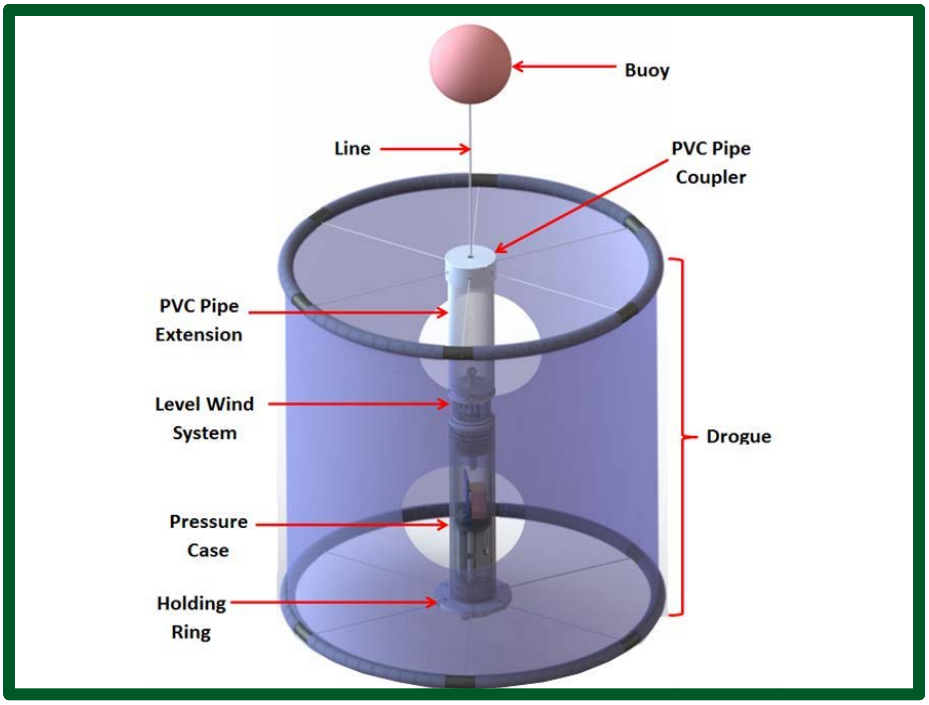
ESTCP
Cost and Performance Report

(ER-201432)



Demonstration of New Tools for Improved Source and Recontamination Potential Assessment

February 2018

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14. ABSTRACT
The objective of this project was to demonstrate a family of technologies adapted from the oceanographic and environmental arenas that could significantly improve the ability to address contaminant source exposure, transport, and fate challenges at Department of Defense (DoD) coastal sites in a relatively simple and cost-effective way. Through the integration of these technologies, the goal was to develop and demonstrate a spectrum of new capabilities.

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COST & PERFORMANCE REPORT

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ACRONYMS AND ABBREVIATIONS

ADCP	<found in Table 2>
BMP	Best Management Practice
BPTCP	Bay Protection and Toxic Cleanup Program
cm/y	Centimeters per Year
C/T	Conductivity/Temperature
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CH3D	Curvilinear Hydrodynamics in Three Dimensions
COC	Contaminant of concern
CODE	Coastal Ocean Dynamics Experiment
CTD	Conductivity, Temperature, and Depth
CWA	Clean Water Act
DDT	Dichlorodiphenyltrichloroethane
DDX	Dichlorodiphenyltrichloroethane and its isomers
DGT	Diffusive Gradient in Thin Film
DOC	<found in Table 3>
DoD	Department of Defense
DPS	Drifting Particle Simulator
DrEx	Drifting Exposure System
DU	Decision Unit
EFDC	Environmental Fluid Dynamics Code
ER	Environmental Restoration
ESTCP	Environmental Technology Certification Program
GeoXT	Trimble GeoXT Global Positioning System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
g	Grams
$g/cm^2/y$	Grams per Centimeter Square per Year
HOBO	Onset HOBO Conductivity and Temperature Data Logger
IDW	Investigation Derived Waste
IR	Installation Restoration
JBPHH	Joint Base Pearl Harbor Hickam
kg	Kilograms
LSPC	Loading Simulation Program in C++

m	Meters
m^2	Meters Squared
m^3	Meters Cubed
MDL	Minimum Detection Limit
MESC	Marine Environmental Survey Capability
m	Meter
µg/kg	Microgram per Kilogram
µm	Micrometers
mm	Millimeters
mg/L	Milligrams per Liter
MPH	Miles Per Hour
NAVFAC	Naval Facilities Engineering Command
NBSD	Naval Base San Diego
NPDES	National Pollutant Discharge Elimination System
OWS	Oil-Water Separator
PAH	Polycyclic Aromatic Hydrocarbon
PAWS	Programmable Automatic Water Sampler
PCB	Polychlorinated Biphenyl
PDMS	Polydimethylsiloxane
PRC	Performance Reference Compound
PRG	Preliminary Remediation Goal
PVC	Polyvinylchloride
RI/FS	Remedial Investigation/Feasibility Study
RPM	Remedial Project Manager
SBAS	Satellite Based Augmentation Systems
SCCWRP	Southern California Coastal Water Research Project
SeDep	Sediment Deposition Detector
SPAWAR	Space and Naval Warfare Command
SPME	Solid Phase Micro Extraction
SSC-PAC	SPAWAR Systems Center Pacific
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TST	Test for Significant Toxicity
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQO	Water Quality Objective

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The objective of this project was to demonstrate a family of technologies adapted from the oceanographic and environmental arenas that could significantly improve the ability to address contaminant source exposure, transport, and fate challenges at Department of Defense (DoD) coastal sites in a relatively simple and cost-effective way. Through the integration of these technologies, the goal was to develop and demonstrate a spectrum of new capabilities.

TECHNOLOGY DESCRIPTION

The demonstration focused on the following three key technologies:

- Drifting Exposure System (DrEx): Surface global positioning system (GPS) drifter with position data telemetry, composite sample collection, and passive sampler capabilities for exposure characterization.
- Drifting Particle Simulator (DPS): GPS drifter with position data telemetry, buoyancy control, bottom detection, and passive sampling capability for measurement of depositional footprints and sampling of source related particles.
- Sediment Deposition Detector (SeDep): Sediment bed scour sensor with high resolution differential pressure sensor, shore cable or in situ data logging, and coupled sediment trap capabilities for simultaneous quantitative measurement of deposition rates and sampling of depositing particles.

DEMONSTRATION RESULTS

Performance analysis focused on the ability of the technologies to provide improved exposure, transport, and fate assessment for potential sources. A key aspect of this performance was the ability to quantify the linkage between ongoing sources and potential recontamination of sediment.

DrEx: Performance for the DrEx system was evaluated during two demonstration events at the mouth of Paleta Creek at Naval Base San Diego (NBSD). The first was conducted during a relatively large storm event while the second was conducted during a smaller event. In both cases, ten drifters were released into the first flush of the storm event to track the stormwater plume and collect samples during exposure periods that ranged from about 12 hours for the large event to about six hours for the small event. Overall, performance results from the DrEx demonstrations indicated: the GPS tracking data from the DrEx systems provided a clear visualization of the area of the bay with connectivity to the stormwater plume; the onboard sensor data from the DrEx units were very useful in evaluating the dynamics of the stormwater plume, the dilution of the plume over time, and the influence of other stormwater sources in the general vicinity; the composite samples from the events provided an effective means for characterizing exposure conditions within the first-flush portion of the discharge plume from both a chemical and toxicological perspective; and the units stayed within the plume and recorded conditions that were consistent with the exposure that would be expected for the first-flush portion of the plume as it disperses into the receiving water.

DPS: Performance of the DPS system was evaluated during two demonstration events in Pearl Harbor. The first event was conducted at the Oscar Pier site in Pearl Harbor and the second event was conducted at the Waiau Generating Station site. During each event, DPS units were deployed at approximately hourly intervals throughout a full 24-hour tidal cycle. The DPS units were tracked until they made bottom contact, and the resulting bottom contact map was used to construct deposition footprints for each of the outfall sites where the demonstrations were performed. Overall, performance results from the DPS demonstrations indicated: the GPS tracking and bottom contact data collected using the DPS systems provided a clear visualization of the area of the harbor with connectivity to the outfall, the depth, spatial and time scales of the transport area, and the spatial location and size characteristics of the deposition footprint; the DPS system can act as a platform for sensors to track background or storm event conditions during the trajectories of the drifters; and the results compare favorably to model simulations for particle transport and settling performed for the same sites.

SeDep: Performance of the SeDep system was evaluated during a single demonstration event at the Oscar Pier site in Pearl Harbor. Based on the DPS deposition footprint results, ten SeDep units were deployed in the nearfield area of the footprint with an additional unit deployed further into the harbor and further out toward the entrance to characterize the far field areas of the footprint. Deposition data were collected continuously over the 42-day period of the deployment. Overall, performance results from the SeDep demonstrations indicated: the SeDep sensor systems provided a unique temporal quantification of cumulative sediment deposition under conditions that are representative of DoD harbors subject to stormwater and other sediment transport processes; the sediment traps that were collocated with the SeDep sensors provided an effective means of collecting deposited sediments, and the deposition rates were consistent with expectations regarding the typical rates in Pearl Harbor; and in conjunction with the deposition data, the sediment trap and surface sediment chemistry were useful in evaluating the potential for recontamination at the deployment site.

IMPLEMENTATION ISSUES

The over-arching strategy for implementation of the technologies was based on several key components including: the technology is well demonstrated and documented, standard operating procedures are developed and available, equipment is available on the open market, technology service providers are available to DoD users, and regulators have visibility of the technology. The demonstrations were well documented through the Environmental Technology Certification Program (ESTCP) Site Selection Memorandum, Demonstration Plan, and this Technical Report, as well as through a series of conference presentations and publications. Standard operating procedures have been developed and documented for all of the technologies in manuals provided by the equipment companies, as well as in the procedural documents contained in the ESTCP Demonstration Plan. The equipment, described in this document, is currently available from vendors with the exception of the SeDep system. For this system, a relationship with a commercial vendor was not finalized, although the system is based directly on the commercially available system. Service providers collaborated in the project and have experience with the equipment. The technologies, particularly the SeDep system, would still benefit from further demonstration by early adopters under a broader range of applications, and would also benefit from further exposure to regulatory agencies that have oversight of stormwater and/or sediment cleanups.

1.0 INTRODUCTION

1.1 BACKGROUND

Current methods for assessing stormwater exposure, fate, and transport are limited. Compliance programs generally focus on end-of-pipe monitoring for first-flush conditions. These measurements are often highly variable and provide little insight into actual environmental exposure, impact, fate, and transport (Katz et al., 2006). Methods for assessing particle transport and fate at Department of Defense (DoD) coastal sites is also limited. Sediment transport models have been applied on larger scales but are highly complex and usually of inadequate resolution to resolve small stormwater discharges (Chadwick et al., 2007; Gailani et al., 2007). Field based methods that have been used include sediment sampling near outfalls, sediment traps placed near outfalls, and geochronology analysis of sediment cores collected in suspected depositions zones (Apitz and Chadwick, 2002; Magar et al., 2009; Blake et al., 2007). Sediment sampling near the outfalls provides indirect evidence of potential fate of particles, but lacks any direct linkage, and is often confounded by high spatial heterogeneity of contaminant levels in sediments. Sediment traps in active harbor areas provide a measure of sediment deposition that incorporates all forms of transport and resuspension, but are unable to distinguish source deposits from these other depositional sources. Geochronology in active harbor areas is often confounded by historical disturbance of the sediments by dredging and resuspension events, and thus cannot be reliably applied in many of the areas of interest. Because of the limitations of current methods, there is a high degree of uncertainty in the exposure, transport, and fate associated with these sources, and new tools are needed that can help the DoD better manage these challenges.

Global Positioning System (GPS) drifters have been used in oceanographic applications for many years (Davis, 1985; Breivik et al., 2013; Ponte et al., 2012; Halle and Largier, 2011). Although the drifters have not been extensively demonstrated in this application, these types of drifter systems are ideally suited to track the exposure associated with stormwater plumes. Recent examples of GPS drifter applications to stormwater include tracking of coliforms in stormwater plumes (McCorquodale et al., 2004) and tracking of river runoff plumes on the coast of California (Ohlmann et al., 2005). The systems are low-cost, easy to deploy, and their water tracking capabilities have been well characterized. They can be configured to track near-surface water parcels, where buoyant stormwater plumes often persist, and they ideally mimic the drifting exposure scenario that is characteristic of many of the sensitive planktonic larval species that are sensitive to stormwater impacts (McCorquodale et al., 2004; Ohlmann et al., 2005; USGS, 2006). At the same time, they capture all of the complex transport and mixing processes that will provide such an improved exposure scenario compared to current end-of-pipe and grab-sample type approaches.

Load-cell based scour sensors were originally developed by the United States Geological Survey (USGS) to investigate sediment bed level changes in shallow streams and rivers due to flow driven changes in scour and deposition (Carpenter, 2000; Rickly Hydrological Company, 2013). Scour sensors have not been previously evaluated for use in source evaluation for contaminated sediment deposition, but are ideally suited to this application for complex DoD harbors where other traditional methods are limited by resuspension, dredging, and other confounding processes.

Scour sensors are envisioned to be embedded in the deposition zones identified by drifter measurements and/or modeling simulations to provide a direct measurement of net deposition over both episodic and long-term time scales. To enhance the resolution of the sensor, the use of differential pressure sensors rather than direct pressure sensors was evaluated so that the signal is not swamped by deeper water sites or large-scale tidal fluctuations (Paroscientific Inc., 2013). These sensors are envisioned to be co-deployed with sediment traps during discharge events so that a new deposition could be de-convolved from the total deposition into the trap.

1.2 OBJECTIVES OF THE DEMONSTRATION

Based on the requirements described above, the objective of this project was to demonstrate a family of technologies adapted from the oceanographic and environmental arenas that could significantly improve the ability to address contaminant source exposure, transport, and fate challenges at DoD coastal sites in a relatively simple and cost-effective way.

Through the integration of technologies, the goal was to develop and demonstrate a spectrum of new capabilities. The demonstration focused on the following three key technologies:

- Drifting Exposure System (DrEx): Surface GPS drifter with position data telemetry, composite sample collection, and passive sampler capabilities for exposure characterization.
- Drifting Particle Simulator (DPS): GPS drifter with position data telemetry, buoyancy control, bottom detection, and passive sampling capability for measurement of depositional footprints and sampling of source related particles.
- Sediment Deposition Detector (SeDep): Sediment bed scour sensor with high resolution differential pressure sensor, shore cable or in situ data logging, and coupled sediment trap capabilities for simultaneous quantitative measurement of deposition rates and sampling of depositing particles.

These technologies are envisioned to provide a broad new set of capabilities that are highly applicable to characterizing the exposure, transport, and fate of stormwater contaminant sources (Figure 1). Each of these technologies underwent refinement and testing in the first year of the project prior to these field demonstrations. The current versions of the commercial prototype systems are described in Section 2.

1.3 REGULATORY DRIVERS

The three key technologies are targeted to reduce DoD total ownership costs by: (1) avoiding costly active stormwater Best Management Practices (BMPs) and containment systems targeted toward stormwater discharges based solely on end-of-pipe discharge violations, and (2) avoiding major costs associated with recontamination of remediated sediment sites. DoD regulatory drivers for stormwater are generally mandated under the Clean Water Act (CWA) and regulatory drivers for sediment can fall under both the CWA and the Comprehensive Environmental Response Compensation, and Liability Act (CERCLA). These potential cost impacts are significant considering that installations such as Naval Base San Diego (NBSD) are faced with first-flush capture requirements for stormwater that could cost in excess of $100M, and Pearl Harbor is preparing to invest ~$40M in sediment remediation while still faced with potential source control uncertainties.

