (Site CC1-T). For comparison, dissolved concentrations of copper ranged from 4.3-4.8 μg/L in the three pre-storm receiving water samples collected in the same area; and was 3.2 μg/L at the SSC Pacific dock near the mouth of San Diego Bay.

Measured concentrations of dissolved zinc (another commonly identified COC in stormwater runoff) in all samples from San Diego Bay, were below USEPA acute and chronic criteria of 90 and 81 µg/L, respectively. Concentrations of dissolved zinc ranged from 10 to 32 µg/L in all samples from the Chollas Creek channel and off NBSD. This compares to pre-storm sample concentrations off NBSD ranging from 18 to 27 µg/L, and a concentration of 14 µg/L at the SSC Pacific dock near the mouth of San Diego Bay. Dissolved concentrations of nickel and lead measured in select receiving water composite samples also did not exceeded toxic concentrations of concern.

DGTs Compared to Receiving Water Composites. Time-weighted average labile concentrations of trace metals were measured by mounting DGTs both inside and outside a single test chamber on each SEA Ring for another more integrated measure of exposure to trace metals. Labile copper and zinc concentrations closely mimicked spatial trends observed for composites of the 8 grab samples collected at each station, but DGT concentrations were consistently lower. DGT copper averaged 43% and 56% of the dissolved composite value inside and outside the SEA Rings, respectively. DGT zinc averaged 71% and 76% of the composites, respectively. Correlations were statistically significant ($p<0.05$) for all comparisons, with the exception of the Inside DGTs for Copper (Figure 5.7). These results are expected as the DGT provides a labile metal concentration that is typically a fraction of the operationally defined dissolved (<0.45 µm) fraction (Zhang and Davison 1995). These results provide confidence that the exposure conditions inside the SEA Rings were similar to ambient conditions outside, while also successfully demonstrating the ability to integrate passive sampling technologies to better match *in situ* toxicity and chemical exposures.

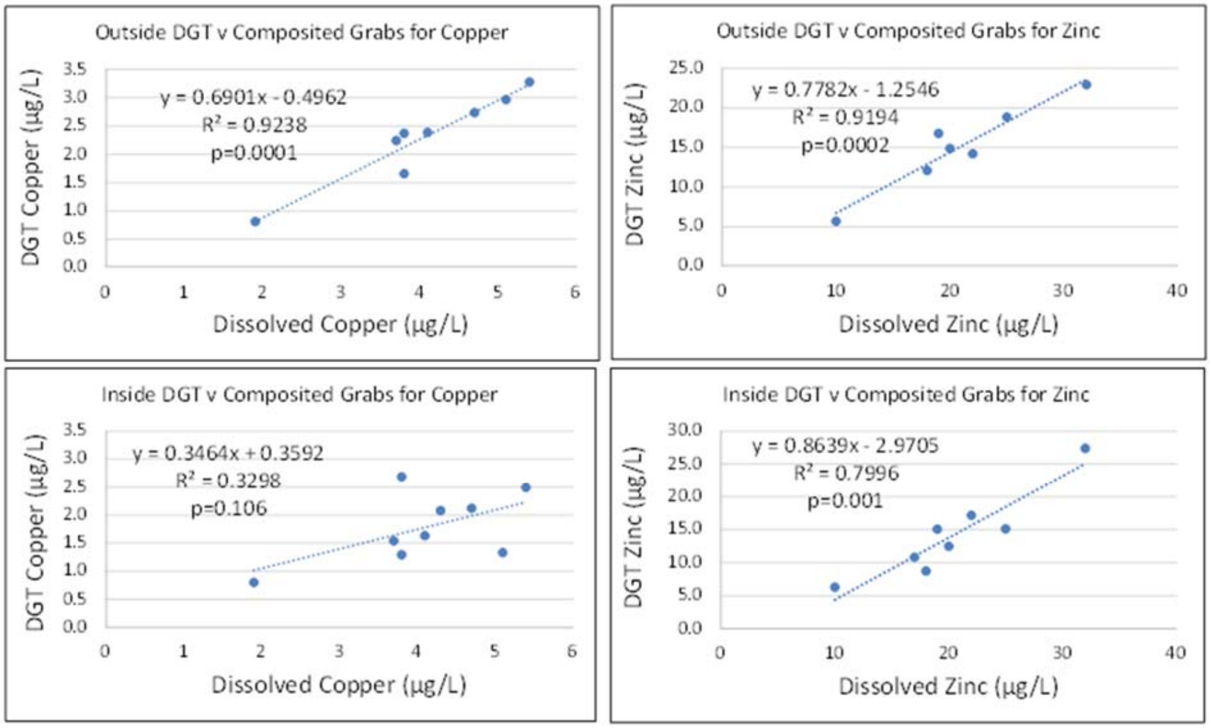


Figure 5.7. Comparison of DGTs Deployed Outside and Inside SEA Rings with Dissolved Copper and Zinc derived from Composite Grab Samples at Nine Stations during Storm Event.

6.0 PERFORMANCE ASSESSMENT

6.1 QUANTITATIVE PERFORMANCE OBJECTIVES

6.1.1 Performance Objective #1: Water Quality Maintenance

This performance objective was met most of the time, and through lessons learned and design refinements over the course of the project, deficiencies have been virtually eliminated. Water quality (temperature, DO, pH, salinity) was monitored in select SEA Rings during all deployments. Small data loggers (Troll 9500 multi-sensor or HOBO conductivity, temperature, and DO loggers) were typically placed both inside and outside a representative exposure chamber to compare the effects of the SEA Ring system on water quality maintenance relative to ambient conditions. In general, water quality inside the chambers very closely resembled site conditions, well within the goal of ±50% of ambient conditions. In ~20% of cases, however, DO was recorded as less than 50% of ambient at some point in the exposure period. The Version 3 SEA Ring appears to have eliminated concerns regarding battery discharge and water exchange, which is consistent with improved DO concentrations even in high oxygen demand sediments. An example of DO using Version 3 units from two different stations (off cap [fine grained] and on cap [sandy]), both showing comparable water quality between the chambers and the ambient environment for the 2015 post-remedy monitoring effort at Quantico MCB are shown in Figure 6.1.

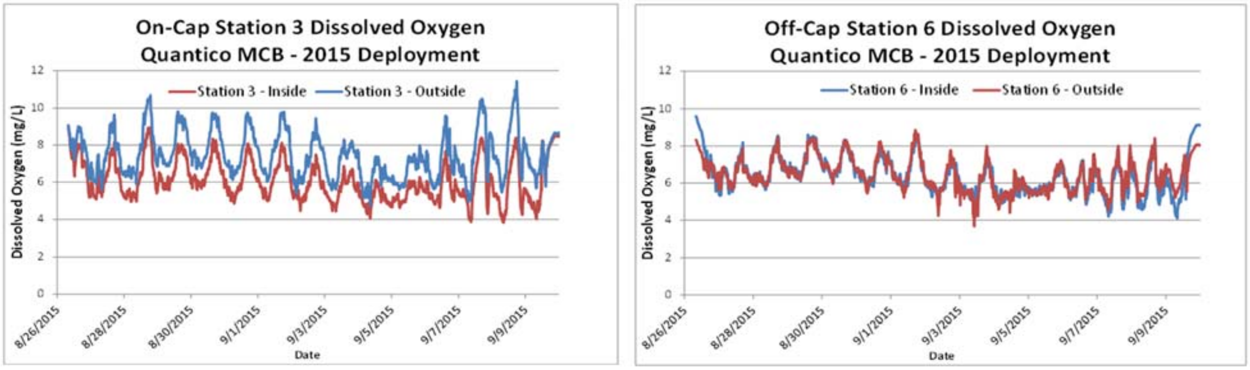


Figure 6.1. DO Measured within and Outside an Exposure Chamber at Stations 3 (on cap; left) and 6 (off cap; right) during the 2015 MCB Quantico Deployment Using Version 3 SEA Rings.

6.1.2 Performance Objective #2: Pump Flow Rate

The goal for this performance objective was to minimize the variation associated with individual chamber performance in terms of volume exchange rate, with the goal of a minimum of 6 volume turnovers per day during a deployment.

Pump Flow Variability. Laboratory trials showed that pump flow rate met this objective, with well under 50% variability among the 10 chambers on a given SEA Ring.

Mean flow rate among the 10 ports in the Version 3 pump system ranged from 310 to 340 mL per 6 seconds (3.1 to 3.4 L/minute), varying <9% among chambers.

Volume Exchange Rate. For all of the deployments performed, the targeted minimum of 14 turnovers per day were achieved, exceeding the 6 turnover per day minimum criterion by greater than a factor of two. With the evolution from the Version 2 to Version 3 SEA Rings, example turnover rates were 58 and 137 chamber volumes per day, respectively, for the 35 month post-remedy monitoring event at PSNS when a combination of both types of units were employed. For the stormwater demonstration at NBSD, 144 turnovers per day were achieved using Version 2 units over a 4-day period. Version 3 exchange rates could be considerably greater if desired for relatively short (e.g., 4 day) term deployments.

6.1.3 Performance Objective #3: Sediment/Organism Recovery

Successful recovery of organisms or sediment within deployed exposure chambers was achieved across all field demonstrations, and averaged well over the 80% goal. In some cases, individual replicates (or all replicates in rarer cases) exhibited mortality or loss of test organisms from other reasons. Because toxicity, predation, escape, or diver error/removal difficulties associated with the recovery process are potential causes for lower numbers of recovered organisms compared to deployed organisms, the height of the core was documented and sometimes used to help interpret reasons for organism loss.

PSNS. For the PSNS demonstrations (4 events), *M. nasuta* numbers recovered alive averaged 72% relative to number deployed, but sufficient tissue mass (as replicates within a station were composited) was recovered for tissue analysis 93% of the time (37 out of 40 stations).

N. caecoides recovery was acceptable in terms of tissue mass required for analysis for 24 out of 40 (60%) SEA Rings deployed over the four sampling events, considerably less than that for the freshwater oligochaete (*L. variegatus*) used at Quantico.

MCB Quantico. For the Quantico demonstrations, *C. fluminea* met this criterion with 100% of SEA Rings deployed (20 out of 20) providing tissue to support analytical requirements. In terms of numbers of clams recovered, 92.5% of clams were recovered alive over the three events (range = 83-100%), with the baseline 2012 event resulting in the highest recovery (100% clams deployed recovered alive). Sufficient clam tissue for DDX analysis was available for all stations and all events (100%).

L. variegatus recoveries met success criteria with 19 out of 20 (95%) SEA Rings deployed over the three sampling events (Figure 5.4). The one SEA Ring that did not provide sufficient tissue mass was placed at Station 3 during the 2-month post cap placement event (QT2). Upon recovery, it was found that syringes with worms had not been depressed (miscommunication with divers), so they were never released to sediment after the device was installed. It should be noted that tissue mass submitted to the analytical labs varied considerably (Figure 5.4). The delicate process required to separate *L. variegatus* from sediment associated fauna such as filamentous algae can be extremely difficult, so once sufficient mass was obtained for analysis, subsequent efforts to recover were sometimes deemed unnecessary.

NBSD. For the NBSD demonstration, some minor toxicity was observed both for laboratory and *in situ* exposures, therefore, organism recovery comparisons were made between laboratory reference controls and the two reference sites (SPAWAR Pier and OF-F) for all test species (Table 6.1-1).

Laboratory controls in this case are the pre-storm grab samples collected at the SPAWAR Pier reference location. In most cases, SEA Ring recoveries were similar or better than laboratory recoveries. The overall average recovery rate for SEA Rings for the two reference stations and four species was 92%.

Table 6.1-1. Laboratory and SEA Ring Recoveries from Reference Locations Associated with Storm Event at NBSD.

Species	Endpoint	Laboratory SPAWAR Pier	SEA Ring SPAWAR Pier	SEA Ring OF-F
N. arenaceodentata	% Survival	100 (0)	90 (14)	100 (0)
M. galloprovincialis	% Normal	80 (6.2)	95 (2.5)	87 (1.6)
A. bahia	% Survival	80 (23)	88 (15)	95 (5.8)
M. pyrifera	% Germination	NA	92 (3.8)	88 (4.2)

6.1.4 Performance Objective #4: Control Performance

This objective was successfully met and is based largely on the USEPA ETV study (McKernan et al. 2014). This study was conducted under controlled laboratory conditions, in which test-acceptability included minimum requirements for test organism survival (or sublethal effects) in controls. Control performance is routinely evaluated to establish test organism health and technical proficiency with the test method for laboratory tests (e.g., ASTM, 1999; USEPA, 1995; USEPA, 2002a). Under normal *in situ* conditions, an appropriate control in the same sense is typically not possible. The laboratory SEA Rings were tested alongside standard laboratory controls during concurrent laboratory verification testing.

Success for this performance objective was assessed by comparison of standard laboratory beaker control test results and the laboratory tested SEA Ring control samples. Sediment toxicity, water column toxicity, and bioaccumulation tests were investigated and for each test condition, the mean result in the SEA Ring was compared to that observed using traditional USEPA methods using two sample t-tests, assuming unequal variances.

For all species tested and their respective endpoints, there were no significant differences between the SEA Ring results and traditional laboratory beaker results (Table 6.1-2). For all test types, the percent difference met the performance objective of <25% difference.

Table 6.1-2. Control Performance Results from the USEPA ETV Comparability Study for Each Test Endpoint in Control Sediment and/or Uncontaminated Seawater.

Test Type	Species Tested and Endpoint	SEA Ring		Laboratory		*p*-value	% Difference
		Mean	SD	Mean	SD		
Sediment Toxicity and Uptake	Polychaete Survival	94	1.9	95	1.7	0.85	1.1
	Polychaete Growth (milligram wet weight)	8.98	1.56	8.24	2.04	0.55	9.0
	Amphipod Survival	96	1.3	94	1.1	0.61	2.1
	Clam Survival	100	0	100	0	> 0.05	0.0
Water Column Toxicity	Topsmelt Survival	96	0.4	100	0	0.37	4.0
	Mysid Survival	90	1.2	100	0	0.18	10

6.1.5 Performance Objective #5: Completion Rate

For the four PSNS demonstrations, all SEA Rings that were deployed were successfully recovered and meaningful tissue data was obtained from 37 of the total 40 SEA Rings deployed (93%).

For the three Quantico demonstrations, a total of 21 SEA Rings were deployed, of which 20 were recovered (95% recovery success). During the T=2 months (2014) post-remedy assessment, one SEA Ring (Station 3) could not be located on recovery. However, a duplicate SEA Ring was deployed at the same station and meaningful tissue data (for *C. fluminea*) was obtained from all stations targeted, allowing overall 95% completion for *C. fluminea* and 90% completion for *L. variegatus*.

For the NBSD demonstration, 100% of SEA Rings were successfully recovered following the deployment period with meaningful data obtained from all stations for all species utilized.

6.1.6 Performance Objective #6: Identification of Confounding Factors

In order to avoid false positive results for a given sample or site, water quality parameters were measured within a representative exposure chamber on the SEA Ring. This was done to ensure that physical parameters were within tolerances of the organisms being utilized and to prevent inaccurate interpretation of adverse effects associated with non-anthropogenic factors.

Water quality sensors were fitted into an integrated cap that allowed for real-time measurements of conditions within an exposure chamber. In some cases, additional water quality sensors were mounted onto the exterior of the exposure chambers for comparative purposes.

Here, we discuss the potential for parameters including temperature, DO, salinity, ammonia, and grain size to have played a role in affecting normal organism behaviors and potential for invalid interpretation of toxicity in site demonstrations or the controlled ETV study.

Temperature. As described for Performance Objective #1 (Water Quality Maintenance), temperature was essentially identical inside and outside the exposure chambers. More importantly for this objective, temperatures were documented to be within the normal range for the test organisms employed at the various sites. Therefore, we don't believe that temperature had any adverse impacts on test organisms or confounded test data.

Dissolved Oxygen. DO inside and outside chambers did vary in some cases. Low DO was nearly always observed in the event that a SEA Ring stopped pumping during the deployment, which would have affected the likelihood for recovering live, healthy organisms. The potential for DO to drop below critical thresholds inside a SEA Ring led to an improved design for measuring water quality (integrated chamber cap with HOBO loggers) development and integration of the Version 3 pump instrumentation, which seems to have resolved this potential confounding factor.

Salinity. Salinity was essentially constant at the PSNS and Quantico sites, and within test organism tolerance. For the NBSD demonstration, however, salinity varied significantly during the storm phase of the demonstration in the Chollas Creek (Figure 5.6) locations.

A salinity gradient was not unexpected, as the SEA Rings were intentionally placed close to sources (e.g., the mouth of Chollas Creek) which resulted in potentially substantial runoff, particularly near the water surface. The three drops in salinity to near 0‰ observed at the site likely affected *N. arenaceodentata* survival, as this marine species is largely intolerant to such drops (Dillon et al. 1993). Therefore, salinity can be a non-contaminant related stressor that needs to be accounted for in stormwater *in situ* monitoring near coastal areas.

Ammonia. Ammonia concentrations were measured in the overlying water from the ETV study only, using HACH Method 10031. Following 20 and 28 day exposures to the marine polychaete (*N. arenaceodentata*) and the bent-nosed clam (*M. nasuta*), respectively, overlying water total ammonia concentrations from the three sediments tested (McKernan et al., 2014) ranged from non-detectable to a maximum of 7.6 milligram per liter, below effects thresholds for these species. Therefore, ammonia was not considered to have contributed to toxicity in the ETV testing.

Sediment Grain Size. Sediment grain size was not believed to be of concern as a confounding factor in this project because the test organisms used in sediment exposures are not known to have any problems with accepting multiple grain sizes (Rosen et al. 2009).

6.1.7 Performance Objective #7: Contaminant Uptake

This objective was met for two of the three ETV tests, differing by 2% and 3% for clams and polychaetes, respectively. Amphipod uptake was 44% higher in the laboratory tests compared with the SEA Ring test, but this difference was not statistically different due to relatively high variability observed for both the laboratory and SEA Ring tests. Amphipods were somewhat averse to burrowing in the relatively fine-grained (50% silt and clay) test sediment during early parts of the exposure which may have affected their exposure to PCBs.

The potential for a more accurate assessment of bioavailable COC is one of the major advantages of *in situ* exposures or laboratory-based exposures. Because bioavailability and potential for biouptake of COCs is dependent on site-specific conditions, it is inappropriate to expect concordance between laboratory-exposed organisms with *in situ* exposed organisms. However, it is appropriate to ensure that the SEA Ring technology provides the same opportunity for bioaccumulation to occur assuming comparable exposure in the laboratory and *in situ*. Through the laboratory-based study conducted under the ETV program, appropriate data and success criteria were obtained with which to make an appropriate comparison of biouptake assuming all conditions were equal.

For select deployments, laboratory bioassays were also conducted on intact sediment cores to demonstrate the difference in variability among SEA Ring replicates with laboratory replicates. This was also an opportunity to make qualitative observations on the difference between *in situ* and laboratory data, as holding such a comparison is inappropriate considering the expected differences between field and laboratory, and thus the rationale for conducting bioassays *in situ*.

6.2 Qualitative Performance Objectives

6.2.1 Performance Objective #8: Ease of Operator Use

ETV Assessment. As part of the USEPA ETV process, operational factors were evaluated. The SEA Ring was operated in the laboratory by the staff at SPAWAR, and also by a Battelle staff member (third-party unbiased verification). During a 4 hour period, the Battelle staff member was trained on use of the SEA Ring, including loading of organisms and measurement of water quality parameters. The Battelle staff member found the SEA Ring easy to operate, but noted that care must be taken when loading some species due to their small size. It should be noted that this is also the case with standard laboratory test methods. The SEA Ring was found to be easy to transport by one person. The waste obtained when operating the SEA Ring was minimal. No maintenance was required when the Battelle staff was onsite.

Site Demonstrations. In the field, operators included at least 10 members (on a cumulative basis) of our extended technical team (over multiple sites and events over a 4+ year period), each with varying levels of familiarity of the test protocols (ranging from nearly none to those who developed and were intimately aware of its use). In addition to the project team, operators also included on-site diver support (i.e., Navy divers at PSNS and USEPA Environmental Response Team divers at Quantico), all of whom had on the spot training on its use.

Those most experienced with the SEA Ring development and understanding of the provided Operation Manual and SOPs had the fewest issues with operation, typical with specialized underwater mechanical equipment. Technical problems experienced with the device were sometimes associated with user inexperience and/or limited understanding of project goals. The multiple details and potential issues associated with using live organisms in the laboratory extend to the field, and this project demonstration was largely successful in that in most cases.

6.2.2 Performance Objective #9: Integration of Passive Samplers

PSDs such as DGTs and SPMEs were successfully integrated in all demonstration deployments for both sediment remedy effectiveness and stormwater assessments (Figure 6.2).

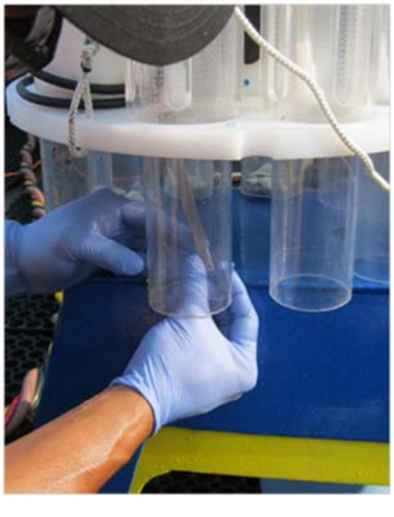


Figure 6.2. Integration of SPME into SEA Ring Chamber at PSNS.

PSNS. A positive relationship was observed between tissue and porewater concentration for both species when all data points (n=37 and n=23 for *M. nasuta* and *N. caecoides*, respectively) for which both tissue and porewater data were available. When the data were averaged across the entire site and expressed on a per event basis, r^2 values of 0.651 and 0.917, for *M. nasuta* (p=0.193) and *N. caecoides* (p=0.043), respectively, were calculated. It is possible that the stronger relationship observed for *N. caecoides* is associated with their preference to deposit feed at a subsurface level (as compared to the surface filter or deposit feeding by *M. nasuta*), thus being more closely in contact with the top several inches of the sediment.

MCB Quantico. SPME deployments were conducted for all 3 events conducted thus far at the site, with meaningful data derived. The full dataset, to include pending monitoring at the site in 2016, will be included in the final report associated with the leveraged project, ESTCP Project ER-201368.

NBSD. Labile copper and zinc concentrations from DGT deployments closely mimicked spatial trends observed for composites of the 8 grab samples collected at each station, but DGT concentrations were consistently lower. As expected, labile concentrations were lower than dissolved, but correlations between the two were generally highly statistically significant. These results provide confidence that the exposure conditions inside the SEA Rings were similar to ambient conditions outside, while also successfully demonstrating the ability to integrate passive sampling technologies to better match *in situ* toxicity and chemical exposures.

6.2.3 Performance Objective #10: Diverless Deployment/Recovery

Successful deployment of the SEA Rings for stormwater evaluations at NBSD were completed without the use of divers for the deployment and recovery operations. However, for PSNS and Quantico demonstrations, divers were required. It should be noted that other activities including SPI camera, passive sampler deployments, and sediment collection also required diver support. Poor visibility at Quantico and depths of 50 feet or more at PSNS presented challenges that ultimately required diver assistance.

Several methods towards diverless recovery at sediment sites have been developed and tested that show promise, including a modification of the Trident Probe pole system (SSC San Diego 2003) and simplified core catchers (Figure 6.3). However, consistent success for any of the methods was dependent on the sample type and potential physical interferences at any given site. The heterogeneity of sediment characteristics at sites evaluated presented challenges, so diver assistance may still be required until an optimal design is verified.

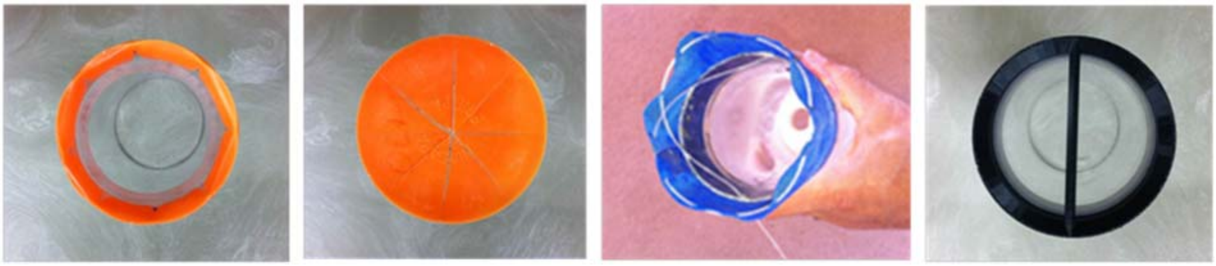


Figure 6.3. Examples of Promising Core Catcher Designs for Capturing Sediment and Test Organisms.

6.2.4 Performance Objective #11: Cost-Benefit

The ultimate benefit is the derivation of more realistic and accurate data from which to base subsequent management actions. The cost of potential management actions (e.g., sediment remediation and stormwater pollutant controls) will in many cases far outweigh the costs to provide data based on more representative exposures using the SEA Rings for decision-making purposes. Significant cost-avoidance may be realized should more realistic *in situ* methods indicate no impact relative to laboratory-based tests that may show an effect under certain scenarios.

The above said, a cost analysis was performed comparing the Sediment Ecosystem Assessment Protocol (SEAP) technology with standard laboratory-based methods under the three scenarios, including a sediment bioaccumulation program at 10 stations, a sediment toxicity program at 10 stations, and a water column toxicity program at 10 stations. The cost for a survey using the SEAP technology and of the scale employed in this project is expected to be on the order of $80-90k for a single sediment or water toxicity testing study and $70-80k for a single bioaccumulation assessment evaluation. These costs were quite comparable to independent laboratory-based approaches, differing by an estimated 7-12%, with the SEAP sometimes being less expensive than the lab estimates. For comparison purposes, a similar assessment was also performed for a smaller program consisting of 6 stations as highlighted and described further in the following Cost Analysis Section (Section 7).

7.0 COST ASSESSMENT

One of the objectives of this project was to develop cost and performance data to support establish a pathway for DoD implementation.

7.1 COST MODEL

The cost for the SEAP technology is primarily controlled by the spatial scale of the site and the number of stations and samples that must be evaluated to adequately satisfy the data quality objectives. For this cost analysis, the site scale and design parameters were similar to that used for the demonstrations in this project. Note that the costs derived for this comparison include a full-scale assessment from the planning stages through sampling/testing and final reporting. In reality, there are many cases where the SEAP technology might provide a valuable add-on component to existing monitoring programs. In these cases, the additional cost to incorporate supporting *in situ* data using the SEA Rings may be very cost effective and a relatively minor component of the cost for an entire, more comprehensive, program.