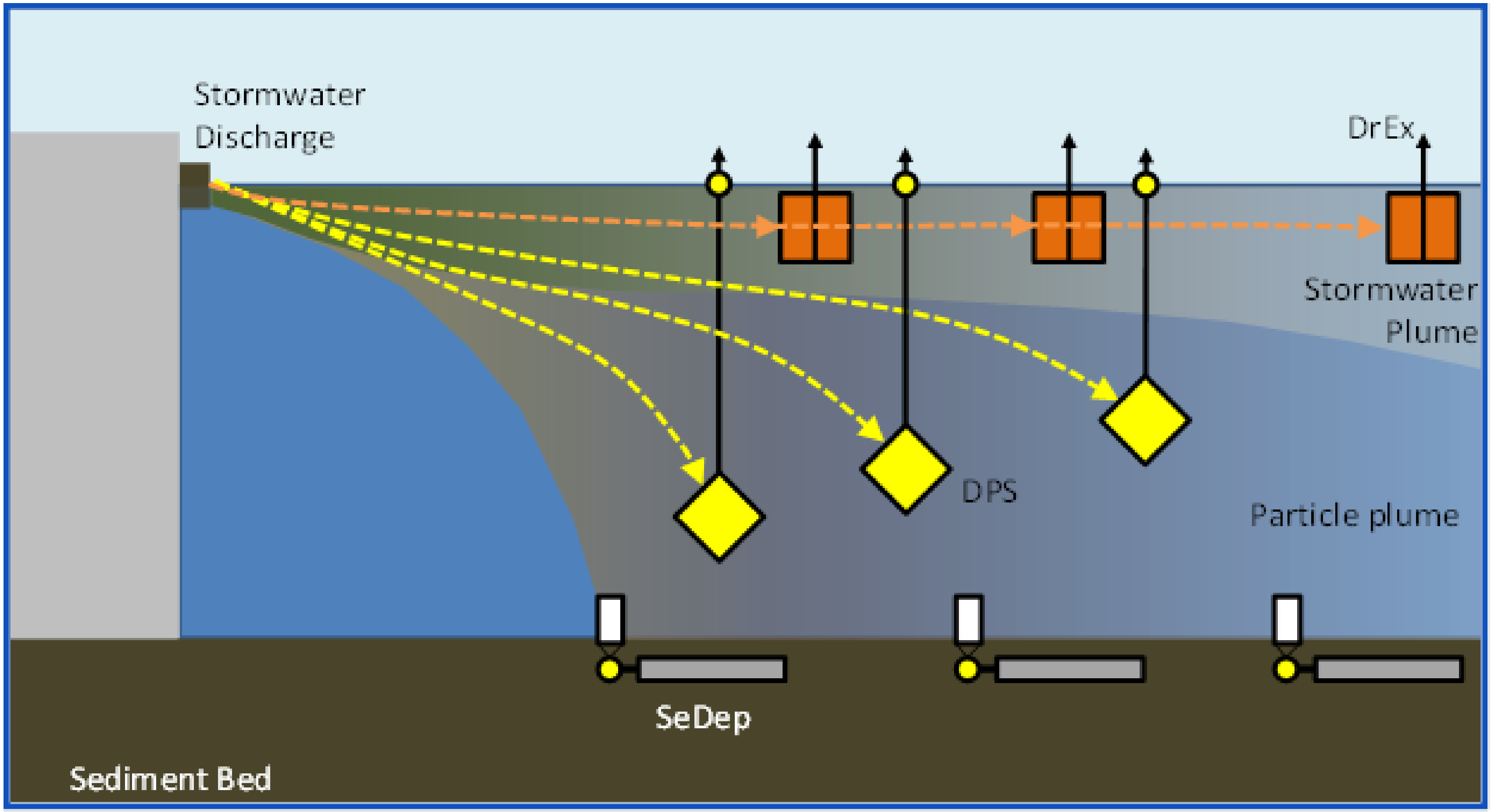

Figure 1. **Concept of Operations for the Three Source Assessment Technologies.**

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2.0 TECHNOLOGY

This section provides an overview of the source assessment technologies to be demonstrated including a description of the origin of the systems, the commercialized configurations, and the potential advantages and limitations of the systems.

2.1 TECHNOLOGY DESCRIPTION AND DEVELOPMENT

The technology developed and demonstrated in this project included three related systems including the DrEx, the DPS, and the SeDep. Descriptions of these systems are summarized below.

2.1.1 Drifting Exposure System

The DrEx is a surface GPS drifter with position tracking and data telemetry, onboard sensors, composite sample collection, and passive sampler capabilities for exposure characterization. The system, developed in collaboration with Brightwaters Instruments, is shown in Figure 2. It is based on their standard Davis/CODE (Coastal Ocean Dynamics Experiment) design but incorporates a new composite sampling capability. The combined system allows for both the tracking and sampling of surface plumes from stormwater and other discharges.

The DrEx system is based on the Brightwaters Model 121 GPS/Iridium Drifter. The Model 121 GPS/Iridium Drifter is a current following (Lagrangian) drifting buoy. It is released in a body of water and moves with the currents over a period of hours to months. Onboard electronics acquire a time series of positions using the GPS as the drifter moves. Positions and optional sensor data are telemetered over the worldwide Iridium satellite network and delivered to the end user using email, a web browser, or ftp. The onboard GPS receiver automatically uses corrections provided by Satellite Based Augmentation Systems (SBAS) to enhance position accuracy in areas of the world served by SBAS. Bidirectional satellite communication allows the drifter to be reconfigured after deployment. This allows the same deployment to serve multiple missions or adapt sampling based on changing conditions.

The water sampling capability for the DrEx system was developed by Brightwaters and is commercially available as the Model 127 Programmable Automatic Water Sampler (PAWS) (Figure 3). The PAWS is an oceanographic water sampling system allowing unattended collection of up to a five-liter surface water sample in a sampling bag. The PAWS consist of a peristaltic pump and interface circuitry inside a watertight polyvinylchloride (PVC) case, a sampling port, and a sample collection bag housed inside a free flooding protective housing. The PAWS is intended for unattended or remote sampling on ships, fixed or drifting buoys, docks, etc. The water sampler connects to the drifter body via a lateral bracket. The pumping system is fully programmable, and the controls can also be accessed in real time via the Iridium communication link.

Figure 2. Commercial Prototype DrEx System.

Figure 3. PAWS Unit.

2.1.2 Drifting Particle Simulator

The DPS is based on an integration of the Pacific Gyre Microstar Lagrangian Drifter design with GPS tracking and Iridium satellite communications and a high-resolution depth-control underwater micro-winch (Figure 4). The DPS Drifter tracks water currents at depths of 1-20 meters (m) and is equipped to accommodate a range of additional sensors. The system is configured with a spherical surface float housing the GPS and Iridium satellite communications, a “Holey Sock” subsurface drogue, and is supported by data archival, mapping, and web access capabilities.

The system is designed to house the underwater micro-winch along the central axis of the subsurface drogue, and maintain adequate drag to drogue ratios for water depths in the range of 1-20 m. A winch system with a surface float connected to the drogue was selected in favor of the original design which envisioned a buoyancy engine and no surface float. Preliminary analysis indicated that control of the vertical settling velocity with the buoyancy engine would be very challenging. In addition, using the surface float allows for constant tracking of the system and development of complete three-dimensional trajectories.

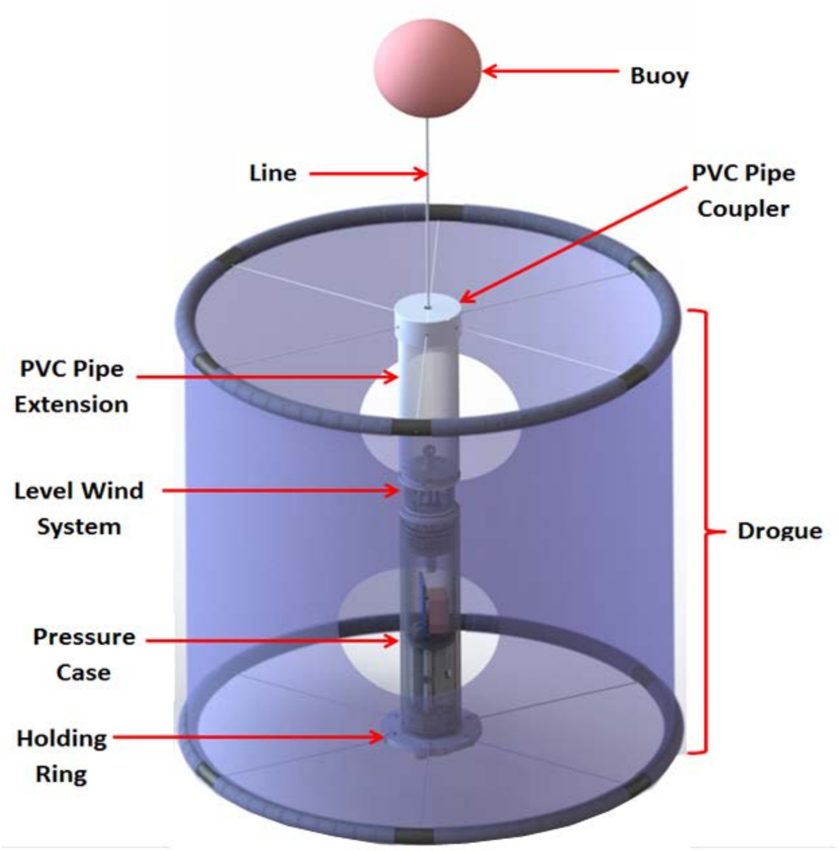

Figure 4. Commercial Prototype DPS System Design.

In combination with the underwater micro-winch, the system provides the ability to use these drifters to mimic the settling velocities of particles by automatically adjusting the depth of subsurface drogue relative to the surface float, allowing for simulation of effective particle settling rates in ocean, river, and lake currents. The underwater micro-winch is a small underwater winch that controls the distance between the surface float and the subsurface drogue of the DPS Drifter. To achieve this, the winch includes a spool, line, drive motor, controller, batteries, pressure sensor, and bottom-detection sensor. The winch is programed by the user to pay out line at a user-selectable rate in the range of typical particle settling rates. The winch incrementally pays out the line at this rate, lowering the subsurface drogue while sensing the drogue's depth in the water. The descent rate can be programmed to mimic effective particle settling rates in the range of the fine silt to sand sized particles that are expected to settle in the relatively near field of the discharge. When the subsurface drogue reaches a user-selectable distance from the bottom, the winch controller activates the winch to reel the subsurface drogue back to the surface (termed “reel-up”).

2.1.3 Sediment Deposition Detector

The SeDep system consists of a standard USGS Load-Cell Scour Sensor provided by Rickly Hydrological Corporation that was modified to incorporate a highly sensitive differential pressure sensor in place of the standard pair of absolute pressure sensors (Figure 5). The Load-Cell Scour Sensor is designed to be sensitive to small changes in sediment load and can measure both scour and deposition as well as variations such as infilling of gravel and cobbles with fine-grained sediment. Previous uses for the sensor include shallow placement in spawning beds of fish for unattended monitoring of deposition, erosion, and substrate temperature; monitoring transport of bedforms in experimental flumes; and monitoring scour at bridge piers or similar structures.

With the new integration of the differential pressure sensor in place of the standard sensor pair, the depth limit of the system is increased by two orders of magnitude from 3.5 meters (m) to 350 m, and the sensitivity is improved by about two orders of magnitude from 3 millimeters (mm) to about 0.05 mm. These improvements were critical to the application of the system for assessment of stormwater events and potential recontamination of the sediment bed. In addition, the standard unit required that cables be run to shore for monitoring, while the new system incorporates an onboard data logger that can be left at the site for extended periods. The SeDep incorporates a standard sediment trap to allow collection and analysis of deposited sediments. The sediments traps are mounted on a stake on the sediment bed that also serves as a mounting location for the sensor data logger.

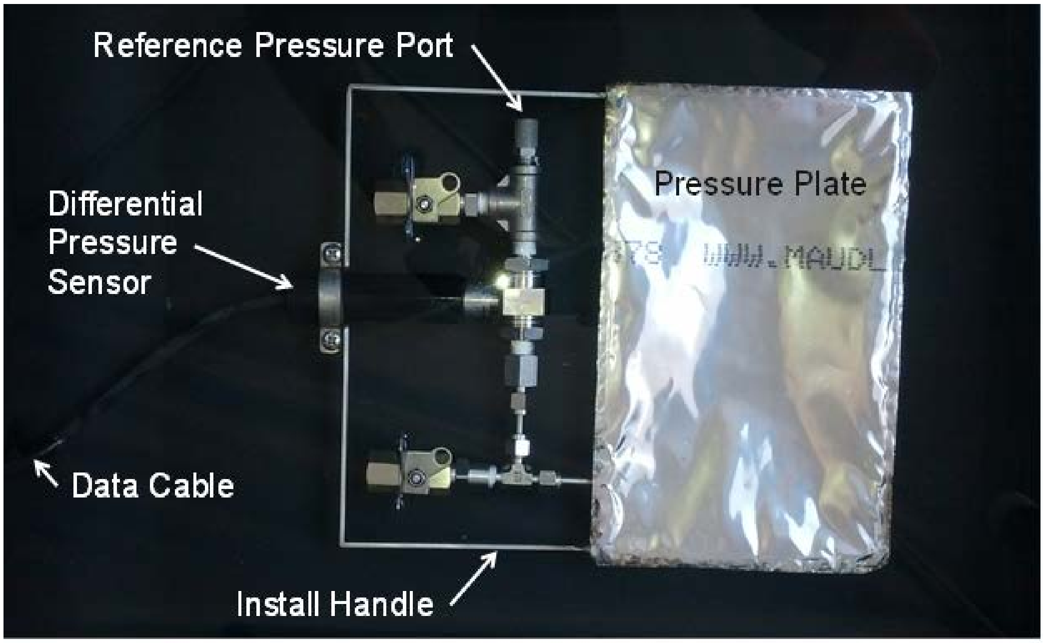

Figure 5. Commercial Prototype SeDep System.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGIES

In general, the technologies are targeted to reduce DoD total ownership costs by: (1) avoiding costly active stormwater BMPs and containment systems targeted toward stormwater discharges based solely on end-of-pipe discharge violations, and (2) avoiding major costs associated with recontamination of remediated sediment sites. These potential cost impacts are significant considering that installations such as NBSD are faced with first-flush capture requirements for stormwater that could cost in excess of $100M, and Pearl Harbor is preparing to invest ~$40M in sediment remediation while still faced with potential source control uncertainties. While the technologies have some limitations, they are expected to better address these critical issues. Some specific advantages and potential disadvantages of the technologies are discussed below.

2.2.1 Drifting Exposure System

The key advantages of the DrEx system over the other systems are: (1) the system inherently follows the plume without an operator having to try to find the plume; (2) the system provides an integrated measure of the exposure that occurs in the plume which is much more realistic than exposure at the end-of-pipe; (3) multiple units can be deployed to give a general estimate of the trajectory, dispersion, and dilution of the plume; (4) the multiple units report in real time so they can be easily found and their operation can be adjusted if necessary; and (5) the multiple units are relatively low cost so that loss of a unit could be accommodated in the implementation strategy. Potential limitations of the DrEx system include: (1) the potential for system loss through ship strike or other damage to the pressure hull; (2) potential complexities in application in active DoD harbor areas due to interference with ships, security booms, piers, and operations; (3) potential challenges in operating during storm events; and (4) results are limited to the events that are monitored, say compared to a model which could potentially simulate a range of different conditions.

2.2.2 Drifting Particle Simulator

Specific advantages of the DPS over the other technologies include: (1) the system inherently follows the particle plume without operator intervention; (2) the system provides a complete three dimensional trajectory under complex hydrodynamic conditions that are often difficult to simulate or predict; (3) the system can accommodate different targeted settling rates and thus be tuned to the particle types of interest;, (4) multiple units can be deployed to give a general estimate of the trajectory, dispersion, and final deposition footprint of the particles; (5) the multiple units report in real time so they can be easily found and their operation can be adjusted if necessary; and (6) the multiple units are relatively low cost so that loss of a unit could be accommodated in the implementation strategy. Potential limitations of the DPS system are similar to those for the DrEx and include: (1) the potential for system loss through ship strike or other damage or entanglement of the system; (2) potential complexities in application in active DoD harbor areas due to interference with ships, security booms, piers, and operations; (3) potential challenges in operating during storm events; and (4) results are limited to the events that are monitored, say compared to a model which could potentially simulate a range of different conditions.