A cost benefit analysis is an important step for any environmental assessment program. In this case, the cost of implementing an *in situ* based program that can provide a more realistic assessment of site-specific conditions, particularly where conditions may vary temporally, must be weighed against the cost of a more controlled laboratory-based assessment that may provide less realism, but requires fewer logistical challenges and resources dedicated to the field. Both situations will still require a field team, sampling equipment, travel logistics/costs, project coordination and oversight, and proper field documentation. However, due to the extra equipment and requirement to both install and retrieve SEA Rings, the field effort costs will be greater for this approach relative to that for a laboratory-only based testing program. A field based *in situ* program, on the other hand, will likewise require fewer resources for laboratory-based tests; testing in the field is performed in lieu of laboratory based tests. Per sample unit test costs are available and provided by certified analytical toxicity testing laboratories. A field based program using the SEA Ring technology will require only a limited number of laboratory-based tests for QA/QC purposes to assess the health of the test animals used for testing: 1) a control exposure of equal duration to that in the field (exposure to clean water or sediment); 2) a water-only reference toxicant test to evaluate the health and sensitivity of the organisms to a known toxicant in relation to historic results for the laboratory; and 3) a travel or other associated method control to assess health of the organisms after transport to and from the field.

In the costing examples provided below, a program that requires an assessment of 10 sample locations will require 10 unit test costs per species for a laboratory-based program. In the cost comparisons provided below in Table 7.3-3 through Table 7.3-8, unit costs are assigned to laboratory-based tests, including those in support of the *in situ* exposures using the SEA Rings, while labor and materials-based costs are associated with all field sampling and testing efforts. A per sample unit-based cost is amenable for laboratory-based toxicity exposures, given the consistent conditions and level of effort required to run the tests. A per site unit cost is less amenable to a field-based deployment, given the many site-specific factors that need to be accounted for at different locations. For this reason, there is only a single unit lab-based cost associated with the *in situ* tests using the SEA Rings (consisting of a laboratory control and reference toxicant test). Thus, the number of unit costs for laboratory tests differs between the standard lab versus *in situ* approaches, as shown below in Table 7.3-3 through Table 7.3-8, for various water and sediment testing program scenarios.

As mentioned, cost estimates to perform an evaluation using the SEA Ring technology will depend on a number of project-specific factors. Key considerations during the cost assessment planning stage will include travel requirements, shipping, security, site accessibility and accessibility of sufficient controlled space to prepare and take care of test organisms prior to deployment, water depths, currents and tides, sediment characteristics, topography and potential obstacles, and Self-container Underwater Breathing Apparatus (SCUBA) requirements.

The cost assessment provided herein for comparison of *in situ* testing using the SEA Rings to a laboratory-only evaluation makes a key assumption that the project is local and does not require extensive travel and shipping efforts. Shipping and travel costs can easily be calculated and added to the program should the efforts be non-local.

7.2 Cost Drivers

The expected cost drivers for the SEAP technology are largely driven by labor, analytical laboratory, supplies, transportation, and capital equipment costs associated with planning, mobilizing, operating, demobilizing, data analysis, and reporting. Capital costs for the SEAP technology has been developed by the manufacturer, Zebra-Tech Ltd., and service cost options are available as the company develops the technology.

For purchase of the equipment, it is expected that capital costs would be amortized over a number of site evaluations before the purchase of new equipment would be required, and that these costs would be recouped through equipment fees passed on to the customer. Estimated costs for other ancillary capital equipment were documented during the demonstrations. Most of the future engineering, modifications, and upgrades to the equipment are expected to be capitalized by the manufacturer and recouped in the purchase, lease, or service cost for the technology.

Operating costs for the technologies are largely controlled by the labor rates and number of personnel required to field the equipment, analyze the data, and generate the documentation associated with the project. These factors were carefully documented during the demonstrations. Other operating costs include analytical costs, consumables, residuals handling, and system maintenance. Most maintenance functions can be carried out by the operating team. Mobilization and demobilization costs are largely related to labor and shipping costs. Shipping costs can vary considerably, depending on the distance to the site and the shipment method. Labor costs for mobilization and demobilization should be relatively constant. Mobilization and demobilization costs were documented as part of the demonstration.

The requirement for a SCUBA team to deploy and retrieve SEA Rings will also have a significant impact on the cost of the program. Given certain inherent limitations that still exist with diverless deployment in waters greater than approximately 1 meter in depth, the cost assumptions for this assessment includes two scenarios: 1) A shallow water deployment in waters less than 1 meter in depth where no SCUBA is required, but possibly a snorkeler and back-up support; and 2) Deployment in waters deeper than 1 meter requiring a full SCUBA team compliant with Navy standards including an on-site dive supervisor, two divers, one back-up diver, and one tender. The tender is for surface support and does not need to be a diver specifically.

Analytical, installation, and performance monitoring costs for the various tools employed were tracked during each demonstration program. All costs, such as labor, materials, analytical costs, shipping, and travel were also monitored and accounted for. SCUBA support was required to deploy and retrieve SEA Rings for the demonstrations at Bremerton PSNS and MCB Quantico, but not NBSD, where all activities were performed from the surface on land or via a small vessel. Specific elements for costing purposes and tracking are shown in Table 7.1-1.

Table 7.1-1. Cost Elements for SEA Ring Demonstration as a Monitoring Tool for *In Situ* Toxicity and Bioaccumulation Testing.

Cost Element	Data Tracked
Baseline Characterization	− Costs associated with labor − Costs associated with material purchases and rentals − Analytical costs − Costs associated with data analysis and interpretation
SEA Ring Deployment and Retrieval	− Costs associated with maintaining SEA Rings so that they are ready for deployment (parts, maintenance costs) − Costs associated with SEA Ring installation and retrieval, including labor, cost of materials, and organisms − Costs associated with SCUBA, if required − Costs associated with pre- and post-monitoring: organism acclimation, water quality monitoring, concurrent laboratory verification tests, and analytical chemistry − Costs due to unanticipated site-specific challenges (e.g., inclement weather, hard substrate, site access, etc.)
Post-Placement Monitoring Costs	− Costs associated with labor − Costs associated with material purchases and rentals − Analytical costs − Costs associated with data analysis and interpretation
Waste Disposal	− Costs associated with waste disposal (i.e., potentially contaminated material captured by the SEA Rings). − Solvents for cleaning testing materials.
Operation and Maintenance Costs	− Costs associated with labor
Long-term Monitoring	− The SEA Ring deployment period for these site demos range from 2-14 days, therefore, long-term monitoring does not apply to this demonstration.

7.3 COST ANALYSIS

Cost issues are critical to the evaluation and acceptance of innovative technologies. Along with demonstrating and validating the SEAP technology, an important goal of this project was to develop and validate, to the extent possible, the expected operational costs of the technology. Relevant costs and related data, as described in this section, were tracked and documented during the demonstration so that the operational costs of the technology can be estimated with a high degree of confidence.

During the course of the project, commercialization has proceeded in partnership with three private companies: 1) Zebra-Tech Ltd., a specialty marine equipment design and engineering firm, designed and manufactured the SEA Rings; 2) AMEC, an environmental consulting firm, has supported design, testing, and commercial/regulatory outreach support for the SEAP Technology; and 3) Nautilus Environmental, a commercial toxicity lab, provided field, laboratory, data analysis, and reporting support. AMEC has also purchased 4 of the latest version SEA Rings and has been conducting *in situ* testing with them off SIO in support of their NPDES Permit for facility and stormwater discharges to an Area of Biological Significance. The costs summarized below are largely based on data provided by these commercial entities through their experience on the demonstration projects and many additional efforts completed during the demonstration project. Documentation of associated labor efforts and equipment costs from program leads and partners at SPAWAR Pacific and the University of Michigan have also been incorporated into the final estimates provided herein.

7.3.1 Life-Cycle Costs

Estimates of life-cycle costs for the technology were based on the expected working life of the systems (5 to 10 years). The cost analysis incorporates these costs via equipment fees that are passed on to the customer (Table 7.3-1). The current rates indicate that the capital investment for the SEA Rings, including ancillary equipment, could be recouped within the expected 5-10 year working life, with approximately 25 uses per year, well within the expected market demand for the technology. The market demand for this technology appears to be growing based on new regulations nation-wide that are including a greater emphasis on understanding impacts to the receiving water systems we are trying to protect. As an example, new Municipal Separate Stormwater System (MS4) regulations in California now require assessment of sediments in the receiving waters as a part of their permit obligations. New requirements to capture and treat stormwater, and continued efforts to clean up historically contaminated sites are in desperate need of assessment approaches that can better assess *in situ* conditions to help determine whether more intensive Best Management Practices or remediation efforts are required in the first place. Such methods are also greatly needed to better assess long term trends and whether actions taken result in a positive benefit to the environment.

There is currently no comparable off the market technology for *in situ* toxicity testing. Instead, the approach taken here evaluates the typical cost for laboratory-based toxicity testing programs compared to *in situ* testing using a defined suite of organism types. Three hypothetical scenarios are compared using commonly used test organisms that were included in this demonstration program: 1) acute/chronic whole sediment tests using an amphipod, a bivalve or echinoderm embryo, and a polychaete worm; 2) acute/chronic water column tests using mysid shrimp, a bivalve or echinoderm embryo, and a plant (giant kelp); and 3) sediment bioaccumulation tests using a bivalve and polychaete worm. Each scenario includes associated planning efforts and labor for field collection of samples to provide a more direct comparison for a total monitoring program that might implement *in situ* testing. The cost difference for similar species within a general class or family is minimal, so all cost comparisons are performed for just the general classes of test species described above.

Table 7.3-1. Life-Cycle Capital Cost Investment and Recovery Estimates.

Item	Initial Unit Cost ($)	Purchase for proposed program to evaluate 10 sites	Total Cost ($)
SEA Ring Unit	$6,000	10	$60,000
Ancillary – Spare Parts/Toolkit	$2,000	1	$2,000
Ancillary – Field Computer	$1,000	1	$1,000
		TOTAL	$63,000
Equipment Replacement Cost Estimate			
Inflation Rate Estimate – 4%			
		Years of Use	
	0	5	10
SEA Rings and Ancillary Equip.	$63,000	$76,649	$93,255
Equipment Rental Rates Including Inflation and Maintenance			
Maintenance Rate Estimate – 5%			
		Rental Rate (Per SEA Ring)	
		Years of Use	
	Uses per Yr	5	10
SEA Rings and Ancillary Equip.	2	$805	$490
	5	$322	$196
	10	$161	$98
	15	$107	$65
	20	$80	$49
Current Rental Rates			
Per SEA Ring/week			$500

A cost analysis for the SEAP technology relative to laboratory-based methods under the three scenarios described above is summarized in Table 7.3-3 to Table 7.3-8. Comparisons were included for both a 6 site (see Final Technical Report for details) and 10 site sampling program with specific assumptions included in the notes section of each table. Costs provided assume a local project. Additional costs would be incurred for travel and shipping of equipment for a non-local project.

Based on a hypothetical full scale site assessment requiring collection and testing of samples at 10 locations inclusive of a reference site, the cost for an *in situ* survey using the SEAP technology is expected to be on the order of $90K to $95K for a single sediment or water toxicity testing study and $80K to $85K for a single bioaccumulation assessment evaluation When a SCUBA team is not required, these costs will drop by approximately $10K (based on $2.5K per day for a 4-day field effort). At the scale represented, these ranges, inclusive of a SCUBA team, are very comparable to that for programs using standard laboratory-only based methods; approximately 8% greater for a sediment toxicity assessment, a 4% reduction relative to laboratory-only methods for assessment of bioaccumulation, and a 14% increase relative to laboratory-only methods for water column toxicity tests. Excluding or replacing the giant kelp test would make both water column approaches nearly equivalent due to the post-*in situ* analysis required in a laboratory setting for this test species. If SCUBA is not required, the costs for *in situ* testing using the SEAP methodology is either equivalent to or less than that for traditional laboratory-only studies. These costs do not include any supporting analyses that might be conducted on a project/site-specific basis. Additional assumptions related to these costs are provided in the notes column of each table. Much of the cost difference stems from the greater field labor associated with preparing, installing, and recovering the SEA Rings. Although the focus of the assessment is *in situ* using the SEAP technology, limited concurrent laboratory-based tests may still be required, depending on project objectives to assess animal health, sensitivity, and test acceptability.

A second cost comparison was conducted assuming a smaller scale program with 6 sampling locations. Based on a hypothetical full scale site assessment requiring collection and testing of samples at 6 locations inclusive of a reference site, the cost for an *in situ* survey using the SEAP technology is expected to be on the order of $70K to $80K for a single sediment or water toxicity testing study and $65K to $70K for a single bioaccumulation assessment evaluation. When a SCUBA team is not required, these costs drop by approximately $7.5K (based on $2.5K per day for a 3-day field effort). These estimated costs, inclusive of a SCUBA team, for the sediment and water toxicity tests are approximately 10-25% greater using the SEAP technology. Without a SCUBA requirement, the increased costs using the SEAP technology decreases to 10-15% for sediment and water column toxicity, and is nearly identical for bioaccumulation testing. This shows the economy of scale with regard to using the *in situ* SEA Ring methodology. Depending on the program needs, additional options and leveraging may be accomplished by conducting simultaneous toxicity and bioaccumulation tests *in situ*.