2.2.3 Sediment Deposition Detector

The key advantages of the SeDep system over the other systems are: (1) the system provides a direct time-series measurement of deposition through storm events, (2) the system is sensitive enough to distinguish small individual events, (3) the character of the time series can help distinguish deposition from resuspension, (4) the integrated sediment trap can provide material for physical and chemical characterization with the knowledge of if that material was associated with a stormwater deposition event, and (5) the system is relatively low cost so multiple units can be deployed to address spatial variation. Potential limitations of the SeDep system include: (1) they require divers for installation, (2) they have a limited track record and are still somewhat developmental, and (3) the sensors only measure mass and do not distinguish particle type.

3.0 PERFORMANCE OBJECTIVES

Performance analysis focused on the ability of the technologies to provide improved exposure, transport, and fate assessment for stormwater sources in a cost-effective manner. A key aspect of this performance was the ability to improve the understanding of the linkage between the ongoing sources and potential recontamination of sediment. This requires the ability to accurately track the trajectory of the plume and associated particle-bound contaminants and establish reliable measures of event-based depositional footprints. Performance was measured against the performance criteria established in the demonstration plan. Quantitative and qualitative performance objectives and metrics for the three technologies are summarized in Table 1 and Table 2 respectively. Details of the three technologies quantitative and qualitative performance objectives, supporting measurements, and performance outcomes are provided in Section 6.

Table 1. Summary of Project Quantitative Performance Objectives and Metrics.

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
DrEx System		
Tracking accuracy	GPS accuracy data and statistics during field deployments	<5 m for >90% of the deployment period
Communications reliability	Telemetry link data and statistics during field deployments	Reliable position data transmitted >90% of the deployment period
Water sampler performance	Sample volume collected over time and at completion	Reliable composite sample with total volume within 10% of target
System survivability under field conditions	Data and statistics on successful mission completion, system failures, lost units during field deployments	>80% survivability under field conditions
DPS System		
Tracking accuracy	GPS accuracy data and statistics during field deployments	<5 m for >90% of the time the system is at the surface
Communications reliability	Telemetry link data and statistics during field deployments	Reliable position data transmitted >90% of the deployment period
Settling rate performance	Depth data from pressure sensor onboard DPS	Accurate settling rate within 10% of target rate
System survivability under field conditions	Data and statistics on successful mission completion, system failures, lost units during field deployments	>80% survivability under field conditions
SeDep System		
Deposition detection sensitivity	Data from controlled tank testing and field deployments including sediment traps	Sensitivity <1 mm of deposition for typical particle sizes Comparable deposition to short term trap results
Measurement reliability	Differential pressure data from field deployments	Reliable pressure data collected >90% the deployment period
System survivability under field conditions	Data and statistics on successful mission completion, system failures, lost units during field deployments	>80% survivability under field conditions

Table 2. Summary of Project Qualitative Performance Objectives and Metrics.

Performance Objective	Data Requirements	Success Criteria
Qualitative Performance Objectives		
DrEx System		
Surface plume tracking effectiveness	DrEx GPS trajectory data, onboard salinity and temperature sensor data, and Marine Environmental Survey Capability (MESC) plume tracking data	Onboard salinity and temperature signature is consistent with plume characteristics DrEx trajectories are consistent with spatial surface plume mapping results
DPS System		
Particle plume tracking effectiveness	DPS trajectory data from the GPS and pressure sensors, onboard turbidity sensor data, and MESC particle tracking data from Acoustic Doppler Current Profiler (ADCP) and profiled sensors	Onboard turbidity signature is consistent with plume characteristics DPS trajectories are consistent with spatial particle plume mapping results
SeDep System		
Ease of installation and retrieval	Feedback from the dive team	Ability to install a typical system array within a reasonable time period of 1-2 days

3.1 DRIFTING EXPOSURE SYSTEM

For the DrEx system, a series of quantitative and qualitative performance objectives were established. Quantitative objectives focused on tracking accuracy, communications reliability, water sampler operation, and system survivability under field conditions. Tracking accuracy of the GPS system is important to reliable measurements of the plume trajectory. Reliable data communications are important to the performance of the system in active harbor areas allowing for real-time tracking without having to utilize extensive boats and crews to follow the drifters. Communications are also important for any modifications to the sampling and for final location and retrieval of the system. An important aspect of the DrEx system is its ability to collect samples during the deployment period. Reliable sample operations are reflected in the proper collection of composite sample volumes based on the programming of the system. Because of the unattended nature of the systems and the complex, harsh, and active areas where they will be deployed, survivability is a key performance metric for the systems. Survivability in this case refers to successful mission completion, without major system failures or lost units during field deployments. The primary qualitative performance objective for the DrEx was that the drifters reliably track the surface plume of a stormwater discharge release. While this is difficult to determine quantitatively, a number of methods were used to give a quantitative assessment of the plume tracking performance including onboard salinity and temperature measurements, and plume tracking measurements made with water quality instruments from the survey boat during the discharge event.

3.2 DRIFTING PARTICLE SIMULATOR

For the DPS system, a series of quantitative and qualitative performance objectives were established similar to the DrEx but adapted to the particle tracking capability of the system. Quantitative objectives focused on tracking accuracy, communications reliability, settling rate performance, and system survivability under field conditions. Tracking accuracy of the GPS system is important to reliable measurements of the plume trajectory. Reliable data communications are important to the performance of the system in active harbor areas because they allow for real-time tracking without having to utilize extensive boats and crews to follow the drifters. Communications will also be important for any modifications to the sampling and for final location and retrieval of the system. An important aspect of the DPS system is its ability to simulate the effective rate of settling for discharge related particles during the deployment period. Because of the unattended nature of the systems and the complex, harsh, and active areas where they will be deployed, survivability is a key performance metric for the systems. The primary qualitative performance object for the DPS is that the drifters reliably track the particle plume of a stormwater discharge release. While this is difficult to determine quantitatively, the results were compared qualitatively to results from numerical modeling simulations for the same areas to provide a basis for assessing performance.

3.3 SEDIMENT DEPOSITION DETECTOR

For the SeDep system, a series of quantitative and qualitative performance objectives were established. Quantitative objectives focused on deposition detection sensitivity, measurement reliability, and system survivability under field conditions. Deposition detection sensitivity is important because the goal is to be able to detect relatively small events associated with individual storm related deposition as well as longer term accumulation associated with multiple events. Measurement reliability is important because the sensors will be largely unattended and if they are not reliable, then the deposition events may not be captured in the data. Because of the unattended nature of the systems and the complex, harsh, and active areas where they will be deployed, survivability is also a key performance metric for the system. The primary qualitative performance objective for the SeDep is that the system be reasonably easy to install and use in the field. Overly complex or difficult to deploy systems incur higher costs and are less likely to be adopted at actual sites.

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4.0 SITE DESCRIPTION

The project was initially structured around two demonstrations with the first demonstration focusing on surface plume tracking with the DrEx system for stormwater or other releases where an understanding of the plume trajectory and the exposure that occurs in the plume are key objectives. The second demonstration focused on tracking the fate of particles associated with discharge plumes from ongoing sources and their potential impacts to sediments and sediment remedies using the DPS and SeDep systems. For the first demonstration, NBSD was selected with a focus on the surface water discharge plume from Paleta Creek. For the second demonstration, Joint Base Pearl Harbor Hickam (JBPHH) was selected with a focus on potential ongoing sources in the area of Oscar Pier in the Entrance Channel portion of Pearl Harbor. During the course of the project, another opportunity arose to utilize the DPS system at a second site in Pearl Harbor at the former Navy Drum Storage site adjacent to the Waiau Power Plant Area. The sites utilized in the project are briefly described in sections 4.1-4.3 and can be found in a detailed Site Selection Memorandum that was prepared as part of this project and is available on request.

4.1 DEMONSTRATION 1: NAVAL BASE SAN DIEGO – PALETA CREEK

The NBSD is the principal homeport of the Pacific Fleet, consisting of 46 Navy ships, one Coast Guard cutter, seven Military Sealift Command logistical support platforms, and several research and auxiliary vessels. NBSD is home to 213 individual commands, each having specific and specialized fleet support purposes. NBSD proper is comprised of over 1,600 land acres and 326 acres of water. The wetside of NBSD consists of the Bay front area west of Harbor Drive. The dryside consists of the community facilities complex east of Harbor Drive. The wetside is intensively developed and supports waterfront operations, ship berthing and maintenance, station maintenance, training, administration, and logistics functions. Operational facilities include piers, quay walls, small craft berthing facilities, fueling facilities, armories, and waterfront operations buildings. NBSD contains 13 berthing piers, a mole pier, two channels, and various quay walls that have a total shoreline measurement of approximately 5.6 miles.

Paleta Creek is a small urban creek that flows episodically from National City, CA, through NBSD into San Diego Bay (Figure 6) (California Regional Water Quality Control Board - San Diego Region, 2013). Paleta Creek is a highly channelized creek with the highest flow rates associated with storm events and highly variable flows for the rest of year. Extended periods with no surface flows occur during dry weather, although pools of standing water may be present. It is one of six watercourses that feed into San Diego Bay and is part of the Pueblo San Diego watershed. The watershed is ~2,160 acres and is highly urbanized, with commercial and industrial land uses dominating the shoreline around the bay. The land uses incorporating the largest acreage (and percent of area) in the watershed includes: low and high density residential, roads/freeways, military, commercial institutional, and open space/recreation. Much bayside property is owned and operated by the U.S. Navy, and although the Navy owns only a small percentage of the watershed, the submerged lands within the creek mouth are within the Navy property line. San Diego Bay, where the creek discharges, is also valued as a wildlife habitat and refuge for migratory and estuarine birds, endangered species, marine mammals, and as a spawning area for near-shore marine fishes. In addition, San Diego Bay supports many recreational uses including swimming, sailing, sport fishing, and recreational boating.

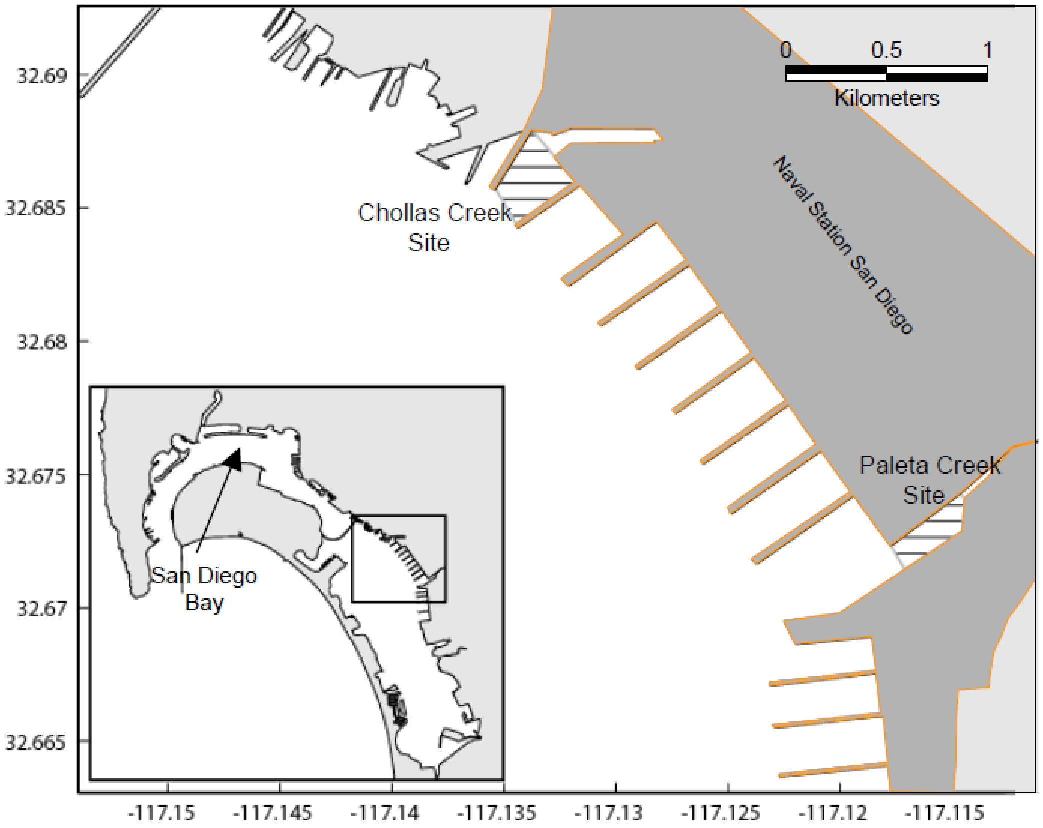

Figure 6. Location Map of the Paleta Creek Site (adapted from Southern California Coastal Water Research Project [SCCWRP] and Space and Naval Warfare Command [SPAWAR], 2005).

4.2 DEMONSTRATION 2: JOINT BASE PEARL HARBOR HICKAM – OSCAR PIER

Pearl Harbor is a delta-shaped natural estuary located on the south-central coast of the island of Oahu, Hawaii (Figure 7). The harbor's 36 miles of linear shoreline encompass approximately 5,000 acres of surface water within four major lochs (West, Middle, East, and Southeast) and a dredged navigation channel that opens to the Pacific Ocean to the south. It is situated at the south end of the central Oahu plain, which separates the island's two mountain ranges: Waianae on the west and Koolau on the east. Pearl Harbor is a natural trap, or sink, for sediments and chemicals present in approximately 110 square miles of watershed, or 20% of Oahu's land surface. Pearl Harbor is a major fleet homeport for nearly 40 warships; service force vessels and submarines; and associated support, training, and repair facilities. In Oct 2010, Naval Station Pearl Harbor merged with adjacent Hickam Air Force Base into JBPHH. JBPHH occupies the majority of the land area immediately surrounding Pearl Harbor, and approximately 75% of the harbor shoreline lies within its boundaries. The base incorporates the following major activities: Naval Station Pearl Harbor, Naval Submarine Base, Hickam Air Force Base, Naval Supply Systems Command Fleet Logistics Center, Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, Naval Facilities Engineering Command Hawaii, JBPHH West Loch Annex, and the Naval Sea Systems Command Detachment/Naval Inactive Ship Maintenance Facility.

Oscar Pier is located in the Entrance Channel of Pearl Harbor (Figure 8). The pier extends from the southeast to the northwest along the western portion of the shipyard area adjacent to Drydock 4. The pier area is actively supporting shipyard operations at JBPHH. National Pollutant Discharge Elimination System (NPDES) discharges are present near the entrances to Drydock 4, and stormwater discharge points line the perimeter of Oscar Pier, draining the adjacent areas of the shipyard and the base. Most of the drainage areas are industrial and dominated by buildings and paved impervious surfaces although there are some recreational, residential, and open spaces in the area as well.

Figure 7. Pearl Harbor Site Map (adapted from U.S. Navy, 2015).

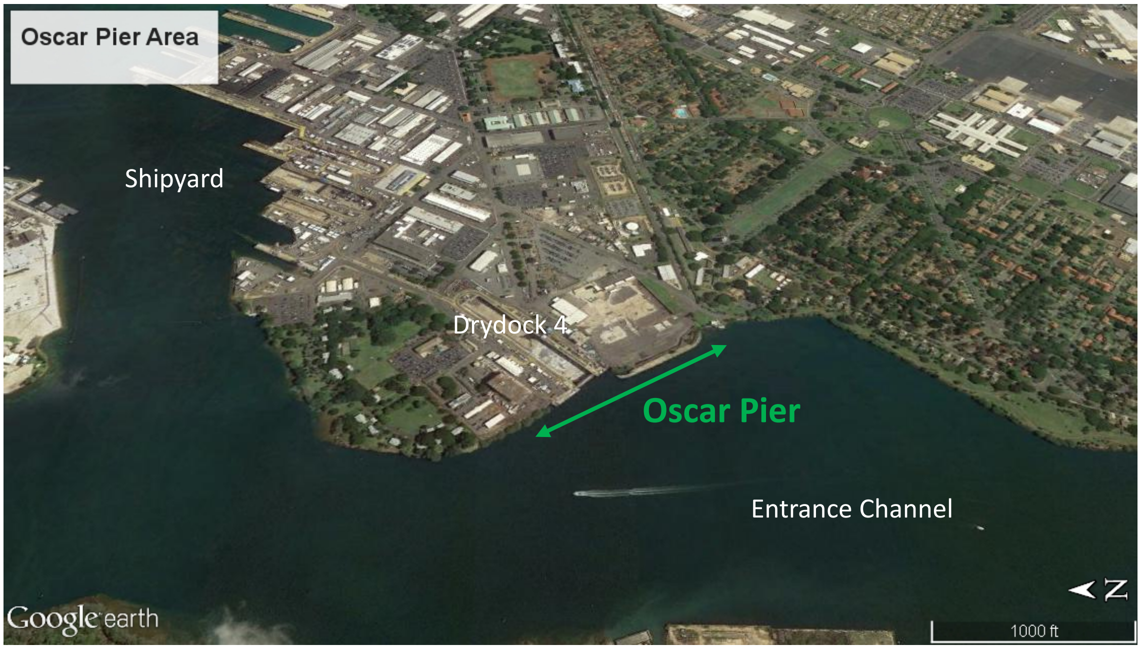

Figure 8. Vicinity of Oscar Pier Showing the Shipyard and Repair Basins Along the Shoreline (Image © Google 2016, Imagery date 1/29/2013).

4.3 DEMONSTRATION 3: JOINT BASE PEARL HARBOR HICKAM – WAIAU POWER PLANT AREA

The study area for the additional DPS survey was focused in the vicinity of the Waiau Power Plant. This area is designated for sediment remediation as decision unit (DU) E-2 (Figure 9) where the contaminant of concern is Total Polychlorinated Biphenyls (PCBs). DU E-2 is located along the northwest shoreline of East Loch, off the Waiau Power Plant, and is composed of two sub-areas: a deeper water sub-area east of the sheet piling groin structure extending out from the power plant, and a smaller sub-area located near the west end of the power plant property. The main power plant discharge outfall is located east of the groin structure in the primary sub-area of the DU. A residential area lies adjacent to the eastern portion of the DU and the former Navy Waiau Drum Storage Facility site was located to the east of the residential area in what is now Neal S Blaisdell Park (Figure 10). Potential contaminant sources in DU E-2 include point and non-point sources from surrounding commercial/industrial properties. Contaminant distribution data suggests surface water runoff and/or the storm drain outfall associated with the Waiau Power Plant are the primary contaminant sources for DU E-2. Available evidence and contaminant distributions indicate that previous or current Navy activities have not contributed to the PCB contamination reported for this DU. However, recently, concerns have been raised with respect to potential historical releases from the former Waiau Drum Storage Facility site located to the east of DU E-2. Historical drawings and aerial photographs indicate the potential operation of an oil-water separator (OWS) at the southwest corner of the site. There is speculation that this OWS may have had a discharge path via a pipe leading southward into Pearl Harbor. Determining whether or not there is a likely hydrodynamic connectivity between the presumed outfall location and the contamination at DU E-2 will help to understand the potential influence of this suspected historical source area.

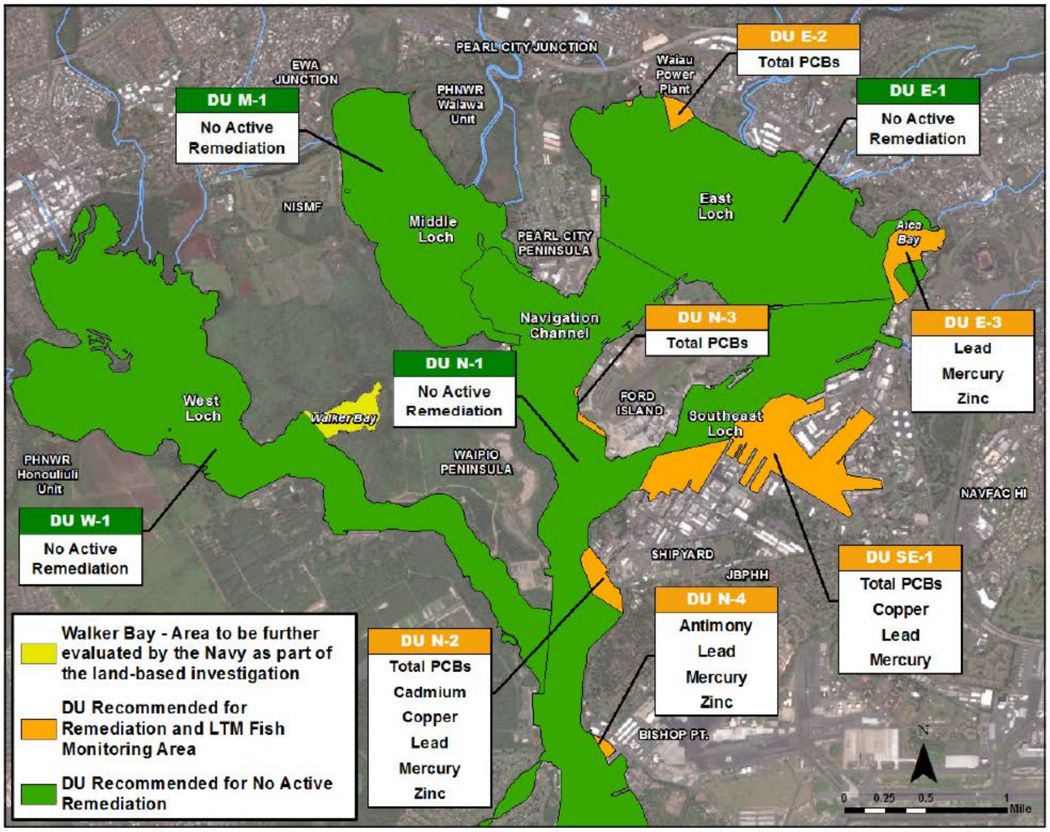

Figure 9. Map of the Pearl Harbor Sediment Site DUs Showing the Location of DU E-2 (US Navy, 2015).

Figure 10. Relationship of the Former Waiau Drum Storage Facility to the Waiau Generating Station (Image © Google 2016, Imagery date 1/29/2013).

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5.0 TEST DESIGN

The project followed an approach that consisted of five primary tasks. Task 1 focused on system integration and testing the three technologies. Task 2 focused on planning including site selection and development of the demonstration plan. Tasks 3-4 entailed the execution of the field demonstrations, and Task 5 encompassed the performance and cost analysis based on the demonstrations. Specific aspects of the experimental design for the field demonstrations are detailed below.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The project incorporated three demonstrations. The focus of the first demonstration was on surface plume tracking and took place at NBSD. The second and third demonstrations focused on particle deposition tracking and took place at JBPHH. Conceptual designs for each of the demonstrations are described below.

5.1.1 Field Demonstration 1: Naval Base San Diego – Paleta Creek

The first field demonstration focused on the DrEx system at NBSD where stormwater exposure is a concern from a compliance perspective as well as a recontamination perspective. In this demonstration, ten DrEx units were deployed at the discharge point of Paleta Creek, a small urban/industrial creek that drains through NBSD. The deployments were timed to occur with the first flush (30 minutes) of two significant storm events (predicted rainfall >0.2 inches). The systems were tracked while the sensor data, composite samples, and passive samples were collected to quantify trajectories and exposures over a period representative of the plume dispersion time (6-12 hours). Tracking was conducted from a small boat using the satellite tracking system and online data access that are part of the DrEx system. Provisions were made for units that became fouled with the shoreline or other obstacles. At the end of the deployment, the units were retrieved, the data downloaded, and the composite and passive samples were processed. Composite samples were analyzed for key physicochemical parameters including temperature, salinity, total suspended solids (TSS), pH, metals (copper, zinc, lead), and organics (Polycyclic Aromatic Hydrocarbon [PAHs], Pesticides and PCBs). Samples were also evaluated using standard laboratory toxicity tests.

5.1.2 Field Demonstration 2: Joint Base Pearl Harbor Hickam – Oscar Pier

The second field demonstration targeted application of the DPS and SeDep systems for tracking particle deposition associated with potential sediment recontamination. This demonstration was planned for stormwater outfalls in the vicinity of Oscar Pier within the Entrance Channel at JBPHH adjacent to targeted sediment cleanup units. In this demonstration, DPS units were deployed at the discharge point of the target source to simulate particle trajectories. These deployments were made in the absence of a storm event to evaluate the general depositional footprint associated with tidal transport away from the outfall area. The underlying assumption was that the momentum of the discharge is quickly dissipated and the transport was tidally dominated. Tracking was conducted from a small boat using the satellite tracking system and online data access that are part of the DPS system. Provisions were made for units that became fouled with the shoreline or other obstacles. Based on results from this initial phase, SeDep units were placed in a distributed pattern throughout the estimated depositional footprint. These were left in place through the course of 2-3 stormwater discharge events. At the end of the deployment, the units were retrieved, the data downloaded, and the SeDep samples were processed for analysis of physical and chemical characteristics.

5.1.3 Field Demonstration 2: Joint Base Pearl Harbor Hickam – Waiau Power Plant

For the third field demonstration, (second DPS demonstration at Pearl Harbor), an additional opportunity arose for a targeted application of the DPS system for tracking particle deposition associated with a potential historical contaminated source. This demonstration was planned for the presumed historical Navy OWS outfall offshore from the former Navy Waiau Drum Storage Facility site in what is now Neal S Blaisdell Park. In this demonstration, a similar approach to the conceptual approach at Oscar Pier was followed but with no SeDep deployments. DPS units were released at the discharge point of the target source to simulate particle trajectories. During these events, the DPS systems were tracked to quantify the three-dimensional trajectories and deposition footprints over a period of 12-24 hours or as required for the units to reach the bottom. Tracking was conducted from a small boat using the satellite tracking system and online data access that are part of the DPS system. Provisions were made for units that became fouled with the shoreline or other obstacles. At the end of the deployment, the units were retrieved, and the data downloaded.

5.2 BASELINE CHARACTERIZATION ACTIVITIES

Baseline characterization activities for the sites are described below. The selected demonstration sites have been the subject of significant site characterization efforts that formed the basis for the baseline characterization.

5.2.1 Naval Base San Diego – Paleta Creek

A number of studies have been conducted to characterize the nature and extent of contamination, the persistence of contamination, the cause of the toxicity, the loading from the watershed, and the linkage of the creek discharges to the sediments in the Paleta Creek mouth area. To help define the baseline conditions and understanding of the site, these studies were reviewed and are briefly summarized below.

5.2.1.1 Regulatory Drivers

The State Water Board identified the 7th Street Channel/Paleta Creek as a high priority candidate toxic hot spot due to repeat amphipod sediment toxicity findings and the presence of multiple degraded benthic communities in the Consolidated Toxic Hotspots Cleanup Plan (State Water Resources Control Board, 1999). Paleta Creek was originally listed on the 303(d) list as impaired primarily because of non-attainment of the toxicity water quality objective (WQO) promulgated for the protection of designated beneficial uses in San Diego Bay. Monitoring data collected during the investigation for the Bay Protection and Toxic Cleanup Program (BPTCP) indicated that sediment toxicity, sediment chemistry, and benthic community measurements exceeded the toxicity WQO. The shoreline segment located at the mouth of Paleta Creek was listed for toxicity water quality impairments resulting in benthic community degradation.

5.2.1.2 Potential Ongoing Sources

Stormwater data collected in Paleta Creek above the tidal influence were used to identify potential pollutant sources; whereas sediment data collected near the mouth of Paleta, Chollas, and Switzer Creeks were used to confirm impairment and relate pollutant loading with pollutant deposition and impairment. Dry weather flows to the bay were not measured as these were assumed to be negligible sources for pollutant loading to the impaired waterbodies.

Multiple point and non-point sources discharge pollutant loads into the mouth of Paleta Creek. Point sources typically discharge at a specific location from pipes, outfalls, and conveyance channels. Non-point sources, such as sheet flow or atmospheric deposition, are diffuse in nature and have multiple routes of entry into surface waters. The pollutants can be deposited either directly to a waterbody or onto land surfaces where the pollutants wash off during storm events. Stormwater runoff from urbanized areas flows off of land with a number of different uses, including residential uses, commercial and industrial uses, roads, highways, and bridges.

5.2.1.3 Transport and Distribution to San Diego Bay

During storm seasons, freshwater inflows and contaminated sediment from runoff over the watershed are discharged into the San Diego Bay from Paleta Creek. The transport and depositions of these contaminated sediments in the creek mouth regions were previously studied by using the 3D hydrodynamic and transport model, Curvilinear Hydrodynamics in Three Dimensions (CH3D) (Chadwick et al., 2005). Creek loadings of freshwater and TSS from the three creeks were calculated using the watershed model, Loading Simulation Program in C++ (LSPC). Using the CH3D model, six historical storms were simulated covering the ranges of the storm strength during 2001-2006. For each storm, the study determined the freshwater plume dynamics, and how much TSS load was deposited within the creek mouth region. Retention factors and attenuation factors of contaminants from the creek loads were estimated. These factors quantify the change of the contaminant mass and sediment mass between the creek loads and the trapped deposits, due to contaminant partitioning and the trapping efficiencies associated with different particle sizes.

5.2.2 Joint Base Pearl Harbor Hickam – Oscar Pier Area

Extensive baseline assessment for the Oscar Pier area in JBPHH (Figure 7) has been carried out by the Navy over the last several years under the Remedial Investigation/Feasibility Studies (RI/FS). A summary of the findings from those studies is presented below.

5.2.2.1 Regulatory Drivers

The Oscar Pier area (Figure 8) is subject to a range of regulatory drivers from the CERCLA, NPDES, and stormwater related requirements. The area is also within the navigation footprint (the area of the harbor considered to be navigable by large ships) and is thus also subject periodically to regulations associated with the dredging program. This demonstration effort focused on drivers associated with CERCLA cleanup of harbor sediments, but is also related to potential ongoing sources from NPDES and stormwater sources (US Navy, 2015). The sediments of Pearl Harbor adjacent to Oscar Pier are being investigated for cleanup as part of a harbor-wide assessment. Oscar Pier resides within a cleanup DU in the Entrance Channel called DU N-2. Contaminants of concern (COCs) identified for sediments within DU N-2 are cadmium, copper, lead, mercury, zinc, and total PCBs.

5.2.2.2 Potential Ongoing Sources

Potential ongoing non-point sources include contributions from urban and industrial lands surrounding the harbor that discharge into the DU through direct surface water. Potential point sources for DU N-2 include docks and piers, releases from ships, storm drain outfalls that may convey runoff from surrounding Navy Installation Restoration (IR) sites, and permitted industrial discharges from Drydock. High total PCB concentrations (670-1000 micrograms per kilogram [µg/kg]) were reported for surface sediments in the Pearl Harbor Sediment RI/FS off storm drain outfalls near Drydock 4; these concentrations may potentially be attributable to the outfalls. The NPDES permits for six outfalls from the four Drydocks in the Pearl Harbor Naval Shipyard and allows for discharge of wastewater from caisson leakage, rainfall, groundwater seepage, single-pass cooling, pump test tailwater, hydroblast tailwater, and hull rinsing. The highest potential for recontamination in DU N-2 is thought to be associated with exposure of contaminated subsurface sediments during maintenance dredging and discharge of contaminated sediments from the storm drain outfalls.

5.2.2.3 Transport and Distribution to Pearl Harbor

Sediment transport modeling, radioisotope data, and shear stress data indicate that DU N-2 is a depositional environment and that erosion in the DU, due to natural processes, is not likely to expose buried sediments. The net sediment deposition rates as measured from the 2009/2012 radioisotope data are 0.44 centimeters per year (cm/y) for under piers and 1.1 cm/y for overwater areas. The only potential erosion mechanisms identified for DU N-2 are propeller wash and extreme events (e.g., hurricanes). The vertical profile data indicate concentration trends toward the surface increasing in the areas off Drydock 4 and the Oscar Pier, indicating potential ongoing sources in these areas or possible exposure of deeper sediment contaminants due to navigation dredging. In general, particulate-based contamination from ongoing sources in the area is expected to deposit to the sediment bed within the tidal distribution distance of the release point.