Note that the unit costs under the laboratory-based section in Table 7.3-3 to Table 7.3-8 differs between the traditional laboratory-only based program and a field-based in situ testing program, as fewer tests will be conducted in a lab setting if *in situ* testing using the SEA Rings is desired. To provide managers a rough per site cost comparison for the above scenarios, the lab and field costs were combined for both laboratory-only and *in situ* based programs and divided by the number of locations. It is important to note that costs for a field program using SEA Rings will depend more on the time required in the field, as opposed to the specific number of sites tested. Based on experience, we have been able to deploy up to 12 SEA Rings in a single day, however, at a larger or more complex site, this rate could be reduced by a factor of 1 to 2. The laboratory-based unit costs are set a priori and are completely independent of the time required in the field.

It is also important to recognize that the SEAP method represents a new technology that provides more realistic information that cannot be achieved through existing laboratory-based methods. Note that *in situ* testing with the SEA Rings will still typically require some degree of side-by-side laboratory-based exposures for quality assurance, so the technology does not strictly replace laboratory methods. Thus, a cost-benefit analysis would be a critical first step prior to entertaining the use of the SEAP technology. A summary of conditions where the greatest benefit of using the SEAP technology might be realized is provided in Table 7.3-2. The ultimate benefit is the derivation of more realistic data from which to base subsequent management actions on. The cost of potential management actions (e.g., sediment remediation and stormwater pollutant controls) will in many cases far outweigh the costs to provide data based on more representative exposures using the SEA Rings for decision-making purposes. Significant cost-avoidance may be realized should more realistic *in situ* methods indicate no impact relative to laboratory-based tests that may show an effect under certain scenarios.

As demonstrated off shore from NBSD for this program, elevated chemical concentrations and toxicity in grab samples of stormwater at the end-of-pipe does not necessarily translate to negative biological effects in the immediate marine receiving waters using comparable test methods and exposure periods. Similarly, use of the predecessor version and latest refined SEA Rings have consistently shown no toxic effects in the marine receiving waters off SIO in La Jolla, CA during rainfall events over the past four years despite frequent toxicity in stormwater collected at the end-of-pipe (Semi-annual NPDES Monitoring Reports for UCSD [2010-2014], and journal publication in progress; Stransky et al.). The implementation of *in situ* exposures provides much greater confidence in the outcome relative to collecting and testing of individual grab samples from the receiving water where one could argue that a critical condition might have been missed. Current NPDES permits for NBSD require regular chemical analysis and toxicity testing of industrial discharges and stormwater from outfalls at over 100 locations for compliance determination. If toxicity is observed, additional testing is required for confirmation. If toxicity is consistent in more than one sample, implementation of a Toxicity Reduction Evaluation Plan is required, followed by contaminant identification and control activities. Such activities may result in overprotective actions with little or no added environmental benefit. Such activities are also very expensive. As an example, an estimate to contain or treat stormwater to meet current recommended end-of pipe criteria for trace metals at the Ports of Los Angeles and Long Beach was close to $1B dollars for a 2 to 5 year 24-hour design storm (AMEC 2011).

Similarly, a more realistic *in situ* toxicity assessment of a contaminated sediment site will provide more confidence for the determination of a most appropriate cost-effective management action. Sediment remediation alternatives are expensive, typically several million dollars or more at any given site, depending on the alternative chosen and volume of questionable material. Leaving the material in place for natural recovery or limiting the area of impact through a more definitive and refined assessment can easily save millions.

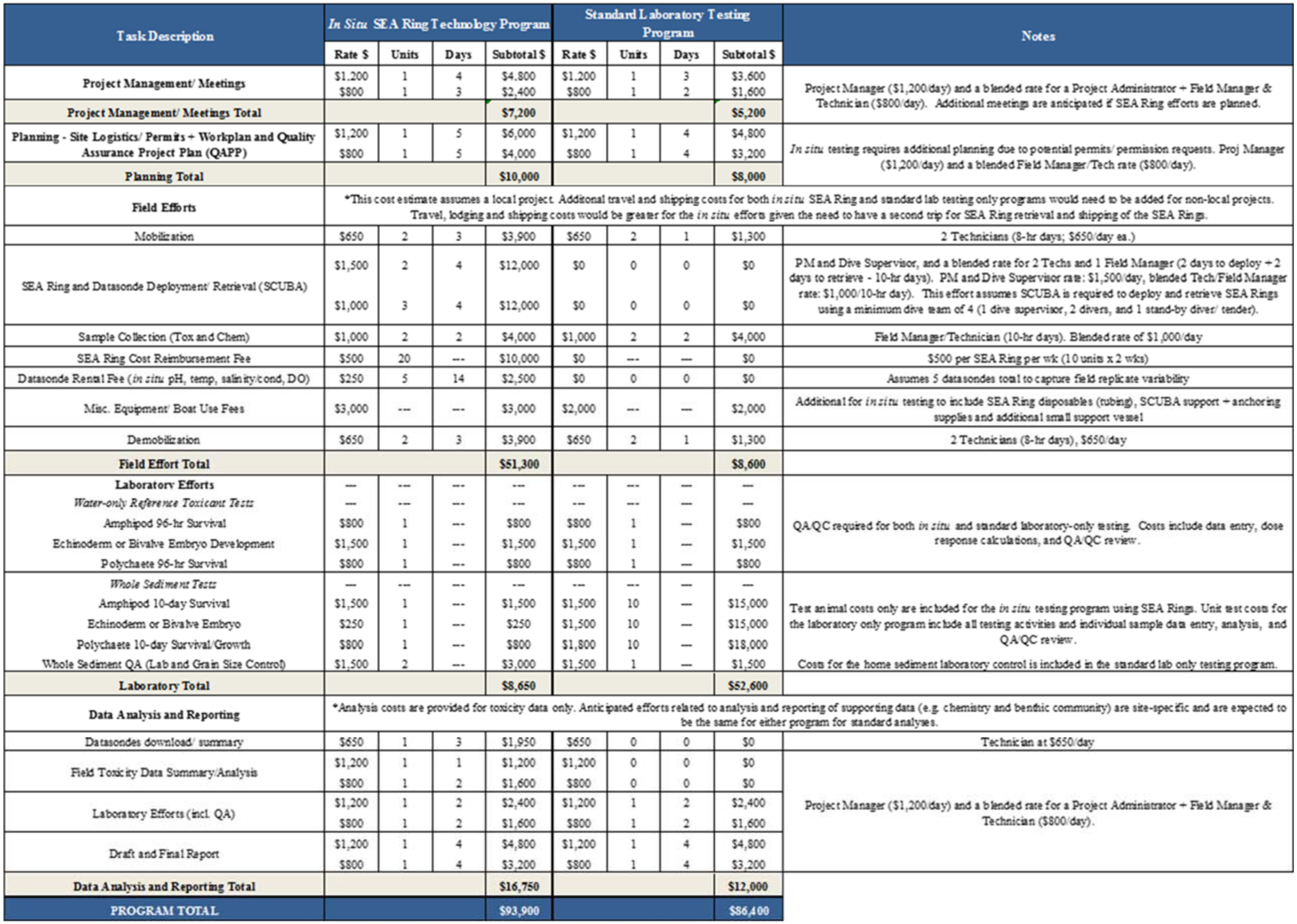
Finally, the SEAP technology has also been shown to provide a more realistic *in situ* assessment of in-place sediment contaminant remedial actions related to reducing contaminant bioavailability, as demonstrated at both Quantico, Virginia and Bremerton, Washington. The data derived *in situ* without collecting and substantially altering the physical structure of the remedial material provides substantially greater confidence in the results. Laboratory-based exposures in some cases during the demonstrations indicated enhanced bioavailability relative to that *in situ*. Relying on these laboratory-based results alone could lead to expensive unwarranted follow-up actions. Alternatively, environmental impact costs through impaired beneficial uses has the potential to be high, should laboratory-based studies show less bioaccumulation or toxicity than more realistic field exposures.

As mentioned in Section **Error! Reference source not found.**, there will be many cases where the SEAP technology might provide a valuable add-on component to existing monitoring programs. In these cases, the additional cost to incorporate supporting *in situ* data using the SEA Rings may be very cost effective and a relatively minor component of the cost for an entire more comprehensive program. As an example, testing with the SEA Rings has been performed as an add-on component to dry and wet-weather ocean receiving water NPDES compliance monitoring for SIO. Tests have been conducted with a suite of three to four species similar to those used for the demonstration project at NBSD. The added cost to include the SEA Ring testing and data analysis at a single compliance location in the receiving water has been approximately $15k per event, a relatively small component (10%) of the overall annual program costs.

Table 7.3-2. Cost-Benefit Decision Assessment for Use of the SEAP Technology.

Greater Benefit	Lesser Benefit
Sites with a developed conceptual site model and known contaminant pathways	Sites with no conceptual site model
Sites with a history of known contaminants and potential to cause toxicity/bioaccumulation based on historical data	Sites with limited "screening-level" assessment data or well documented contaminant pathways
Sites that show "sporadic" toxic effects in laboratory-based tests Sites with documented degraded biological communities	Sites with well documented limited contamination, "reference-like" biological communities, or sites that are known to be highly contaminated/ toxic
Difficult to mimic exposure conditions (e.g., in place sediment remedies, stormwater, groundwater influenced locations, other pulsed exposures) Sites with UXO	Easy to mimic scenarios in a laboratory (e.g., continuous wastewater discharges to a receiving water body with relatively consistent water quality conditions over time)
In-place remedial activity assessment	Testing of multiple experimental remedial alternatives – more cost effective in laboratory-based tests to refine and narrow alternatives for *in situ* trials
Large, complex sites with potentially expensive remedial actions	Small sites with low cost remedial opportunities

Table 7.3-3. Summary of Comparative Costs – Whole Sediment Toxicity Assessment for a 10-Site Program (with SCUBA).