5.2.3 Joint Base Pearl Harbor Hickam – Waiau Power Plant Area

Extensive baseline assessment for the Waiau Power Plant area in JBPHH has been carried out by the Navy over the last several years under the RI/FS. A summary of the findings from those studies is presented below.

5.2.3.1 Regulatory Drivers

The Waiau Power Plant area is subject to a range of regulatory drivers from the CERCLA, NPDES, and stormwater related requirements. The area also borders on the navigation footprint and is thus also subject periodically to regulations associated with the dredging program. This demonstration effort focused on drivers associated with CERCLA cleanup of harbor sediments, but is also related to potential ongoing sources from NPDES and stormwater sources (US Navy, 2015). The sediments of Pearl Harbor adjacent to Waiau Power Plant are being investigated for cleanup as part of a harbor-wide assessment. Waiau Power Plant resides within a cleanup DU in East Loch called DU E-2 (Figure 9). The sediments in this DU generally have high levels of contamination relative to other areas of the harbor. DU E-2 is located along the northwest shoreline of East Loch, off the Waiau Power Plant, and is composed of two sub-areas: a deeper water sub-area east of the sheet piling groin structure extending out from the power plant, and a smaller sub-area located near the west end of the power plant property. The main power plant discharge outfall is located east of the groin structure in the primary sub-area of the DU.

5.2.3.2 Potential Ongoing Sources

Potential contaminant sources in DU E-2 include point and non-point sources from surrounding commercial/industrial properties. Contaminant distribution data suggest that surface water runoff and/or the storm drain outfall associated with the Waiau Power Plant are the primary contaminant sources for DU E-2. Available evidence and contaminant distributions indicate that previous or current Navy activities have not contributed to the PCB contamination reported for this DU. However, recently, concerns have been raised with respect to potential historical releases from the former Waiau Drum Storage Facility site located to the east of DU E-2. Historical drawings and aerial photographs indicate the potential operation of an OWS at the southwest corner of the site. There is speculation that this OWS may have had a discharge path via a pipe leading southward into Pearl Harbor. There is no direct evidence for this pipeline, and its suspected presence is based on typical historical operational practices for similar OWS systems. Determining whether or not there is a likely hydrodynamic connectivity between the suspected outfall location and the contamination at DU E-2 will help to understand the potential influence of this suspected historical source area.

5.2.3.3 Transport and Distribution to Pearl Harbor

The sediment transport evaluation conducted as part of the Pearl Harbor RI/FS indicated that all areas within East Loch are depositional and that erosion is not likely to expose buried sediment. DU E-2 lies outside the maintenance dredging footprint, with limited ship traffic; therefore, sediments are not likely to be disturbed by dredging or propeller wash. However, strong discharge flows from the power plant outfall likely have the potential to resuspend sediments in the area on the eastern side of the groin.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

In this project, the technology components are represented by the three new technologies that are being adapted and demonstrated for the purpose of improved source and recontamination potential assessment. These included the DrEx system which was the focus of the first demonstration, and the DPS and SeDep systems which were the focus of the second demonstration. The basic design and layout of these components is described for each of the demonstrations below.

5.3.1 Naval Base San Diego – Paleta Creek

For the demonstration at the mouth of Paleta Creek, the stormwater discharge emerges from the creek mouth into San Diego Bay in a protected area within the piers at NBSD (termed the inner creek mouth). The discharge from the creek is flashy and responds relatively quickly to precipitation events in the Paleta Creek watershed. Thus, the layout for the demonstration focused on seeding the first-flush discharge from the creek with a concentration of ten drifters within the confined portion of the inner creek mouth directly adjacent to the location where the creek enters the bay. Previous measurement and modeling studies during stormwater discharge events at the site suggested that the extent of the plume following discharge is generally limited to the area within the NBSD pier area for storm events of this typical magnitude. Thus, the distribution of the drifters following release was expected to be generally within this area. The movement of the drifters was initially expected to be governed by the momentum of the discharge from the creek, which was expected to dissipate relatively quickly away from the discharge point at which time the transport would be dominated by tidal currents.

5.3.2 Joint Base Pearl Harbor Hickam – Oscar Pier Area

For the demonstration at Oscar Pier JBPHH, the area of interest was along the pier face adjacent to the Pearl Harbor Entrance Channel. The tides in this area move primarily north and south along the channel during the flood and ebb tide, respectively. Thus, the layout for the first phase of the demonstration was to release groups of DPS units in the vicinity of a selected outfall along Oscar Pier during different stages of the tide. The bottom contact locations for the DPS units were then used to define the deposition footprint for particles linked to the outfall location. The footprint defined from this phase was then used to establish the layout of the SeDep units deployed in the next phase. These systems were left out over an extended period of time to evaluate the deposition associated with multiple stormwater discharge events.

5.3.3 Joint Base Pearl Harbor Hickam – Waiau Power Plant Area

For the demonstration at the Waiau Power Plant area in JBPHH, the area of interest was in East Loch offshore from the former Waiau Drum Storage Facility site and OWS. The tides in this area move primarily east and west along the channel during the flood and ebb tide, respectively. Thus, the layout for the demonstration was to release groups of DPS units in the vicinity of the suspected outfall location during different stages of the tide. The bottom contact locations for the DPS units were then used to define the deposition footprint for particles linked to the outfall location.

5.4 FIELD TESTING

Field testing for these technologies was the primary focus of the demonstration projects. Testing the systems in the field under realistic operational conditions provided the best opportunity to understand their utility and gauge their performance. The field-testing approach for each of the demonstrations is described in detail below.

5.4.1 Naval Base San Diego – Paleta Creek

The field-testing approach for the DrEx demonstration at Paleta Creek included several components including pre-deployment preparation, DrEx deployments, DrEx tracking, DrEx sampling, performance verification measurements, DrEx retrieval, and post-retrieval processing. Subsequent sample, data analysis, and performance verification measurements are described in Section 5.5. The remaining field related components are described below.

5.4.1.1 Preparation

Preparation of the DrEx systems consisted of physical preparation, testing, and programming. The physical preparation of the Model 121 GPS/Iridium Drifter included opening up the main unit; installling fresh batteries; re-sealing the unit; installing the sails; installing the floats; and attaching any lights, reflectors, or flags that were being used for visual tracking and collision avoidance. The physical preparation of the PAWS included installing new tubing, installing the sampling bag, installing the inlet screen, and re-sealing the unit. The PAWS was then attached to the main hull of the Model 121 GPS/Iridium Drifter with its mounting bracket and the power/communication cable was attached. System testing for the DrEx included testing of the GPS, communications, and pumping systems. Programming of the DrEx system included inputting settings for the GPS sampling rate, the communications transmission rate, and several pump settings that are deployment specific.

5.4.1.2 Deployment

Storms in the early part of the season were limited and thus the deployments took place in the January-February timeframe. Once the drifters were prepared, deployment involved loading the units onto the survey boat, transiting to the deployment location at the mouth of Paleta Creek, and releasing the units within the observed discharge plume emerging from the creek. The plan was to track incoming weather systems and mobilize to the deployment area ahead of time based on predictions of rainfall >0.2 inches with a >70% probability within 24 hours of the event. The survey boat was loaded with the drifters and other required equipment and moored at the small boat pier in the Paleta Creek mouth area. Approximately 6 hours ahead of the event, the crew mobilized to the boat and remained on standby for the deployment. Within the first-flush time window, the boat transited the short distance to the discharge area, and the drifters were released into the turbid, low-salinity waters of the plume zone (Figure 11).

Figure 11. DrEx Drifter Being Released into the Flow from Paleta Creek During the Jan 5-6, 2016 Event.

5.4.1.3 Tracking

Following the release of the drifters, the systems were tracked to observe their trajectories, verify operation, and identify and rectify any problems as they transited with the stormwater plume from Paleta Creek (Figure 12). Tracking was performed with a cellular hot-spot installed on the survey boat, allowing internet access to the Brightwaters web-access portal. This allowed real-time monitoring of the positions and water sampling progress. At regular intervals throughout the survey, each DrEx unit was revisited to check on its performance and conduct performance verification measurements as described in Section 5.5.1. In cases where systems became snagged on the piers, shorelines, or other obstacles, intervention was performed to return the unit to free drifting conditions. The tracking period extended over a 6-12-hour period or until the plume has significantly dissipated based on measured salinity and turbidity in the surface waters in the vicinity of the drifters.

Figure 12. Drifters Transiting with the First Flush of the Stormwater Plume from Paleta Creek During the Jan 5-6, 2016 Event.

5.4.1.4 Retrieval

At the end of the field survey, the DrEx units were located using the real-time monitoring and retrieved to the survey boat. Samples were removed from the PAWS units for processing, and data were downloaded from the onboard temperature and salinity sensors. Each unit was inspected for any physical damage, and a series of tests were run to verify that all aspects of the operation were still functional. Any issues or deficiencies were documented. The system was then cleaned, disassembled, and stowed in accordance with demobilization procedures and the system manuals.

5.4.2 Joint Base Pearl Harbor Hickam – Oscar Pier Area

The field-testing approach for the DPS and SeDep demonstration at Pearl Harbor Oscar Pier included a two-phased approach. In the first phase, DPS units were deployed to map the deposition footprint associated with a selected outfall at Oscar Pier. This phase involved multiple components including pre-deployment preparation, DPS deployments, DPS tracking, performance verification measurements, and DPS retrieval. In the second phase, SeDep systems were deployed to monitor deposition events within the footprint defined by the DPS units. This phase involved pre-deployment preparation, SeDep deployments, performance verification measurements, and SeDep retrieval.

5.4.2.1 Phase 1 – DPS Deposition Footprint Mapping

In this phase, DPS units were deployed to map the deposition footprint associated with a selected outfall at Oscar Pier. This phase involved multiple components including pre-deployment preparation, DPS deployments, DPS tracking, performance verification measurements, and DPS retrieval. Performance verification measurements are described in Section 5.5. The remaining components are described below.

Preparation: Preparation of the DPS systems consisted of physical preparation, testing, and programming (Figure 13). Physical preparation included preparation of the Microstar drifter, the winch system, and the ancillary sensors and systems that were planned for use with the drifter. System testing included testing of the GPS, communications, and winch systems. Programming of the DPS drifter system included inputting settings for the GPS sampling rate and the communications transmission rate. For short-term deployments associated with stormwater discharges, the GPS sampling rate was generally set to its minimum interval of two seconds to maximize the spatial resolution of the trajectory measurements. The communication interval was set to five minutes in order to keep track of the system, address any issues, and efficiently retrieve the unit. The primary winch setting was the settling velocity. Assuming a typical silt-sized particle of 10 micrometers (µm), Cheng's formula (Cheng, 1997) was used to estimate a typical settling rate of about 0.56 mm/s or 34 mm/min. This settling velocity was used for all of the DPS units.

Figure 13. The DPS Units Prepared for Deployment Onboard the Survey Boat in Pearl Harbor.

Deployment: Deployment for the Phase 1 field testing of the DPS systems was spread out across the tidal cycle so that the overall extent of the potential deposition zone that is linked to the outfall was captured. DPS units were deployed at approximately 1-1.5hour intervals throughout varying tidal conditions including slack ebb, mid flood, slack flood, and mid ebb. Because only ten systems were accessible, the drifters were retrieved after they made bottom contact, the data were downloaded, the battery charged, and the units were re-released to capture the other target release times. The deployment location was targeted for an outfall at the southeast end of the Oscar Pier area that faced the main navigation channel. Areas of potential concern from an ongoing source perspective are located along this area.

Tracking: Following the release of the drifters, the systems were tracked to observe their trajectories, verify operation, and identify and rectify any problems along the transit paths (Figure 14). Tracking was performed with a cellular hot-spot installed on the survey boat, allowing internet access to the Pacific Gyre web-access portal. This allowed for real-time monitoring of the positions. Tracks were uploaded and plotted on GoogleEarth® to allow visual analysis of the trajectories over time. In cases where systems became snagged on the piers, shorelines, or other obstacles, intervention was performed to return the unit to free drifting conditions. In instances where a unit stopped functioning, efforts were made to locate the unit, diagnose the problem, and either return it to use or document the problem and remove it from operation.

Figure 14. DPS Unit Drifting to the South of the Oscar Pier Outfall Location During the Mar 12-13, 2016 Event.

Retrieval: At the end of the field survey, the DPS units were located using the real-time monitoring and retrieved to the survey boat. The deposition cycle of the drifter was confirmed by observing that the drogue was back at the surface. Data were then downloaded from each unit including the high-resolution GPS and pressure data that define the trajectory, and the bottom detection information from the tilt sensor. Each unit was inspected for any physical damage, and a series of tests were run to verify that all aspects of the operation were still functional. Any issues or deficiencies were documented. The systems were then cleaned, disassembled, and stowed in accordance with demobilization procedures and the system manuals.

5.4.2.2 Phase 2 – SeDep Deposition Monitoring

In the second phase, SeDep systems were deployed to monitor deposition events within the footprint defined by the DPS units. This phase involved pre-deployment preparation, SeDep deployments, performance verification measurements, and SeDep retrieval. Performance verification measurements are described in Section 5.5. The remaining components are described below.

<u>Preparation</u>: Preparation of the SeDep systems included the setup, testing, and programming of the sensors, and the preparation of the sediment traps. Setup of the sensors involved opening the pressure housing, installing new batteries, re-sealing the housing, pre-filling the pressure plate and plumbing with water and purging any residual air, and closing the pressure plate valves as described in the manual (Figure 15). Testing the systems was done by connecting a laptop and monitoring the pressure sensor, opening the valves with the unit submersed in still water, and placing one of the calibration mats (1/8-inch rubber) on the pressure plate to make sure the system was responding as expected. After completing, the valves were reclosed, and the system was kept submersed. Programming the system involved clearing any data from memory, setting the sampling interval, and setting the start time for data recording. Preparing the sediment traps required cleaning the interior, exterior, mesh and caps; securing the mesh over the top; filling the trap ~2/3 full of brine solution; and covering with the cap. After the traps were prepared, they were placed in a rack that held them vertically in preparation for deployment.

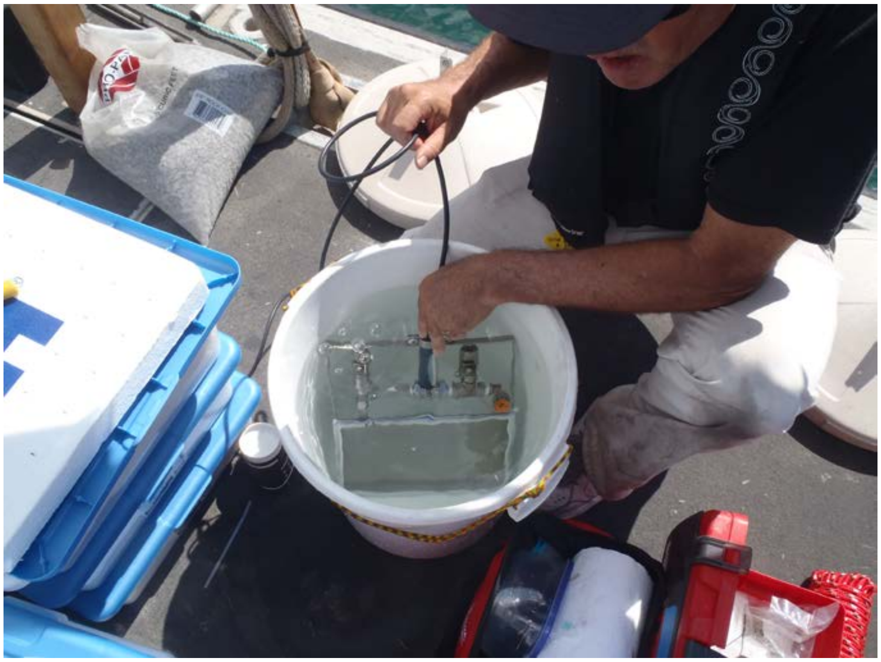

Figure 15. Purging the Pressure Plate on the SeDep Prior to Deployment at the Oscar Pier Site.

<u>Deployment</u>: Deployment of the SeDep system was performed by diver. The procedure required first installing the sediment trap, then installing the SeDep sensor, then mounting the data logger to the sediment trap stake. Installation of the pressure sensor was done by taking the system from the boat down to the sediment surface with the valves open. At the bottom, the system was gently manipulated to make sure any residual air bubbles were out, and then the valves were closed.

The flat pressure plate was then gently inserted into the sediment to a depth of about 7.5 cm using the stainless-steel handles. The cable and data logger were then moved to a distance about 2 m away from the sensor where the sediment trap was installed. The data logger was mounted to the vertical stake that held the sediment trap at about mid-level with the cable running out the bottom into the sediment.

Retrieval: The SeDep systems were deployed for an extended period of 1-2 months to capture deposition associated with multiple runoff events. Following that period, divers were deployed to retrieve the units. This involved first capping the sediment trap (to minimize any diver resuspension effects during the retrieval); collecting a shallow, undisturbed core from above the pressure plate; and then retrieving all of the equipment to the survey boat. Following retrieval, data were downloaded from the pressure sensor data loggers, the trap and core samples were processed for analysis, each unit was inspected for any physical damage, and a series of tests were run to verify that all aspects of the operation were still functional. The systems were then cleaned, disassembled, and stowed in accordance with demobilization procedures and the system manuals.

5.4.3 Joint Base Pearl Harbor Hickam – Waiau Power Plant Area

The field-testing approach for the second DPS demonstration at Pearl Harbor focused on DPS mapping of the potential deposition footprint from a suspected historical Navy OWS outfall believed to have been located at the current site of Neal S Blaisdell Park in Honolulu, HI, on the northern shore of East Loch in Pearl Harbor just east of the Waiau Generating Station (Figure 16). DPS units were deployed to map the deposition footprint associated with a suspected OWS outfall along the western boundary of what was once a Navy drum storage yard and is now the park. This involved multiple components including pre-deployment preparation, DPS deployments, DPS tracking, performance verification measurements, and DPS retrieval. The field-testing approach is described below.

Figure 16. Photo Looking from the Area of the Former Navy Drum Storage Site Toward the Suspected OWS Discharge Location in Pearl Harbor.

5.4.3.1 DPS Deposition Footprint Mapping

DPS units were deployed to map the deposition footprint associated with the suspected OWS outfall off the Waiau area. This involved multiple components including pre-deployment preparation, DPS deployments, DPS tracking, performance verification measurements, and DPS retrieval. Because the site is very shallow, the drogues for the DPS units were modified to reduce their vertical profile dimension to about 24” (Figure 17). This allowed for operation in the shallow waters off of the park area. Other than the change in DPS configuration, the procedures for the Waiau site were comparable to the procedures for the Oscar Pier site and are not repeated here.

Figure 17. DPS System with the Drogue Size Reduced for Shallow Water Operations During the Waiau Event.

5.5 SAMPLING METHODS

Each demonstration incorporated sensor measurements, water, and sampling into both direct aspects of the technologies being demonstrated, as well as the validation measures that were employed. Descriptions of the sampling methods for each of the demonstrations are provided below.

5.5.1 Naval Base San Diego – Paleta Creek

The DrEx system incorporates a range of sensor and water sampling capabilities including positioning, temperature, salinity, pump status, composite samples, and passive samples. In addition, verification measurements and sampling were part of the demonstration to quantify the performance of the system relative to established metrics. These two lines of sampling are summarized below, and details can be found in the project Technical Report (Chadwick, 2017).

5.5.1.1 DrEx Sensor Measurements and Sampling

Sensor measurements were recorded from the GPS, a temperature/salinity logger attached to the drifter, and from monitoring the pump status (Table 3). These data were collected throughout the deployment at a rate of about one measurement per minute. Composite samples and passive samples were also collected from the drifters. Each drifter collected one composite sample and was fitted with metal and organic passive samplers. Composite samples were analyzed for metals, organics, TSS, and toxicity.

5.5.1.2 DrEx Performance Verification Sensor Measurements and Sampling

Additional measurements and sampling were carried out as part of the performance verification for the DrEx. A high-precision sub-meter resolution GPS unit was held alongside the drifter GPS at various intervals during the trajectories to verify the onboard GPS performance. Plume mapping was carried out from the survey boat using a towed Conductivity, Temperature, and Depth (CTD) system (Chadwick and Salazar, 1991) to verify the tracking of the plume by the drifters. Composite samples collected by the drifter were weighed before and after the event to verify the operation of the pumping system.

5.5.1.3 Quality Control

Quality control methods included calibrations, decontamination procedures, quality assurance sampling, and sample documentation (Chadwick et al., 2017).

5.5.2 Joint Base Pearl Harbor Hickam – Oscar Pier Area

As described in the field-testing description above, the demonstration at JBPHH focused on demonstration and validation of the DPS and SeDep systems for monitoring the transport and deposition of stormwater associated particle plumes. The two systems incorporate a range of sensor and sampling capabilities including positioning, depth, bottom detection, deposition mass, and sediment trap accumulated sediments. In addition, verification measurements and sampling were part of the demonstration to quantify the performance of the systems relative to established metrics. These two lines of sampling are summarized below for each phase of the effort, and details can be found in the project Technical Report (Chadwick, 2017).

5.5.2.1 Phase 1 – DPS Sensor Measurements

Sensor measurements were recorded from the GPS, pressure sensor, bottom detector, and a temperature/salinity logger attached to the drifter (Table 4). Position data were collected throughout the deployment at a rate of about one measurement per second and stored onboard the drifter. Position data were also telemetered via the Iridium modem about every five minutes. Depth measurements and line spool distance and bottom detection from the winch sensors were recorded every 30 seconds. Temperature and salinity data were also recorded every 30 seconds on the logger.

5.5.2.2 Phase 1 – DPS Performance Verification Sensor Measurements

Additional measurements were carried out as part of the performance verification for the DPS. A high-precision sub-meter resolution GPS unit was held alongside the DPS surface float GPS at approximately one-hour intervals during the trajectories to verify the onboard GPS performance.

During these position checks, water depths were also measured for post-survey comparison to the pressure sensor on the DPS to verify that the bottom detection system was performing properly.

5.5.2.3 Phase 2 – SeDep Sensor Measurements and Sampling

The sensor measurement records a time series of sediment mass on the deposition sensor, while the sediment trap collects an integrated sample of depositing sediment over time. A surface sediment sample is also collected from above the deposition sensor at the end of the deployment period. Sediment samples were characterized for contaminants of concern, grain size, total organic carbon (TOC), and bulk density (Table 5).

5.5.2.4 Phase 2 – SeDep Performance Verification Sensor Measurements

During the Phase 2 SeDep deployments, performance verification measures focused on deposition detection sensitivity, measurement reliability, system survivability, and ease of use. Detection sensitivity was evaluated during field measurements based on the variability measured during quiescent periods of the deployment when no storm events, ship movements, or other significant sediment transport processes were active.

5.5.2.5 Quality Control

Quality control methods included calibrations, decontamination procedures, quality assurance sampling, and sample documentation for the DPS and SeDep systems (Chadwick, 2017).

Table 3. Total Numbers and Types of Samples for the DrEx Demonstration at NBSD.

Sensor/Sampler	Source	Sampled Via	Data Parameters	Planned Sampling Rate	Expected Number of Samples
GPS	Brightwaters 121 Drifter	Iridium Modem & Post-Survey Download	Serial number, record number, data, time, GPS status, GPS wakeup time, GPS latitude, GPS longitude, External power (on or off), battery level	1/min	1440 per 24 hours
Pump Data	Brightwaters 127 PAWS	Iridium Modem & Post-Survey Download	Pump state, pump direction, volume count, internal humidity, minimum volume count, maximum volume count	1/min	1440 per 24 hours
Temperature	HOBO Conductivity/Salinity Data Logger U24-002-C mounted on drifter	Post-Survey Download	Date, time, temperature, conductivity	1/min	1440 per 24 hours
Salinity	HOBO Conductivity/Salinity Data Logger U24-002-C mounted on drifter	Post-Survey Download	Date, time, temperature, conductivity	1/min	1440 per 24 hours
Upstream Grab Sample	Dipper or Isco Sampler	Grab during first flush	Metals, organics, TSS, DOC, and toxicity	Grab	1 per event
DrEx Composite Sample	Brightwaters 127 PAWS	Continuous pump collection during survey	Metals, organics, TSS, DOC, and toxicity	~2-3 ml/min	1 per drifter
DrEx Passive Metals Sample	DGT disc samplers mounted on drifter	Continuous passive collection during survey	Dissolved metals	N/A	2 per drifter
DrEx Passive Organics Sample	SPME fibers in Teflon tube mounted on drifter	Continuous pumped/passive collection during survey	Dissolved organics	N/A	1 per drifter

Notes: DOC = Dissolved Organic Carbon; TSS = Total Suspended Solids; DGT = Diffusive Gradient in Thin Film Sampler; SPME = Solid Phase Microextraction; HOBO = Onset HOBO conductivity and temperature data logger.

Table 4. Total Numbers and Types of Samples for the Phase 1 DPS/SeDep Demonstration at JBPHH.

Sensor/Sampler	Source	Sampled Via	Data Parameters	Planned Sampling Rate	Expected Number of Samples
Phase 1 DPS					
GPS	DPS Drifter Float	Iridium Modem & Post-Survey Download	Device name, data, time, GPS status, GPS latitude, GPS longitude	Every 2 seconds onboard; Every 5 minutes telemetered	43200 per 24 hours
Drogue Depth	DPS Winch Pressure Sensor	Post-Survey Download	Drogue depth	Every 30 seconds	2880 per 24 hours
Line Payout	DPS Winch Pressure Sensor	Post-Survey Download	Line length	Every 30 seconds	2880 per 24 hours
Bottom Detection	DPS Winch Pressure Sensor	Post-Survey Download	Sensor angle	Every 30 seconds	2880 per 24 hours
Temperature	HOBO Conductivity/Salinity Data Logger U24-002-C mounted on drifter	Post-Survey Download	Date, time, temperature, conductivity	1/minute	1440 per 24 hours
Salinity	HOBO Conductivity/Salinity Data Logger U24-002-C mounted on drifter	Post-Survey Download	Date, time, temperature, conductivity	1/minute	1440 per 24 hours

Notes: GPS = Global Positioning System; HOBO = Onset HOBO conductivity and temperature data logger.

Table 5. Total Numbers and Types of Samples for the Phase 2 DPS/SeDep Demonstration at JBPHH.

Sensor/Sampler	Source	Sampled Via	Data Parameters	Planned Sampling Rate	Expected Number of Samples
Phase 2 SeDep					
GPS	Trimble GeoXH	Survey boat postioned at station marker	Date, Time, GPS latitude, GPS longitude, GPS precision	At deployment	One time
Depostion mass	SeDep pressure sensor	Post-Survey Download	Deposition mass	Raw 1/minute, averaged to 1/hour	1440 per 24 hours, averaged to 24 per 24 hours
Depostion mass and chemistry	SeDep Sediment Trap	Post-Survey Collection	Depostion mass, organics, metals, particle size, TOC, bulk density (dependent on available mass)	One time	Composite 3 traps from each station
Depostion chemistry	Diver core at SeDep pressure plate	Post-Survey Collection	Depostion mass, organics, metals, particle size, TOC, bulk density (dependent on available mass)	One time	Composite 3 cores from each station

Notes: GPS = Global Positioning System; HOBO = Onset HOBO conductivity and temperature data logger; GeoXH = Trimble GeoXH global positioning system; TOC = Total Organic Carbon.

5.6 SAMPLING RESULTS

Sampling results from the field demonstrations are presented below. Results are organized by technology and field event. The DPS and SeDep results are presented together for the Pearl Harbor Oscar Pier demonstration because they were used in an integrated manner.

5.6.1 DrEx Demonstration Results

The primary data collected from the DrEx systems included position data, sensor data, and sample data. Position data were used to define the trajectory of the stormwater plume. Sensor data from the DrEx included temperature and salinity from the onboard data logger. These data were examined to determine the relative fraction of stormwater in the surface plume, the change in that fraction over time, and the degree to which the DrEx systems stayed within the stormwater plume. Results from the chemical and toxicological analysis of the composite and passive samples were used to calculate statistics related to exposure and effects associated with the discharge plume.

Verification data for the DrEx demonstration included sub-meter resolution GPS data and plume mapping data from the survey boat using a towed or profiled CTD system. Differences between the paired samples from the drifter and verification GPS data sets were analyzed to evaluate the accuracy of the DrEx trajectory data. Plume mapping data from the towed/profiled CTD were used to produce a series of spatial maps of temperature and salinity. These maps were overlaid with the DrEx positions to qualitatively evaluate the correspondence of the trajectories with the observed location of the discharge plume. Reliability of the DrEx communications link was analyzed to determine the percent of time that the communications link is maintained during the survey period. The survivability of the units was calculated as the percent of units that successfully completed the mission, accounting for units that were lost, disabled, malfunction, etc. Analysis was also performed to compare the programmed sample volumes to the actual collected volumes. Results for each of the two DrEx field demonstration events are presented below.

5.6.1.1 Jan 5-6, 2016 Storm Event

<u>Precipitation and Tides</u>: The first DrEx demonstration survey was conducted during a storm event on Jan 5-6, 2016 at the mouth of Paleta Creek at NBSD. The hydrograph for the storm (Figure 18) shows that the rainfall came in two main waves with the main wave occurring between about 08:00 and 15:00 on 1/5/16, and the second smaller wave coming between about 12:00 and 14:00 on 1/6/16 (after the drifters had been retrieved). The cumulative rainfall for the first wave was about 45 mm. Ten drifters were released into the first flush of this event at the mouth of Paleta Creek. The first flush was identified by monitoring the salinity at the mouth of the creek. Ten DrEx systems were released during the period from 13:34 to 14:11 on 1/5/16. The systems were allowed to drift for an exposure period of approximately 12 hours. The tide was flooding during the release period, and cycled from flood to ebb and back to flood during the drift period (Figure 18). Tidal range was on the order of 1 m during the event.

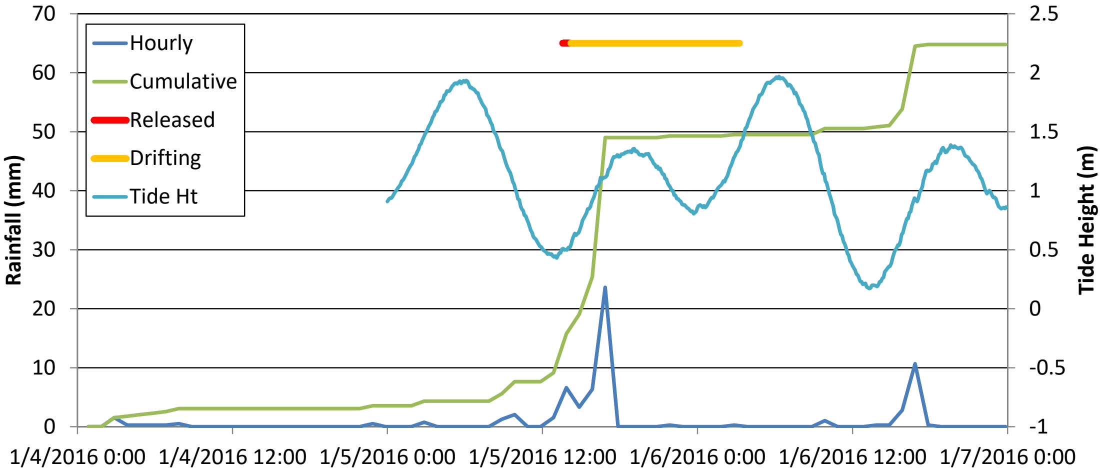

Figure 18. Hydrograph and Tides for the Jan 5-6, 2016 Storm Event Relative to the Drifter Release and Transit Periods.