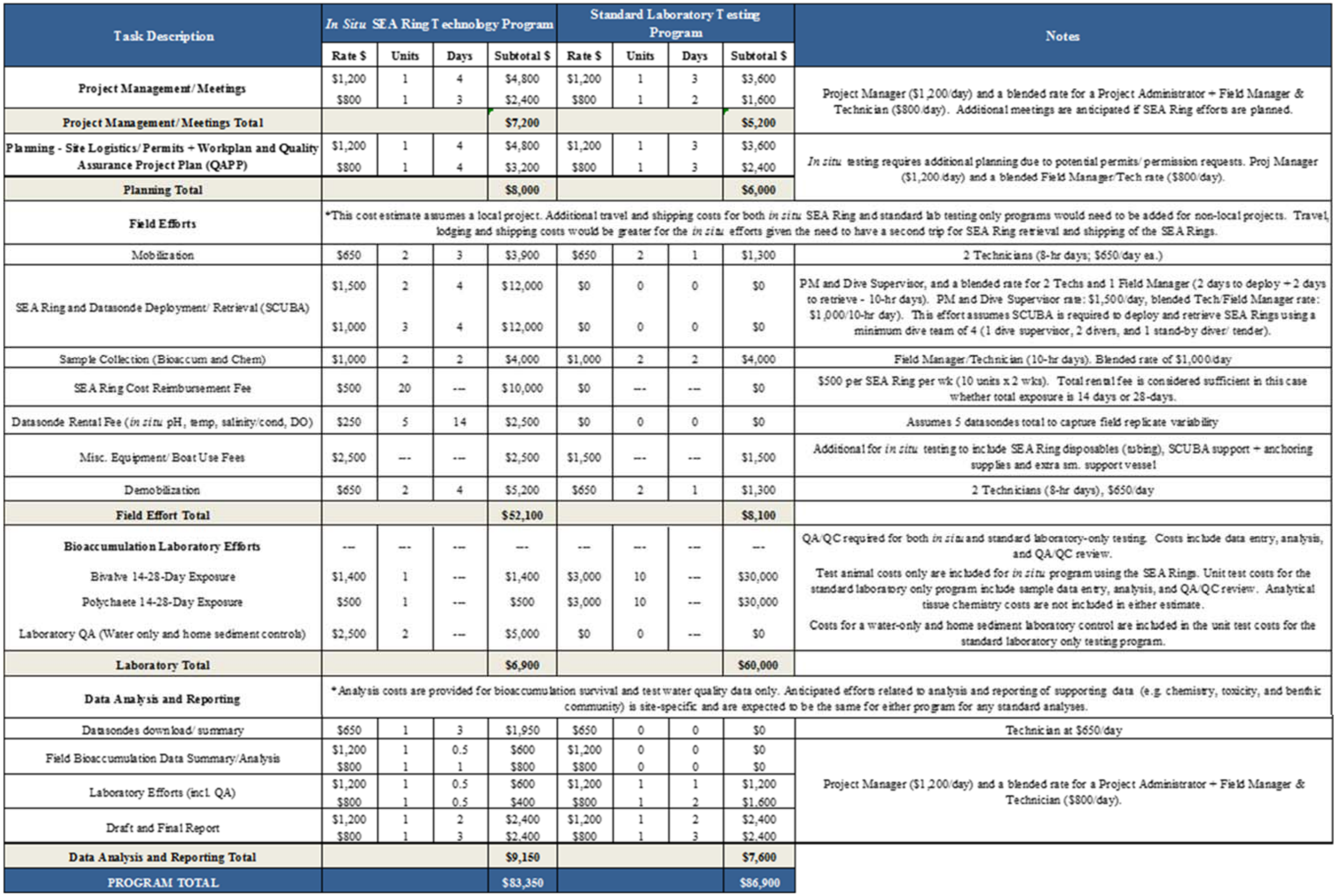


Task Description	*In Situ* SEA Ring Technology Program				Standard Laboratory Testing Program				Notes
	Rate $	Units	Days	Subtotal $	Rate $	Units	Days	Subtotal $	
Project Management/ Meetings	$1.200	1	4	$4.800	$1.200	1	3	$3.600	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day). Additional meetings are anticipated if SEA Ring efforts are planned.
	$800	1	3	$2,400	$800	1	2	$1,600	
Project Management/ Meetings Total				**$7,200**				**$5,200**	
Planning - Site Logistics/ Permits + Workplan and Quality Assurance Project Plan (QAPP)	$1,200	1	5	$6,000	$1,200	1	4	$4,800	*In situ* testing requires additional planning due to potential permits/ permission requests. Proj Manager ($1,200/day) and a blended Field Manager/Tech rate ($800/day).
	$800	1	5	$4,000	$800	1	4	$3,200	
Planning Total				**$10,000**				**$8,000**	
Field Efforts	*This cost estimate assumes a local project. Additonal travel and shipping costs for both *in situ* SEA Ring and standard lab testing only programs would need to be added for non-local projects. Travel, lodging and shipping costs would be greater for the *in situ* efforts given the need to have a second trip for SEA Ring retrieval and shipping of the SEA Rings.								
Mobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days; $650/day ea.)
SEA Ring and Datasonde Deployment/ Retrieval (SCUBA)	$1,500	2	4	$12,000	$0	0	0	$0	PM and Dive Supervisor, and a blended rate for 2 Techs and 1 Field Manager (2 days to deploy + 2 days to retrieve - 10-hr days). PM and Dive Supervisor rate: $1,500/day, blended Tech/Field Manager rate: $1,000/10-hr day). This effort assumes SCUBA is required to deploy and retrieve SEA Rings using a minimum dive team of 4 (1 dive supervisor, 2 divers, and 1 stand-by diver/ tender).
	$1,000	3	4	$12,000	$0	0	0	$0	
Sample Collection (Tox and Chem)	$1,000	2	2	$4,000	$1,000	2	2	$4,000	Field Manager/Technician (10-hr days). Blended rate of $1,000/day
SEA Ring Cost Reimbursement Fee	$500	20	---	$10,000	$0	---	—	$0	$500 per SEA Ring per wk (10 units x 2 wks)
Datasonde Rental Fee (*in situ* pH, temp, salinity/cond, DO)	$250	5	14	$2,500	$0	0	0	$0	Assumes 5 datasondes total to capture field replicate variability
Misc. Equipment/ Boat Use Fees	$3,000	---	---	$3,000	$2,000	---	—	$2,000	Additional for *in situ* testing to include SEA Ring disposables (tubing), SCUBA support + anchoring supplies and additional small support vessel
Demobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days), $650/day
Field Effort Total				**$51,300**				**$8,600**	
Laboratory Efforts	—	---	---	---	---	---	—	—	QA/QC required for both *in situ* and standard laboratory-only testing. Costs include data entry, dose response calculations, and QA/QC review.
Water-only Reference Toxicant Tests	—	---	---	---	---	---	—	—	
Amphipod 96-hr Survival	$800	1	---	$800	$800	1	—	$800	
Echinoderm or Bivalve Embryo Development	$1,500	1	---	$1,500	$1,500	1	—	$1,500	
Polychaete 96-hr Survival	$800	1	---	$800	$800	1	—	$800	
Whole Sediment Tests	—	---	---	---	---	---	—	—	Test animal costs only are included for the *in situ* testing program using SEA Rings. Unit test costs for the laboratory only program include all testing activities and individual sample data entry, analysis, and QA/QC review.
Amphipod 10-day Survival	$1,500	1	---	$1,500	$1,500	10	—	$15,000	
Echinoderm or Bivalve Embryo	$250	1	---	$250	$1,500	10	—	$15,000	
Polychaete 10-day Survival/Growth	$800	1	---	$800	$1,800	10	—	$18,000	
Whole Sediment QA (Lab and Grain Size Control)	$1,500	2	---	$3,000	$1,500	1	—	$1,500	Costs for the home sediment laboratory control is included in the standard lab only testing program.
Laboratory Total				**$8,650**				**$52,600**	
Data Analysis and Reporting	*Analysis costs are provided for toxicity data only. Anticipated efforts related to analysis and reporting of supporting data (e.g. chemistry and benthic community) are site-specific and are expected to be the same for either program for standard analyses.								
Datasondes download/ summary	$650	1	3	$1,950	$650	0	0	$0	Technician at $650/day
Field Toxicity Data Summary/Analysis	$1,200	1	1	$1,200	$1,200	0	0	$0	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day).
	$800	1	2	$1,600	$800	0	0	$0	
Laboratory Efforts (incl. QA)	$1,200	1	2	$2,400	$1,200	1	2	$2,400	
	$800	1	2	$1,600	$800	1	2	$1,600	
Draft and Final Report	$1,200	1	4	$4,800	$1,200	1	4	$4,800	
	$800	1	4	$3,200	$800	1	4	$3,200	
Data Analysis and Reporting Total				**$16,750**				**$12,000**	
PROGRAM TOTAL				**$93,900**				**$86,400**	

Table 7.3-4. Summary of Comparative Costs – Whole Sediment Toxicity Assessment for a 10-Site Program (without SCUBA).

Task Description	*In Situ* SEA Ring Technology Program				Standard Laboratory Testing Program				Notes
	Rate $	Units	Days	Subtotal $	Rate $	Units	Days	Subtotal $	
Project Management/ Meetings	$1.200 $800	1 1	4 3	$4.800 $2.400	$1.200 $800	1 1	3 2	$3.600 $1.600	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day). Additional meetings are anticipated if SEA Ring efforts are planned.
Project Management/ Meetings Total				**$7,200**				**$5,200**	
Planning - Site Logistics/ Permits + Workplan and Quality Assurance Project Plan (QAPP)	$1.200 $800	1 1	5 5	$6.000 $4,000	$1.200 $800	1 1	4 4	$4.800 $3,200	*In situ* testing requires additional planning due to potential permits/ permission requests. Proj Manager ($1,200/day) and a blended Field Manager/Tech rate ($800/day).
Planning Total				**$10,000**				**$8,000**	
Field Efforts	*This cost estimate assumes a local project. Additonal travel and shipping costs for both *in situ* SEA Ring and standard lab testing only programs would need to be added for non-local projects. Travel, lodging and shipping costs would be greater for the *in situ* efforts given the need to have a second trip for SEA Ring retrieval and shipping of the SEA Rings.								
Mobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days; $650/day ea.)
SEA Ring and Datasonde Deployment/ Retrieval (no SCUBA required)	$1,500 $1,000	1 2	4 4	$6,000 $8,000	$0 $0	0 0	0 0	$0 $0	PM and a blended rate for 2 Techs and 1 Field Manager (2 days to deploy + 2 days to retrieve - 10-hr days).
Sample Collection (Tox and Chem)	$1,000	2	2	$4,000	$1,000	2	2	$4,000	Field Manager/Technician (10-hr days). Blended rate of $1,000/day
SEA Ring Cost Reimbursement Fee	$500	20	---	$10,000	$0	---	—	$0	$500 per SEA Ring per wk (10 units x 2 wks)
Datasonde Rental Fee (*in situ* pH, temp, salinity/cond, DO)	$250	5	14	$2,500	$0	0	0	$0	Assumes 5 datasondes total to capture field replicate variability
Misc. Equipment/ Boat Use Fees	$3,000	---	---	$3,000	$2,000	---	—	$2,000	Additional for *in situ* testing to include SEA Ring disposables (tubing), SCUBA support + anchoring supplies and additional small support vessel
Demobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days), $650/day
Field Effort Total				**$41,300**				**$8,600**	
Laboratory Efforts	---	---	---	---	---	---	—	---	QA/QC required for both *in situ* and standard laboratory-only testing. Costs include data entry, dose response calculations, and QA/QC review.
Water-only Reference Toxicant Tests	---	---	---	---	---	---	—	---	
Amphipod 96-hr Survival	$800	1	---	$800	$800	1	—	$800	
Echinoderm or Bivalve Embryo Development	$1,500	1	---	$1,500	$1,500	1	—	$1,500	
Polychaete 96-hr Survival	$800	1	---	$800	$800	1	—	$800	
Whole Sediment Tests	---	---	---	---	---	---	—	---	Test animal costs only are included for the *in situ* testing program using SEA Rings. Unit test costs for the laboratory only program include all testing activities and individual sample data entry, analysis, and QA/QC review. Costs for the home sediment laboratory control is included in the standard lab only testing program.
Amphipod 10-day Survival	$1,500	1	---	$1,500	$1,500	10	—	$15,000	
Echinoderm or Bivalve Embryo	$250	1	---	$250	$1,500	10	—	$15,000	
Polychaete 10-day Survival/Growth	$800	1	---	$800	$1,800	10	—	$18,000	
Whole Sediment QA (Lab and Grain Size Control)	$1,500	2	---	$3,000	$1,500	1	—	$1,500	
Laboratory Total				**$8,650**				**$52,600**	
Data Analysis and Reporting	*Analysis costs are provided for toxicity data only. Anticipated efforts related to analysis and reporting of supporting data (e.g. chemistry and benthic community) are site-specific and are expected to be the same for either program for standard analyses.								
Datasondes download/ summary	$650	1	3	$1,950	$650	0	0	$0	Technician at $650/day
Field Toxicity Data Summary/Analysis	$1,200 $800	1 1	1 2	$1,200 $1,600	$1,200 $800	0 0	0 0	$0 $0	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day).
Laboratory Efforts (incl. QA)	$1,200 $800	1 1	2 2	$2,400 $1,600	$1,200 $800	1 1	2 2	$2,400 $1,600	
Draft and Final Report	$1,200 $800	1 1	4 4	$4,800 $3,200	$1,200 $800	1 1	4 4	$4,800 $3,200	
Data Analysis and Reporting Total				**$16,750**				**$12,000**	
PROGRAM TOTAL				**$83,900**				**$86,400**	

Table 7.3-5. Summary of Comparative Costs – Bioaccumulation Assessment for a 10-Site Program (with SCUBA).