DrEx GPS Tracking: Trajectories for the DrEx systems are shown in Figure 19. Nine out of the ten DrEx units provided trajectory data, while one unit (109) shut down and did not record trajectory data due to a malfunction with the magnetic reed switch. The drifters followed a fairly similar path toward the southwest from the release point and along the northern side of the Mole Pier until reaching the pier head. At that point, five of the systems transited around the end of the Mole Pier to the south (along the ship channel) and into the area between the Mole Pier and Pier 10. The other four systems returned into the original area between the Mole Pier and Pier 8. The systems that transited to the south into the Mole Pier/Pier 10 area generally eddied around within the pier area with three ending up near the head of the Mole Pier, and two ending up further in adjacent to a ship that was moored on the south side of the Mole Pier. Of the systems that returned to the Mole Pier/Pier 8 area, three transited all the way back into the creek mouth area, close to the original release point, and one eddied off to the north near Pier 8 and ended up in the central portion of the outer pier area.

Overall, the GPS tracking data from the DrEx systems provided a clear visualization of the area of the bay with connectivity to the stormwater plume, the spatial and time scale of the plume, the rate of movement of the plume, the rate of spreading of the plume, and the relationship to complex forcing from the stormwater and the tide. These are all key aspects in understanding the complex nature and extent of the stormwater exposure associated with the stormwater discharge event.

DrEx Sensor Data: Sensors mounted on the DrEx units recorded temperature and salinity continuously during the survey event. Evaluation of this data focused primarily on the salinity data because it provided a direct indicator of the presence of the stormwater plume and the degree of mixing with bay water.

All ten of the drifters provided usable sensor data including 109, even though no position data were collected for the unit. The time-series results indicated that the drifters generally stayed within the plume based on the salinity levels remaining well below ambient bay levels. The salinity data can also be used to calculate the stormwater fraction along the drifter tracks as

$$SW = 1 - \frac{S}{S_o}$$

where SW is the fraction of stormwater within the plume, S is the measured salinity, and S_o is the background bay water salinity (~33.75 psu). Results for the stormwater fraction are shown in Figure 20. The results show that while the stormwater fraction often started close to 100% at the time of release, the plume was quickly diluted with bay water even within the narrow channel area near the creek mouth such that the stormwater fraction was generally reduced to within the range of 20-40%.

In general, the sensor data from the DrEx units were very useful in evaluating the dynamics of the stormwater plume, the dilution of the plume over time, and the influence of other stormwater sources in the general vicinity.

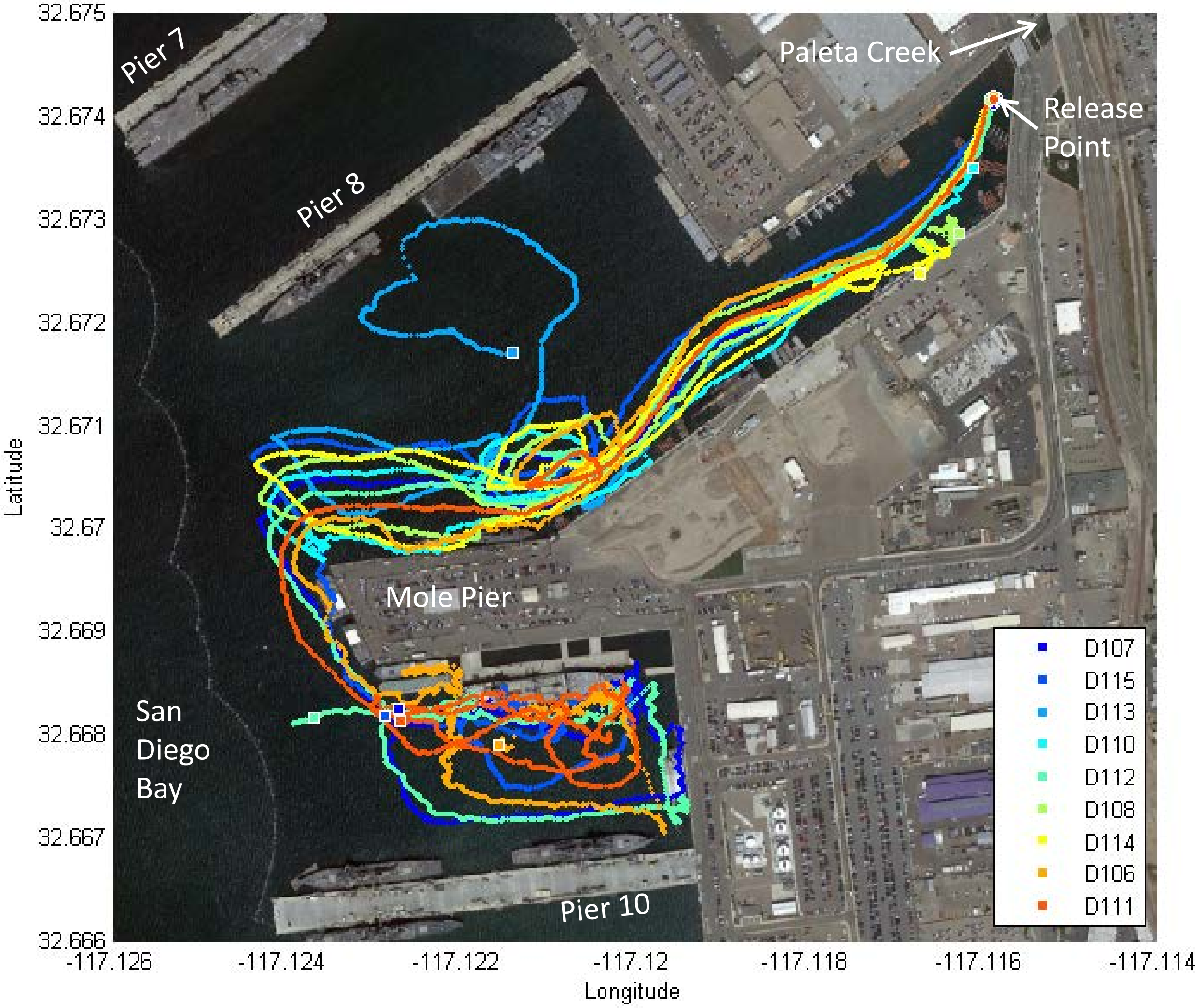

Figure 19. DrEx Trajectories for the First-flush Release During the Jan 5-6, 2016 Event.

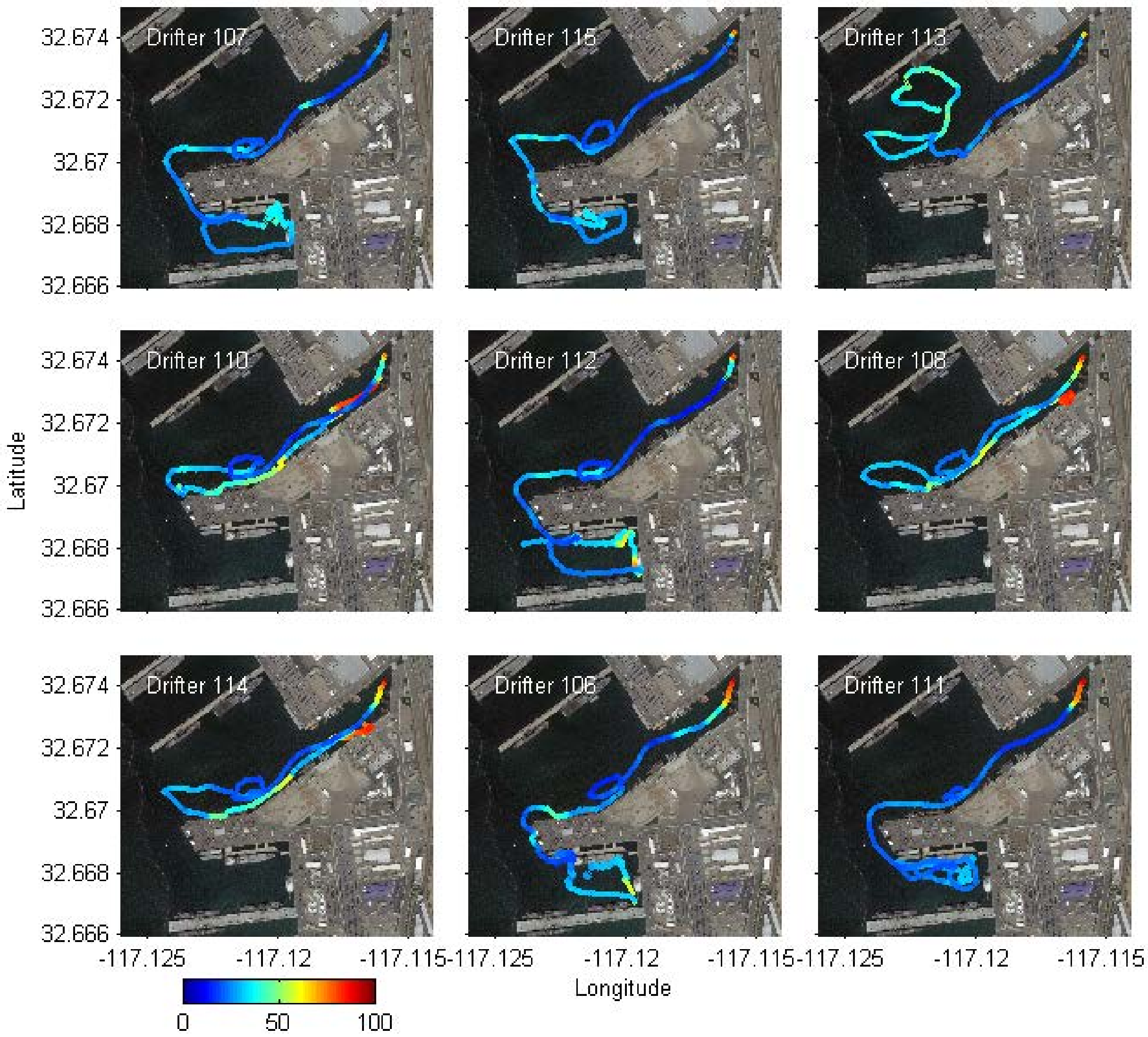

Figure 20. Individual DrEx Trajectories with Overlaid Stormwater Fraction for the Jan 5-6, 2016 Event. Color Bar Indicates the Percent of Stormwater.

<u>DrEx Composite Samples</u>: A unique aspect of the DrEx system is its ability to collect composite samples while drifting and tracking the stormwater plume. This sampling capability allows for both chemical and toxicological characterization of the exposure that occurs in the surface waters of these stormwater plumes. This exposure is much more characteristic of the exposure that would be expected for the sensitive larval stage of species such as fish and mollusks that inhabit the bay.

For the Jan 5-6, 2016 storm event, composite samples were successfully collected by eight of the DrEx units (106, 107, 108, 110, 111, 112, 113, and 114). Faulty tube connections, bag leaks, and magnetic switch malfunctions all impacted the sampling to some degree. Samples were analyzed for chemicals of interest for the Paleta Creek total maximum daily load (TMDL) including TSS, metals (copper and zinc), PCBs, PAHs and the chlorinated pesticides Dichlorodiphenyltrichloroethane (DDT) and Chlordane. Results for TSS showed the expected high level of particulate in the discharge from Paleta Creek but significantly reduced levels in the DrEx composite samples.

Similar patterns were observed for total concentrations of metal and organic contaminants. Highest concentrations for all contaminants were observed in the first-flush discharge sample. Total copper concentrations were about 92% lower in the composite samples compared to the discharge and total zinc concentrations which were reduced by about 88% on average (Figure 21). For Total PCBs, Dichlorodiphenyltrichloroethane and its isomers (DDX), and Chlordane, concentrations were reduced to levels below detection limits. For Total PAHs, DrEx composite samples were about 98% lower than discharge samples. Thus, overall exposure to total chemical concentrations was generally reduced by about 88-98% in the stormwater plume over a 12-hour period compared to concentrations in the first flush measured at the discharge point at the mouth of the creek.

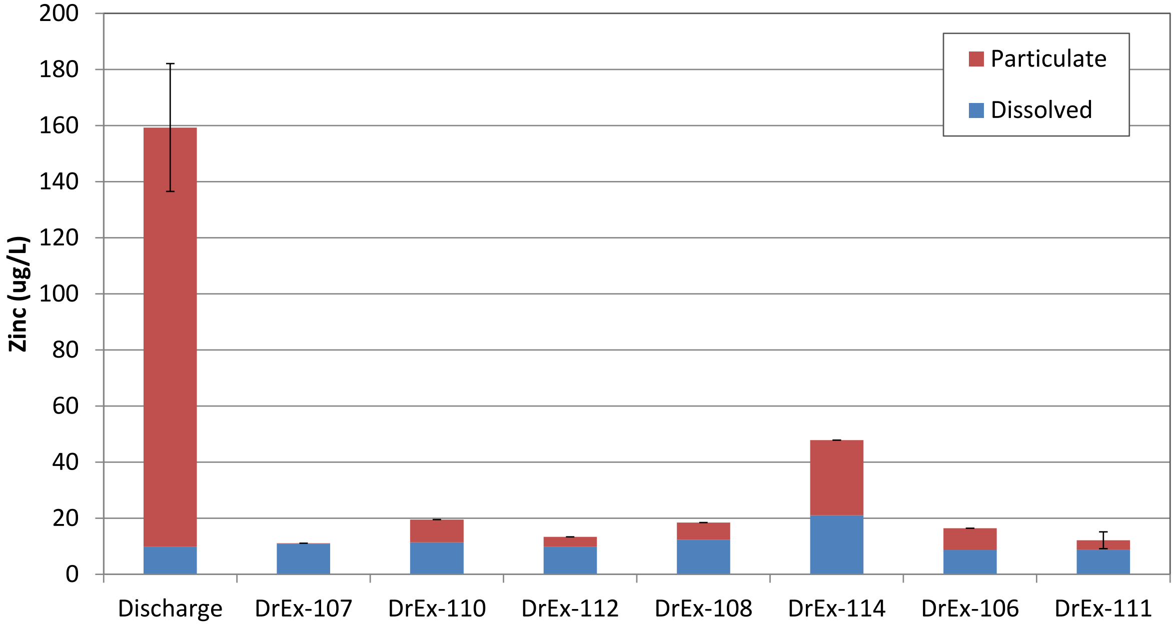

Figure 21. Dissolved and Particulate Zinc Concentrations in the First-flush Discharge Water at the Mouth of Paleta Creek, and for the DrEx 12-hour Composite Samples from the Stormwater Plume During the Jan 5-6, 2016 Event.

Toxicity was also evaluated in the discharge and DrEx composite samples. Chronic toxicity testing with purple sea urchin (*Strongylocentrotus purpuratus*) embryos was performed using standardized protocols (Table 6). For the Jan 5-6 storm event, samples from DrEx 106 and 107 resulted in toxic responses at the highest testable concentration using Student's t-test when compared to laboratory controls. The Test for Significant Toxicity (TST) provided similar results and also found the sample from DrEx 114 to be significantly lower from its respective controls. Based on the available chemistry data, it appeared that measured levels of organic contaminants were generally too low to cause toxicity. Dissolved copper and zinc levels were also generally relatively low, but in some instances were approaching levels that could cause chronic toxicity.

Overall, the composite samples from the Jan 5-6, 2016 event provided an effective means for characterizing exposure conditions within the first-flush portion of the discharge plume from both a chemical and toxicological perspective.

Table 6. Summary of Toxicity Results for the Discharge Sample and DrEx Composite Samples from the Jan 5-6, 2016 Event.

Test Concentration (%)	Sea Urchin Mean 96-hr Development (% normal)							
	Ambient Sample	Drifter 106	Drifter 107	Drifter 108	Drifter 110	Drifter 111	Drifter 112	Drifter 114
Lab Control	86.3	86.3	86.3	86.3	86.3	86.3	86.3	86.3
Brine Control	82.3	82.3	82.3	82.3	82.3	82.3	82.3	82.3
10	83.5	**49.0**^{b}	98.5	99.5	97.8	98.8	98.8	98.8
100*	**57.0**^{a}	**20.0**^{c}	**9.8**^{c}	89.5	77.3	93.5	90.5	71.5
TST Results	Toxic	Toxic	Toxic	Not Toxic	Not Toxic	Not Toxic	Not Toxic	Toxic

Values in **bold** indicate a statistically significant decrease compared to the brine control as determined with the student's one tailed t-test.