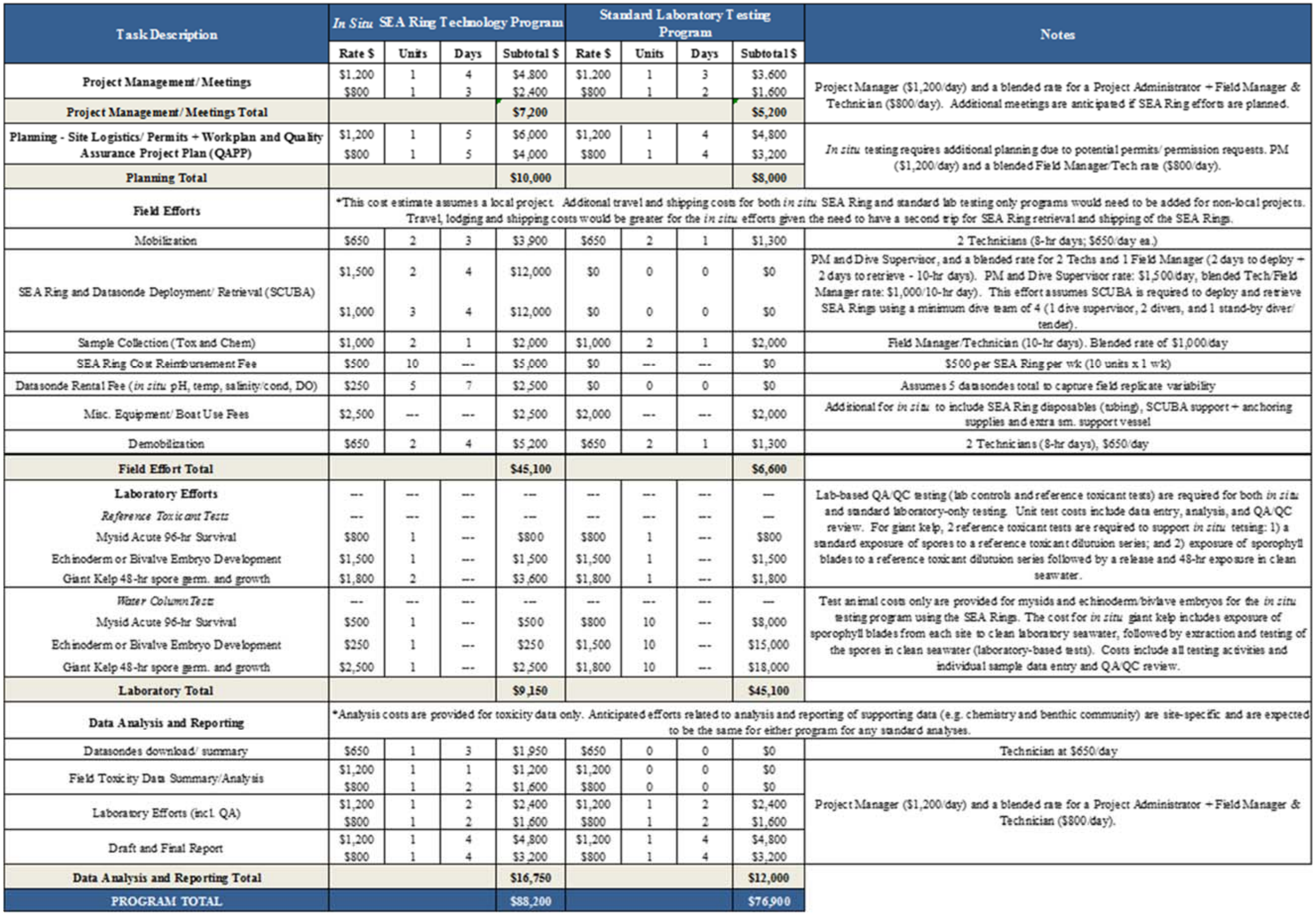


Task Description	*In Situ* SEA Ring Technology Program				Standard Laboratory Testing Program				Notes
	Rate $	Units	Days	Subtotal $	Rate $	Units	Days	Subtotal $	
Project Management/ Meetings	$1,200	1	4	$4,800	$1,200	1	3	$3,600	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day). Additional meetings are anticipated if SEA Ring efforts are planned.
	$800	1	3	$2,400	$800	1	2	$1,600	
Project Management/ Meetings Total				**$7,200**				**$5,200**	
Planning - Site Logistics/ Permits + Workplan and Quality Assurance Project Plan (QAPP)	$1,200	1	4	$4,800	$1,200	1	3	$3,600	*In situ* testing requires additional planning due to potential permits/ permission requests. Proj Manager ($1,200/day) and a blended Field Manager/Tech rate ($800/day).
	$800	1	4	$3,200	$800	1	3	$2,400	
Planning Total				**$8,000**				**$6,000**	
Field Efforts	*This cost estimate assumes a local project. Additional travel and shipping costs for both *in situ* SEA Ring and standard lab testing only programs would need to be added for non-local projects. Travel, lodging and shipping costs would be greater for the *in situ* efforts given the need to have a second trip for SEA Ring retrieval and shipping of the SEA Rings.								
Mobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days; $650/day ea.)
SEA Ring and Datasonde Deployment/ Retrieval (SCUBA)	$1,500	2	4	$12,000	$0	0	0	$0	PM and Dive Supervisor, and a blended rate for 2 Techs and 1 Field Manager (2 days to deploy + 2 days to retrieve - 10-hr days). PM and Dive Supervisor rate: $1,500/day, blended Tech/Field Manager rate: $1,000/10-hr day). This effort assumes SCUBA is required to deploy and retrieve SEA Rings using a minimum dive team of 4 (1 dive supervisor, 2 divers, and 1 stand-by diver/ tender).
	$1,000	3	4	$12,000	$0	0	0	$0	
Sample Collection (Bioaccum and Chem)	$1,000	2	2	$4,000	$1,000	2	2	$4,000	Field Manager/Technician (10-hr days). Blended rate of $1,000/day
SEA Ring Cost Reimbursement Fee	$500	20	---	$10,000	$0	---	---	$0	$500 per SEA Ring per wk (10 units x 2 wks). Total rental fee is considered sufficient in this case whether total exposure is 14 days or 28-days.
Datasonde Rental Fee (*in situ* pH, temp, salinity/cond, DO)	$250	5	14	$2,500	$0	0	0	$0	Assumes 5 datasondes total to capture field replicate variability
Misc. Equipment/ Boat Use Fees	$2,500	---	---	$2,500	$1,500	---	---	$1,500	Additional for *in situ* testing to include SEA Ring disposables (tubing), SCUBA support + anchoring supplies and extra sm. support vessel
Demobilization	$650	2	4	$5,200	$650	2	1	$1,300	2 Technicians (8-hr days), $650/day
Field Effort Total				**$52,100**				**$8,100**	
Bioaccumulation Laboratory Efforts	---	---	---	---	---	---	---	---	QA/QC required for both *in situ* and standard laboratory-only testing. Costs include data entry, analysis, and QA/QC review.
Bivalve 14-28-Day Exposure	$1,400	1	---	$1,400	$3,000	10	---	$30,000	Test animal costs only are included for *in situ* program using the SEA Rings. Unit test costs for the standard laboratory only program include sample data entry, analysis, and QA/QC review. Analytical tissue chemistry costs are not included in either estimate.
Polychaete 14-28-Day Exposure	$500	1	---	$500	$3,000	10	---	$30,000	
Laboratory QA (Water only and home sediment controls)	$2,500	2	---	$5,000	$0	0	---	$0	Costs for a water-only and home sediment laboratory control are included in the unit test costs for the standard laboratory only testing program.
Laboratory Total				**$6,900**				**$60,000**	
Data Analysis and Reporting	*Analysis costs are provided for bioaccumulation survival and test water quality data only. Anticipated efforts related to analysis and reporting of supporting data (e.g. chemistry, toxicity, and benthic community) is site-specific and are expected to be the same for either program for any standard analyses.								
Datasondes download/ summary	$650	1	3	$1,950	$650	0	0	$0	Technician at $650/day
Field Bioaccumulation Data Summary/Analysis	$1,200	1	0.5	$600	$1,200	0	0	$0	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day).
	$800	1	1	$800	$800	0	0	$0	
Laboratory Efforts (incl. QA)	$1,200	1	0.5	$600	$1,200	1	1	$1,200	
	$800	1	0.5	$400	$800	1	2	$1,600	
Draft and Final Report	$1,200	1	2	$2,400	$1,200	1	2	$2,400	
	$800	1	3	$2,400	$800	1	3	$2,400	
Data Analysis and Reporting Total				**$9,150**				**$7,600**	
PROGRAM TOTAL				**$83,350**				**$86,900**	

Table 7.3-6. Summary of Comparative Costs – Bioaccumulation Assessment for a 10-Site Program (without SCUBA).

Task Description	*In Situ* SEA Ring Technology Program				Standard Laboratory Testing Program				Notes
	Rate $	Units	Days	Subtotal $	Rate $	Units	Days	Subtotal $	
Project Management/Meetings	$1,200	1	4	$4,800	$1,200	1	3	$3,600	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day). Additional meetings are anticipated if SEA Ring efforts are planned.
	$800	1	3	$2,400	$800	1	2	$1,600	
Project Management/Meetings Total				**$7,200**				**$5,200**	
Planning - Site Logistics/Permits + Workplan and Quality Assurance Project Plan (QAPP)	$1,200	1	4	$4,800	$1,200	1	3	$3,600	*In situ* testing requires additional planning due to potential permits/permission requests. Proj Manager ($1,200/day) and a blended Field Manager/Tech rate ($800/day).
	$800	1	4	$3,200	$800	1	3	$2,400	
Planning Total				**$8,000**				**$6,000**	
Field Efforts	*This cost estimate assumes a local project. Additional travel and shipping costs for both *in situ* SEA Ring and standard lab testing only programs would need to be added for non-local projects. Travel, lodging and shipping costs would be greater for the *in situ* efforts given the need to have a second trip for SEA Ring retrieval and shipping of the SEA Rings.								
Mobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days; $650/day ea.)
SEA Ring and Datasonde Deployment/Retrieval (no SCUBA required)	$1,500	1	4	$6,000	$0	0	0	$0	PM and a blended rate for 2 Techs and 1 Field Manager (2 days to deploy + 2 days to retrieve - 10-hr days).
	$1,000	2	4	$8,000	$0	0	0	$0	
Sample Collection (Bioaccum and Chem)	$1,000	2	2	$4,000	$1,000	2	2	$4,000	Field Manager/Technician (10-hr days). Blended rate of $1,000/day
SEA Ring Cost Reimbursement Fee	$500	20	---	$10,000	$0	---	---	$0	$500 per SEA Ring per wk (10 units x 2 wks). Total rental fee is considered sufficient in this case whether total exposure is 14 days or 28-days.
Datasonde Rental Fee (*in situ* pH, temp, salinity/cond, DO)	$250	5	14	$2,500	$0	0	0	$0	Assumes 5 datasondes total to capture field replicate variability
Misc. Equipment/Boat Use Fees	$2,500	---	---	$2,500	$1,500	---	---	$1,500	Additional for *in situ* testing to include SEA Ring disposables (tubing), SCUBA support + anchoring supplies and extra sm. support vessel
Demobilization	$650	2	4	$5,200	$650	2	1	$1,300	2 Technicians (8-hr days), $650/day
Field Effort Total				**$42,100**				**$8,100**	
Bioaccumulation Laboratory Efforts	---	---	---	---	---	---	---	---	QA/QC required for both *in situ* and standard laboratory-only testing. Costs include data entry, analysis, and QA/QC review.
Bivalve 14-28-Day Exposure	$1,400	1	---	$1,400	$3,000	10	---	$30,000	Test animal costs only are included for *in situ* program using the SEA Rings. Unit test costs for the standard laboratory only program include sample data entry, analysis, and QA/QC review. Analytical tissue chemistry costs are not included in either estimate.
Polychaete 14-28-Day Exposure	$500	1	---	$500	$3,000	10	---	$30,000	
Laboratory QA (Water only and home sediment controls)	$2,500	2	---	$5,000	$0	0	---	$0	Costs for a water-only and home sediment laboratory control are included in the unit test costs for the standard laboratory only testing program.
Laboratory Total				**$6,900**				**$60,000**	
Data Analysis and Reporting	*Analysis costs are provided for bioaccumulation survival and test water quality data only. Anticipated efforts related to analysis and reporting of supporting data (e.g. chemistry, toxicity, and benthic community) is site-specific and are expected to be the same for either program for any standard analyses.								
Datasondes download/summary	$650	1	3	$1,950	$650	0	0	$0	Technician at $650/day
Field Bioaccumulation Data Summary/Analysis	$1,200	1	0.5	$600	$1,200	0	0	$0	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day).
	$800	1	1	$800	$800	0	0	$0	
Laboratory Efforts (incl. QA)	$1,200	1	0.5	$600	$1,200	1	1	$1,200	
	$800	1	0.5	$400	$800	1	2	$1,600	
Draft and Final Report	$1,200	1	2	$2,400	$1,200	1	2	$2,400	
	$800	1	3	$2,400	$800	1	3	$2,400	
Data Analysis and Reporting Total				**$9,150**				**$7,600**	
PROGRAM TOTAL				**$73,350**				**$86,900**	

Table 7.3-7. Summary of Comparative Costs – Water Column Toxicity Assessment for a 10-Site Program (with SCUBA).



Task Description	*In Situ* SEA Ring Technology Program				Standard Laboratory Testing Program				Notes
	Rate $	Units	Days	Subtotal $	Rate $	Units	Days	Subtotal $	
Project Management/ Meetings	$1.200 $800	1 1	4 3	$4.800 $2.400	$1.200 $800	1 1	3 2	$3.600 $1.600	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day). Additional meetings are anticipated if SEA Ring efforts are planned.
Project Management/ Meetings Total				**$7,200**				**$5,200**	
Planning - Site Logistics/ Permits + Workplan and Quality Assurance Project Plan (QAPP)	$1,200 $800	1 1	5 5	$6,000 $4,000	$1,200 $800	1 1	4 4	$4,800 $3,200	*In situ* testing requires additional planning due to potential permits/ permission requests. PM ($1,200/day) and a blended Field Manager/Tech rate ($800/day).
Planning Total				**$10,000**				**$8,000**	
Field Efforts	*This cost estimate assumes a local project. Additonal travel and shipping costs for both *in situ* SEA Ring and standard lab testing only programs would need to be added for non-local projects. Travel, lodging and shipping costs would be greater for the *in situ* efforts given the need to have a second trip for SEA Ring retrieval and shipping of the SEA Rings.								
Mobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days; $650/day ea.)
SEA Ring and Datasonde Deployment/ Retrieval (SCUBA)	$1,500 $1,000	2 3	4 4	$12,000 $12,000	$0 $0	0 0	0 0	$0 $0	PM and Dive Supervisor, and a blended rate for 2 Techs and 1 Field Manager (2 days to deploy + 2 days to retrieve - 10-hr days). PM and Dive Supervisor rate: $1,500/day, blended Tech/Field Manager rate: $1,000/10-hr day). This effort assumes SCUBA is required to deploy and retrieve SEA Rings using a minimum dive team of 4 (1 dive supervisor, 2 divers, and 1 stand-by diver/ tender).
Sample Collection (Tox and Chem)	$1,000	2	1	$2,000	$1,000	2	1	$2,000	Field Manager/Technician (10-hr days). Blended rate of $1,000/day
SEA Ring Cost Reimbursement Fee	$500	10	---	$5,000	$0	---	---	$0	$500 per SEA Ring per wk (10 units x 1 wk)
Datasonde Rental Fee (*in situ* pH, temp, salinity/cond, DO)	$250	5	7	$2,500	$0	0	0	$0	Assumes 5 datasondes total to capture field replicate variability
Misc. Equipment/ Boat Use Fees	$2,500	---	---	$2,500	$2,000	---	---	$2,000	Additional for *in situ* to include SEA Ring disposables (tubing), SCUBA support + anchoring supplies and extra sm. support vessel
Demobilization	$650	2	4	$5,200	$650	2	1	$1,300	2 Technicians (8-hr days), $650/day
Field Effort Total				**$45,100**				**$6,600**	
Laboratory Efforts	---	---	---	---	---	---	---	---	Lab-based QA/QC testing (lab controls and reference toxicant tests) are required for both *in situ* and standard laboratory-only testing. Unit test costs include data entry, analysis, and QA/QC review. For giant kelp, 2 reference toxicant tests are required to support *in situ* tetsing: 1) a standard exposure of spores to a reference toxicant dilutuion series; and 2) exposure of sporophyll blades to a reference toxicant dilutuion series followed by a release and 48-hr exposure in clean seawater.
Reference Toxicant Tests	---	---	---	---	---	---	---	---	
Mysid Acute 96-hr Survival	$800	1	---	$800	$800	1	---	$800	
Echinoderm or Bivalve Embryo Development	$1,500	1	---	$1,500	$1,500	1	---	$1,500	
Giant Kelp 48-hr spore germ. and growth	$1,800	2	---	$3,600	$1,800	1	---	$1,800	
Water Column Tests	---	---	---	---	---	---	---	---	Test animal costs only are provided for mysids and echinoderm/bivlave embryos for the *in situ* testing program using the SEA Rings. The cost for *in situ* giant kelp includes exposure of sporophyll blades from each site to clean laboratory seawater, followed by extraction and testing of the spores in clean seawater (laboratory-based tests). Costs include all testing activities and individual sample data entry and QA/QC review.
Mysid Acute 96-hr Survival	$500	1	---	$500	$800	10	---	$8,000	
Echinoderm or Bivalve Embryo Development	$250	1	---	$250	$1,500	10	---	$15,000	
Giant Kelp 48-hr spore germ. and growth	$2,500	1	---	$2,500	$1,800	10	---	$18,000	
Laboratory Total				**$9,150**				**$45,100**	
Data Analysis and Reporting	*Analysis costs are provided for toxicity data only. Anticipated efforts related to analysis and reporting of supporting data (e.g. chemistry and benthic community) are site-specific and are expected to be the same for either program for any standard analyses.								
Datasondes download/ summary	$650	1	3	$1,950	$650	0	0	$0	Technician at $650/day
Field Toxicity Data Summary/Analysis	$1,200 $800	1 1	1 2	$1,200 $1,600	$1,200 $800	0 0	0 0	$0 $0	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day).
Laboratory Efforts (incl. QA)	$1,200 $800	1 1	2 2	$2,400 $1,600	$1,200 $800	1 1	2 2	$2,400 $1,600	
Draft and Final Report	$1,200 $800	1 1	4 4	$4,800 $3,200	$1,200 $800	1 1	4 4	$4,800 $3,200	
Data Analysis and Reporting Total				**$16,750**				**$12,000**	
PROGRAM TOTAL				**$88,200**				**$76,900**	

Table 7.3-8. Summary of Comparative Costs – Water Column Toxicity Assessment for a 10-Site Program (without SCUBA).

Task Description	***In Situ* SEA Ring Technology Program**				**Standard Laboratory Testing Program**				**Notes**
	Rate $	**Units**	**Days**	**Subtotal $**	**Rate $**	**Units**	**Days**	**Subtotal $**	
Project Management/ Meetings	$1,200	1	4	$4,800	$1,200	1	3	$3,600	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day). Additional meetings are anticipated if SEA Ring efforts are planned.
	$800	1	3	$2,400	$800	1	2	$1,600	
Project Management/ Meetings Total				**$7,200**				**$5,200**	
Planning - Site Logistics/ Permits + Workplan and Quality Assurance Project Plan (QAPP)	$1,200	1	5	$6,000	$1,200	1	4	$4,800	*In situ* testing requires additional planning due to potential permits/ permission requests. PM ($1,200/day) and a blended Field Manager/Tech rate ($800/day).
	$800	1	5	$4,000	$800	1	4	$3,200	
Planning Total				**$10,000**				**$8,000**	
Field Efforts	*This cost estimate assumes a local project. Additonal travel and shipping costs for both *in situ* SEA Ring and standard lab testing only programs would need to be added for non-local projects. Travel, lodging and shipping costs would be greater for the *in situ* efforts given the need to have a second trip for SEA Ring retrieval and shipping of the SEA Rings.								
Mobilization	$650	2	3	$3,900	$650	2	1	$1,300	2 Technicians (8-hr days; $650/day ea.)
SEA Ring and Datasonde Deployment/ Retrieval (no SCUBA required)	$1,500	1	4	$6,000	$0	0	0	$0	PM and a blended rate for 2 Techs and 1 Field Manager (2 days to deploy + 2 days to retrieve - 10-hr days).
	$1,000	2	4	$8,000	$0	0	0	$0	
Sample Collection (Tox and Chem)	$1,000	2	1	$2,000	$1,000	2	1	$2,000	Field Manager/Technician (10-hr days). Blended rate of $1,000/day
SEA Ring Cost Reimbursement Fee	$500	10	---	$5,000	$0	---	---	$0	$500 per SEA Ring per wk (10 units x 1 wk)
Datasonde Rental Fee (*in situ* pH, temp, salinity/cond, DO)	$250	5	7	$2,500	$0	0	0	$0	Assumes 5 datasondes total to capture field replicate variability
Misc. Equipment/ Boat Use Fees	$2,500	---	---	$2,500	$2,000	---	---	$2,000	Additional for *in situ* to include SEA Ring disposables (tubing), SCUBA support + anchoring supplies and extra sm. support vessel
Demobilization	$650	2	4	$5,200	$650	2	1	$1,300	2 Technicians (8-hr days), $650/day
Field Effort Total				**$35,100**				**$6,600**	
Laboratory Efforts	---	---	---	---	---	---	---	---	Lab-based QA/QC testing (lab controls and reference toxicant tests) are required for both *in situ* and standard laboratory-only testing. Unit test costs include data entry, analysis, and QA/QC review. For giant kelp, 2 reference toxicant tests are required to support *in situ* tetsing: 1) a standard exposure of spores to a reference toxicant dilutuion series; and 2) exposure of sporophyll blades to a reference toxicant dilutuion series followed by a release and 48-hr exposure in clean seawater.
Reference Toxicant Tests	---	---	---	---	---	---	---	---	
Mysid Acute 96-hr Survival	$800	1	---	$800	$800	1	---	$800	
Echinoderm or Bivalve Embryo Development	$1,500	1	---	$1,500	$1,500	1	---	$1,500	
Giant Kelp 48-hr spore germ. and growth	$1,800	2	---	$3,600	$1,800	1	---	$1,800	
Water ColumnTests	---	---	---	---	---	---	---	---	Test animal costs only are provided for mysids and echinoderm/bivlave embryos for the *in situ* testing program using the SEA Rings. The cost for *in situ* giant kelp includes exposure of sporophyll blades from each site to clean laboratory seawater, followed by extraction and testing of the spores in clean seawater (laboratory-based tests). Costs include all testing activities and individual sample data entry and QA/QC review.
Mysid Acute 96-hr Survival	$500	1	---	$500	$800	10	---	$8,000	
Echinoderm or Bivalve Embryo Development	$250	1	---	$250	$1,500	10	---	$15,000	
Giant Kelp 48-hr spore germ. and growth	$2,500	1	---	$2,500	$1,800	10	---	$18,000	
Laboratory Total				**$9,150**				**$45,100**	
Data Analysis and Reporting	*Analysis costs are provided for toxicity data only. Anticipated efforts related to analysis and reporting of supporting data (e.g. chemistry and benthic community) are site-specific and are expected to be the same for either program for any standard analyses.								
Datasondes download/ summary	$650	1	3	$1,950	$650	0	0	$0	Technician at $650/day
Field Toxicity Data Summary/Analysis	$1,200	1	1	$1,200	$1,200	0	0	$0	Project Manager ($1,200/day) and a blended rate for a Project Administrator + Field Manager & Technician ($800/day).
	$800	1	2	$1,600	$800	0	0	$0	
Laboratory Efforts (incl. QA)	$1,200	1	2	$2,400	$1,200	1	2	$2,400	
	$800	1	2	$1,600	$800	1	2	$1,600	
Draft and Final Report	$1,200	1	4	$4,800	$1,200	1	4	$4,800	
	$800	1	4	$3,200	$800	1	4	$3,200	
Data Analysis and Reporting Total				**$16,750**				**$12,000**	
PROGRAM TOTAL				**$78,200**				**$76,900**	

8.0 IMPLEMENTATION ISSUES

There have been extensive efforts over the course of the demonstration program towards acceptance for incorporation into a range of regulatory compliance efforts at both DoD and non-DoD sites. Demonstration results for this effort were incorporated into a much broader evaluation of sediment remedy effectiveness at PSNS and MCB Quantico. These results will be available for review and comment by relevant local, state, and federal regulators, and stakeholders. The demonstration at NBSD will provide valuable support related to NPDES Permit compliance for stormwater discharges from the base.

The ability of the SEA Rings to provide comparable toxicity and bioaccumulation data relative to traditional USEPA and ASTM-approved laboratory methods in concurrent side-by-side testing was evaluated under the USEPA's ETV third party testing program. Results of this evaluation concluded that the SEA Ring produced toxicity and bioaccumulation test results that were highly comparable to standard laboratory-based methods when conducted under similar exposure conditions in both spiked seawater and contaminated sediments. Technology verification by the ETV program is documented in a verification statement (McKernan et al. 2014).

Extensive outreach efforts have also been conducted throughout the course of the SEAP technology demonstration project. Technology transfer of the SEAP methodology to numerous DoD and non-DoD activities that could use this technology has been accomplished through the publication of journal articles (e.g., Burton et al. 2012; Rosen et al. 2012), the distribution of a white paper (Stransky et al. 2009), and the presentation of the technology and demonstration results at conferences (e.g., Rosen et al. 2011, Rosen et al. 2012b, Burton et al. 2013, Stransky 2011, 2013, and 2014; Stransky et al. 2014a; and Tait et al. 2014). An article was also published in SEA Technology™ magazine (Rosen et al. 2014). Further information regarding the technology and its commercial availability through Zebra Tech, Ltd are available online.

Finally, in person meetings have been organized to present the potential benefits of the SEAP technology with various local and regional regulators in California as new State Policies and NPDES Permits are being drafted related to assessing the toxicity of stormwater. The interest level received has been exceptionally high and encouraging. The technology was highlighted in front of a regional monitoring coalition in southern California to support large-scale regional efforts in 2013, known as Bight '13 (Stransky 2014b). We expect that demonstration of similar sediment testing methods will occur as part of future monitoring efforts to support the Bight program.

As stated previously, commercial equipment suppliers and service providers have already been identified and are currently applying the technologies at sites. At the time of this publication, negotiations are also in progress to potentially use the SEA Ring Technology to support NPDES compliance requirements for the first large-scale desalination plant on the United States West Coast, as well as the first offshore aquaculture facility currently in the development stage to be placed off the coast of southern California. Together, these collective efforts should help to successfully transition this technology to support both DoD and commercial needs.

End-user concerns were minimally expressed at any of the demonstration sties, with most interactions very positive. The technical team did observe some challenges during the demonstration, and through lessons-learned after each deployment, made substantial modifications along the way to produce and demonstrate the current device (Version 3) that eliminates most of these. Early concerns we primarily associated with the Version 2 pump reliability and battery life.

Periodic pump jamming and unexpected reduced battery life present critical issues regarding maintenance of sufficient water exchange for both water quality reasons and for accurate incorporation of site-specific water characteristics, desired in *in situ* exposures. These critical issues were virtually eliminated with Version 3, and we recommend use of this design as the technology becomes further validated and integrated into potential regulatory programs. Most recently, Version 3 SEA Rings were incorporated into the *in situ* receiving water monitoring under SERDP Project ER-2428 (Lead PI, Dr. Danny Reible), during which all units performed optimally for the 28 day exposure.

One additional performance objective not achieved at every site has been the ability to deploy and retrieve the SEA Rings for sediment assessments without diver support. Several methods have been developed and tested that show promise, but consistent success for any of the methods tried is currently dependent on the sample type and potential physical interferences at any given site. The heterogeneity of the bottom at those sites evaluated during the demonstrations raised enough concern to abandon any attempts without diver-assisted deployments and recovery. Extensive shell debris and worm tubes along with the amendment itself at PSNS made deployment and recovery of the SEA Rings challenging even with divers. Likewise, woody debris at Quantico made this a challenging site as well. The use of divers ensured secure placement in areas with limited interference, and successful recovery of sediment in each replicate core by digging around and manually securing a cap to each. On the other hand, all deployments and recovery of SEA Rings for the stormwater demonstration at NBSD were conducted from the surface without any in-water support.

A number of important lessons were learned over the course of the project. All three demonstrations were based on newly commercialized SEA Rings that were produced by Zebra-Tech Ltd. Based on experience from the demonstrations, a list of modifications to further enhance the capability of the SEA Rings and to make them more user friendly have since been identified and developed into the latest commercially available system (Version 3). Revised SOPs, a new pumping system, and modified test chambers to increase flow have been developed and demonstrated, with success.

Sediment capture devices can be entertained and used for locations with a known physically consistent surface, however, in-water support should currently still be planned for near term sediment assessment programs until a more fail safe capture device is demonstrated. Underwater video/photo/audio capabilities were also very useful during the demonstration projects to confirm placement and monitor performance without being in the water. Use of this ancillary support is recommended as a standard practice, whenever available.

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APPENDIX A POINTS OF CONTACT

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APPENDIX B STEP-BY-STEP PICTORIAL DESCRIPTION

This appendix provides a pictorial overview of the procedures associated with SEA Ring sampler preparation, shipment to the site, field deployment, retrieval and shipment of samples back to the laboratory. For detailed information, the user should consult both the Standard Operating Procedures and the SEA Ring Operations Manuals provided in the Final Technical Report associated with this technology demonstration. It is anticipated that updates to the Operations Manual will be provided by Zebra-Tech, Ltd: http://www.zebra-tech.co.nz/.

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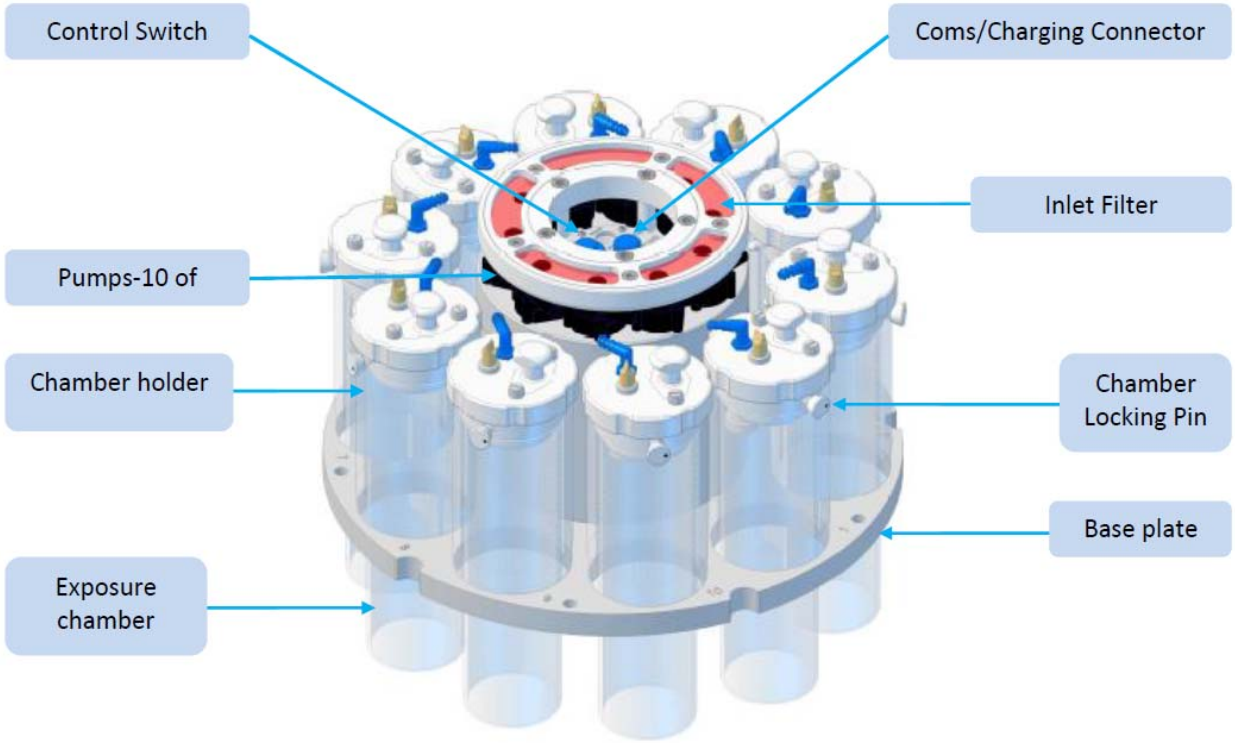

Figure B.1. Overview of Basic Components Associated with the Version 3 SEA Ring.

From SEA Ring Operation Manual, Version 1.7. https://www.serdp-estcp.org/content/download/42177/402168/file/ER-201130%20Final%20Report.pdf

Start time (HH:MM) 15 8
Start date (MM:DD:YY) 12 15 14
Stop time (HH:MM) 16 55
Stop date (MM:DD:YY) 12 11 15
Chamber flush duration 0 min 10 sec
Chamber flush interval 2 min 00 sec

Active Chambers
☑ 1
☑ 2
☑ 3
☑ 4
☑ 5
☑ 6
☑ 7
☑ 8
☑ 9
☑ 10

SEA Ring time/date 16:13:51 12/15/ 2014
PC time/date 16:13:52 12/15/2014

Sea Ring serial number -001

Voltage: 8V - Memory used status: 1%

Figure B.2. Programming the SEA Ring involves connecting the device to a laptop computer loaded with SEA Ring software via the coms/charging connector (left). The coms connector is used to program the SEA Ring and offload pump performance data, while the charging connector is used to fully charge the internal battery system prior to deployment. During programming, a simple menu (right) is used to set the time for pump start (e.g. deployment time), the pumping frequency and duration, select for which chambers to activate, and to verify battery voltage and memory space.

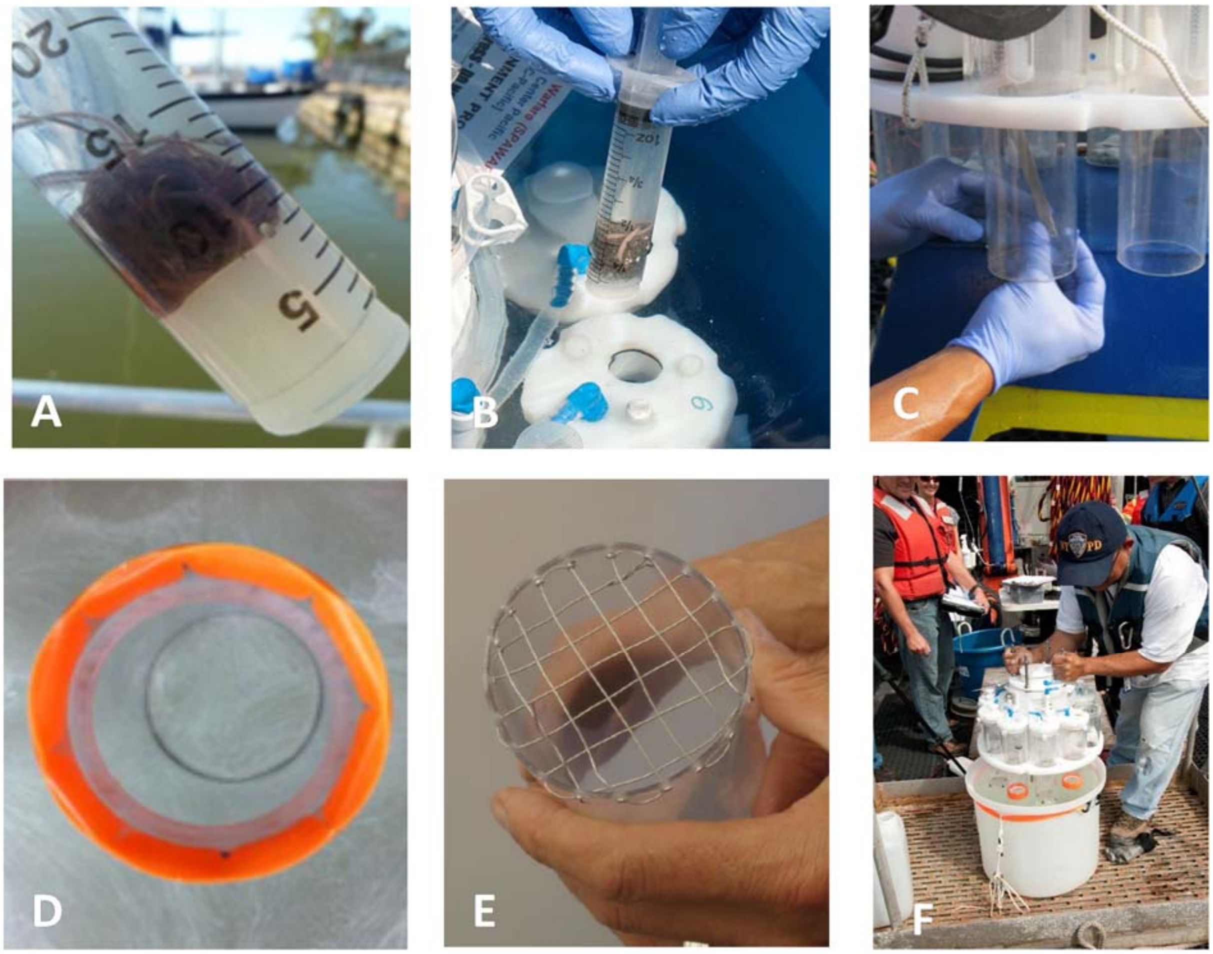

Figure B.3. Assembling and Loading of the SEA Ring.

Multiple options exist for assembly and deployment of the SEA Ring, which are ultimately dependent on site- and project-specific objectives. As an example, organism loading syringes and various other chamber consumable parts allow are shown here, including (A) modified off the shelf 30 mL syringes for loading relatively small organisms via a silicone stopper during transport; (B) placement of syringes into SEA Ring chamber holders; (C) incorporation of PSDs into exposure chambers; (D) incorporation of small organism recovery devices (e.g. modified core catchers); (E) larger organism (e.g. clam) deployment and recovery options (e.g. ½” titanium mesh); and (F) transfer of a loaded SEA Ring into a Chemtainer in preparation for field deployment.

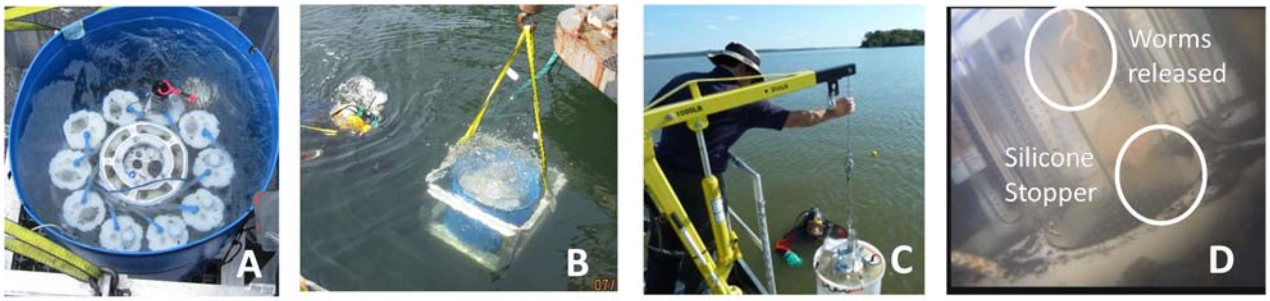

Figure B.4. SEA Ring Deployment.

Transport of SEA Rings to sediment sites involve placement into an 18-gallon container (A) that is typically delivered by divers (B) at deep water sites. Another example of delivery to the field site involves small boat transfer via a winch to SCUBA or free divers at shallow sites (C). Once surface sediment SEA Rings are in place, free or SCUBA divers depress syringes holding smaller organisms during transfer within a silicone stopper, allowing for burrowing into the site sediment (D). Larger organisms (e.g. clams) are automatically exposed to surface sediments based on deployment approach used in Figure B3E.

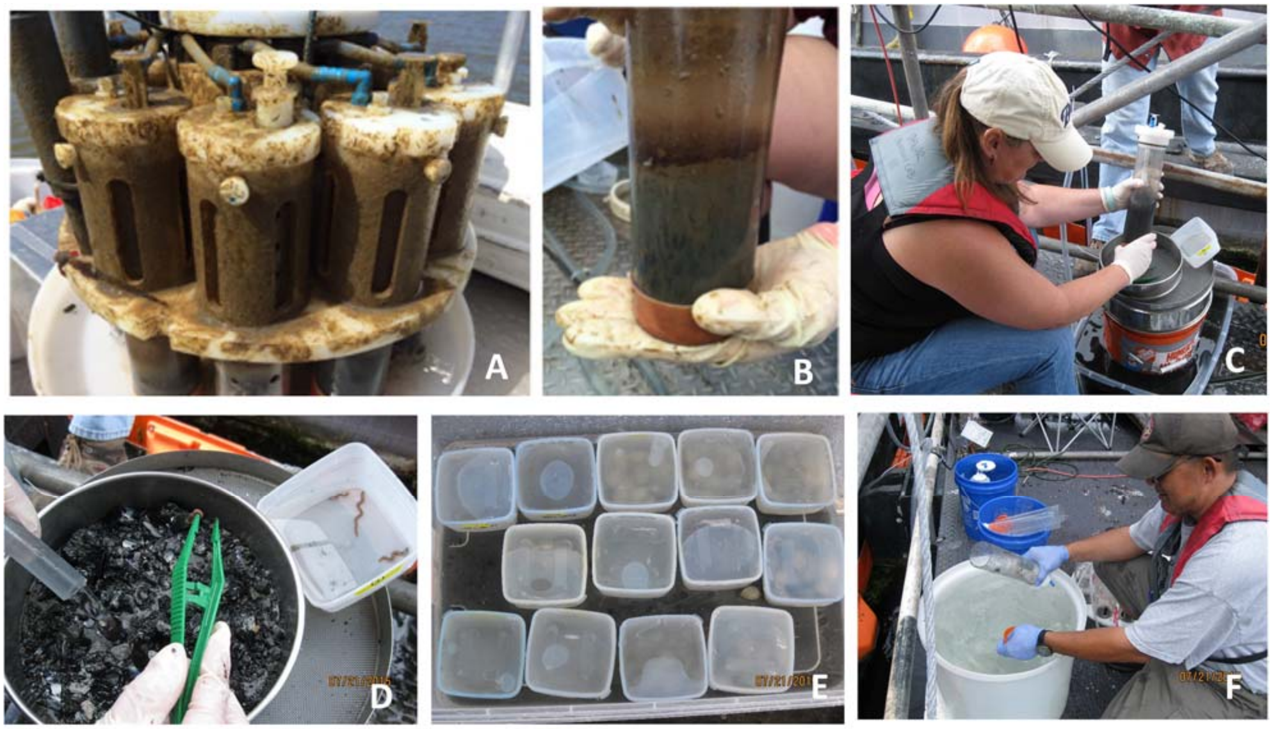

Figure B.5. SEA Ring Recovery and Processing.

Following recovery of SEA Rings by hand or automated capping of chambers (A), initial observations of the sediment core integrity and organism presence are immediately documented (B). Sequentially, exposure chambers are processed on site using appropriately sized sieves and site water as a rinse water using pond pumps (C and D). Organisms are transferred to clean cups (D and E) on site, maintained at site water temperature, and then transferred via ice chests to on-site laboratory or hotel room for further purging of sediment particles overnight prior to processing and shipment to the analytical laboratory. During the recovery operations, all reusable parts are scrubbed and cleaned with site water (F), which is followed by further cleaning of components under standard SOPs referenced above.

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