Level of statistical significance: a - <0.05, b - <0.01, c - ≤0.001.

*Indicates the highest concentration possible to test was <100% effluent, due to the addition of hypersaline brine; Actual values tested are as follows: Ambient (49.1%), 106 (84.8%), 107 (86.8%), 108 (78.3%), 110 (73.8%), 111 (86.8%), 112 (86.3%), 114 (72.9%)

DrEx Passive Samplers: In addition to the composite sampling capabilities, the DrEx system can also accommodate passive samplers. For the Jan 5-6, 2016 storm event, DGT samplers for metals and SPME samplers for organic contaminants were incorporated. The DGTs were simply attached to the drifter frame at mid depth and exposed to the stormwater plume over the 12-hour period of the event. For the SPME samplers, the flow over the sampler was enhanced by using a battery-powered pump with the SPME fibers installed in a Teflon tube in line with the pump flow. DGT samplers were recovered from all ten DrEx units. Duplicate DGT samplers were analyzed for cadmium, copper, lead, and zinc. Water concentrations derived from DGT samplers are generally inferred to represent the labile fraction of the metal. Labile copper averaged about 96% of the dissolved fraction, while labile zinc averaged about 74%. In general, the DGT samplers were relatively easy to adapt to the DrEx units and are well suited to exposure durations that are likely to be typical for the DrEx system. SPME samplers were recovered from all ten DrEx units. SPME samplers were analyzed for PCBs, PAHs, and chlorinated pesticides. In general, only PAHs and dieldrin were detected in the DrEx samples.

Overall, while still developmental, the passive sampler results indicated that there is potential for their application on these drifting exposure systems. The DGT samplers are better suited to the application because the exposure time scale is more in line with the standard DGT method. The SPME samplers have potential, but the application is not truly passive because it requires pumping, and more work is needed to better refine the method and improve the response time.

5.6.1.2 Feb 1, 2016 Storm Event

Precipitation and Tides: The second DrEx demonstration survey was conducted during a storm event on Feb 1, 2016 in the same area as the first survey at the mouth of Paleta Creek at NBSD. The hydrograph for the storm (Figure 22) shows that the rainfall came in a series of small waves between about 21:00 on 1/31/16 and 15:00 on 2/1/16. The cumulative rainfall for the first wave was only about 5 mm even though the prediction for the storm was for >10 mm. Ten DrEx drifters were released into the first flush of this event at the mouth of Paleta Creek. The systems were allowed to drift for an exposure period of approximately 7.5 hours with the shortest duration being about 6.7 hours and the longest duration about 8.5 hours. The deployment was cut short from the planned 12-hour exposure due to high wind and wave conditions combined with a lower than expected precipitation and flow from the creek. The tide was flooding during the release period and cycled from flood to ebb during the drift period (Figure 22). Tidal range was on the order of 1 m during the event.

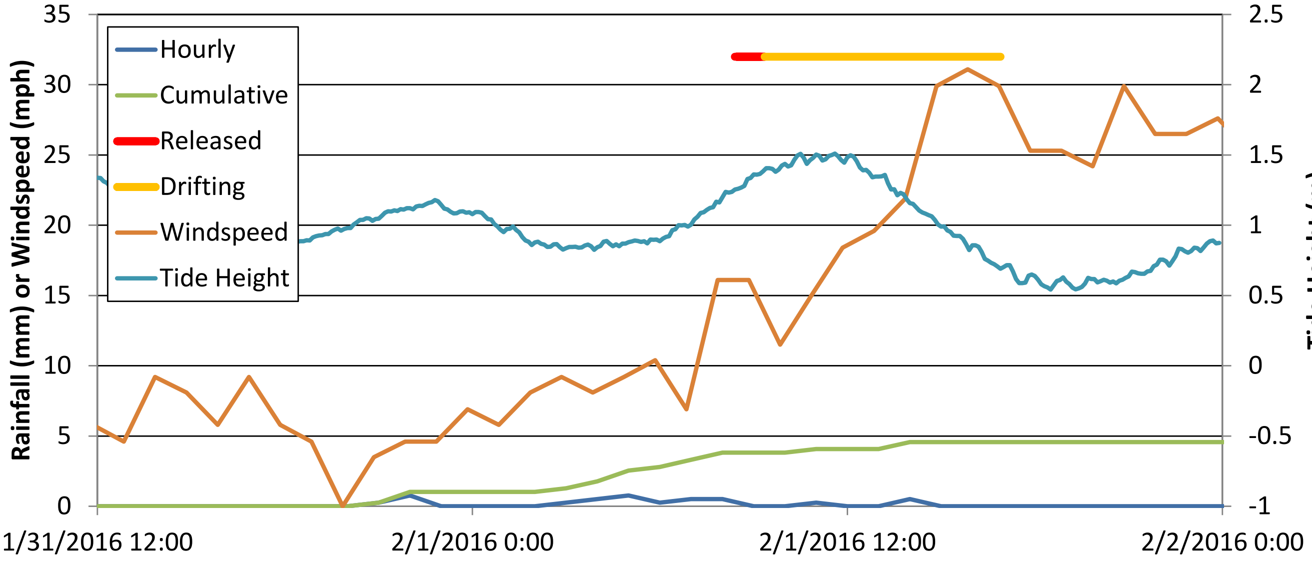

Figure 22. Hydrograph and Tides for the Feb 1, 2016 Storm Event Relative to the Drifter Release and Transit Periods.

DrEx GPS Tracking: Trajectories for the DrEx systems are shown in Figure 23. All ten DrEx units provided trajectory data. The drifters released earlier in the event followed a path toward the southwest from the release point out to the end of the narrow channel that forms the creek mouth area. Subsequent DrEx units traveled shorter and shorter distances with the last few units essentially staying within a close proximity to the release area. The units released earlier in the storm reversed path once they reached the end of the channel area and transited back toward the creek mouth and the release point, ending up in the southeastern corner along the base of the Mole Pier. The other units all stayed within the release area for the duration of the event.

Overall, the GPS tracking data from the DrEx systems provided a clear visualization of the area of the bay with connectivity to the stormwater plume, the spatial and time scale of the plume, the rate of movement of the plume, the rate of spreading of the plume, and the relationship to complex forcing from the stormwater and the tide. These are all key aspects in understanding the complex nature and extent of the stormwater exposure associated with the stormwater discharge event. The deployment during this storm with weaker discharge but higher winds also provided a clear contrast in the spatial scales associated with different stormwater discharge events.

<u>DrEx Sensor Data</u>: Sensors mounted on the DrEx units recorded temperature and salinity continuously during the survey event. Evaluation of this data focused primarily on the salinity data because it provided a direct indicator of the presence of the stormwater plume and the degree of mixing with bay water. Nine out of ten drifters provided usable sensor data, excluding 112 which lost its sensor when the bracket broke off as the unit was slammed into floating equipment that was moored in the creek mouth. The time-series results indicated that the drifters generally stayed within the plume based on the salinity levels remaining well below ambient bay levels. Similar to the first storm event, values were generally low and then rose within the first 1-3 hours of transport. Values then stabilized for several of the drifters (106, 110, 113, and 115), while others showed secondary pulses of lower salinity water (107, 108, 109, 111, and 114). These secondary pulses appeared to be linked to follow on waves of precipitation and discharge that occurred following the release of the drifters (Figure 22).

Results for the stormwater fraction for this second event are shown in Figure 24. The results show the stormwater fraction tended to vary as a function of the distance of the DrEx unit from the creek mouth. For example, DrEx units 115, 106, and 113 that transited out toward the end of the narrow channel showed reductions in stormwater fraction down to the 20-30% range, while the units that stayed near the release area generally stayed above 40-50%. Interestingly, even though the Feb 1, 2016 event was much smaller in magnitude in terms of discharge, the exposure levels in terms of stormwater fraction were comparable or higher than the higher discharge event on Jan 5-6, 2016. In general, the sensor data from the DrEx units were very useful in evaluating the dynamics of the stormwater plume, the dilution of the plume over time, and the influence of other stormwater sources in the general vicinity.

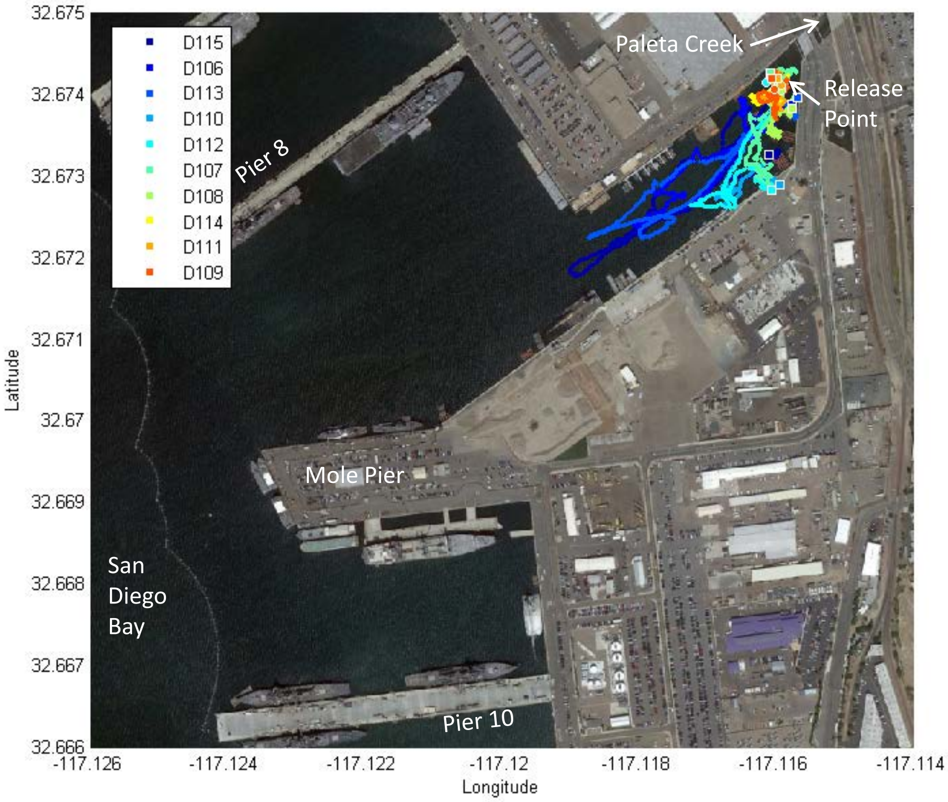

Figure 23. DrEx Trajectories for the First-flush Release During the Feb 1, 2016 Event.

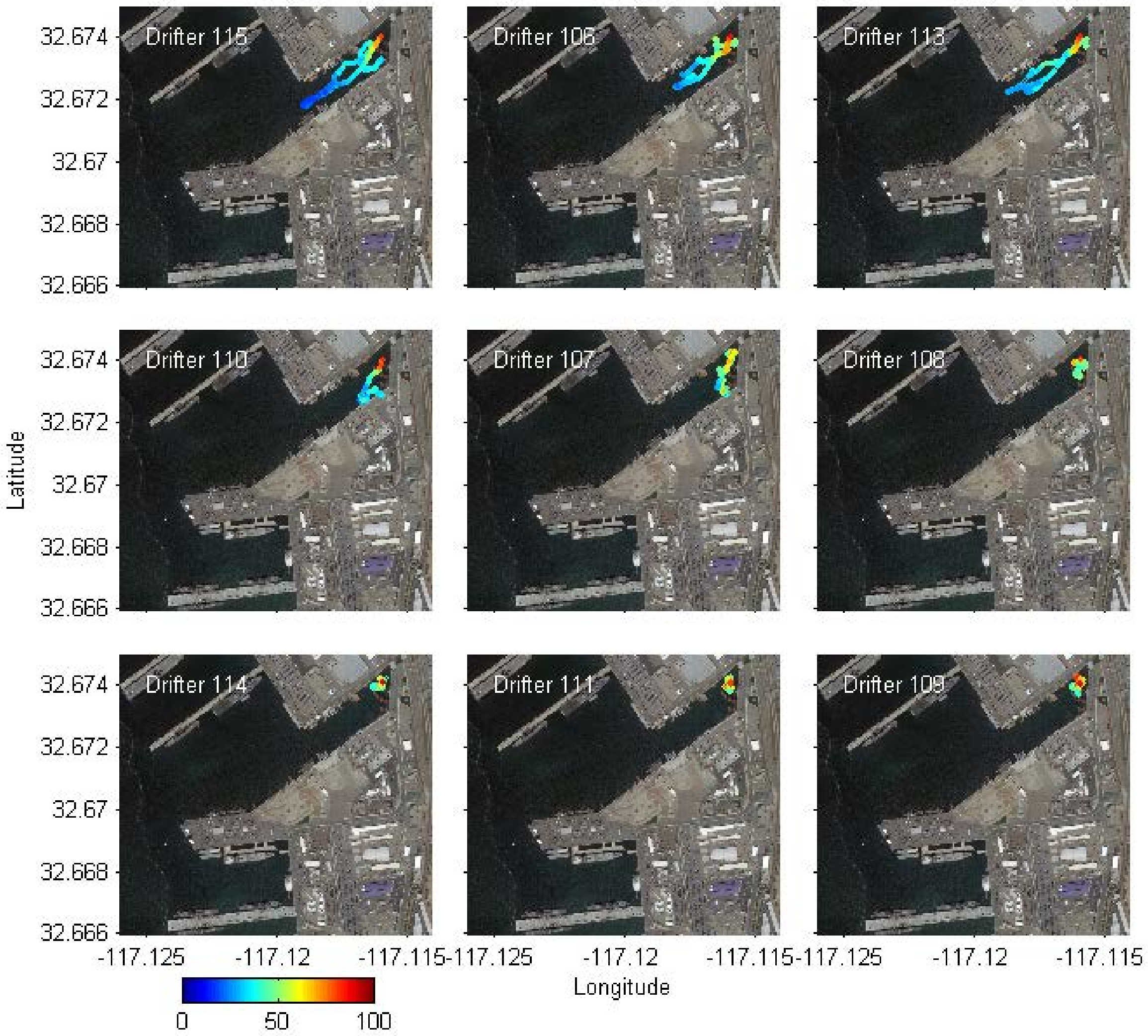

Figure 24. **Individual DrEx Trajectories with Overlaid Stormwater Fraction for the Feb 1, 2016 Event. Color Bar Indicates the Percent of Stormwater.**

<u>DrEx Composite Samples</u>: For the Feb 1, 2016 storm event, composite samples were successfully collected by nine of the ten of the DrEx units. DrEx unit 109 had insufficient volume for analysis due to a bag leakage issue. Thus, chemistry and toxicity results were obtained for a total of nine DrEx units. In addition, grab samples were collected at the mouth of the creek at the time of first flush when the drifters were released.

Samples were analyzed for the same chemicals of interest as the first event. As with the first event, results for TSS showed the expected high level of particulate in the discharge from Paleta Creek but significantly reduced levels in the DrEx composite samples (Figure 25). However, the TSS load in this discharge sample was about 4X lower than for the Jan 5-6, 2016 event. In contrast to the TSS, total metal and organic contaminant concentrations did not show major differences between the discharge sample and the drifter composite samples.

On average, total copper and total zinc concentrations in the drifter composite samples were only 13% and 36% lower than the discharge sample, respectively. Total DDX and Chlordane were not detected in the discharge or the drifter samples. PCBs and PAHs showed some contrast with PCBs detected at low levels in the discharge, but below detection in the drifter samples, and PAHs reduced by about 41% on average in the drifter samples. It appears that the limited transport and dispersion of the plume likely contributed to the reduction in contrast between the discharge levels and plume composite samples for the smaller Feb 1, 2016 storm event. Overall exposure to total chemical concentrations was generally reduced by about 13-41% in the stormwater plume over a 7-hour period compared to concentrations in the first flush measured at the discharge point at the mouth of the creek.

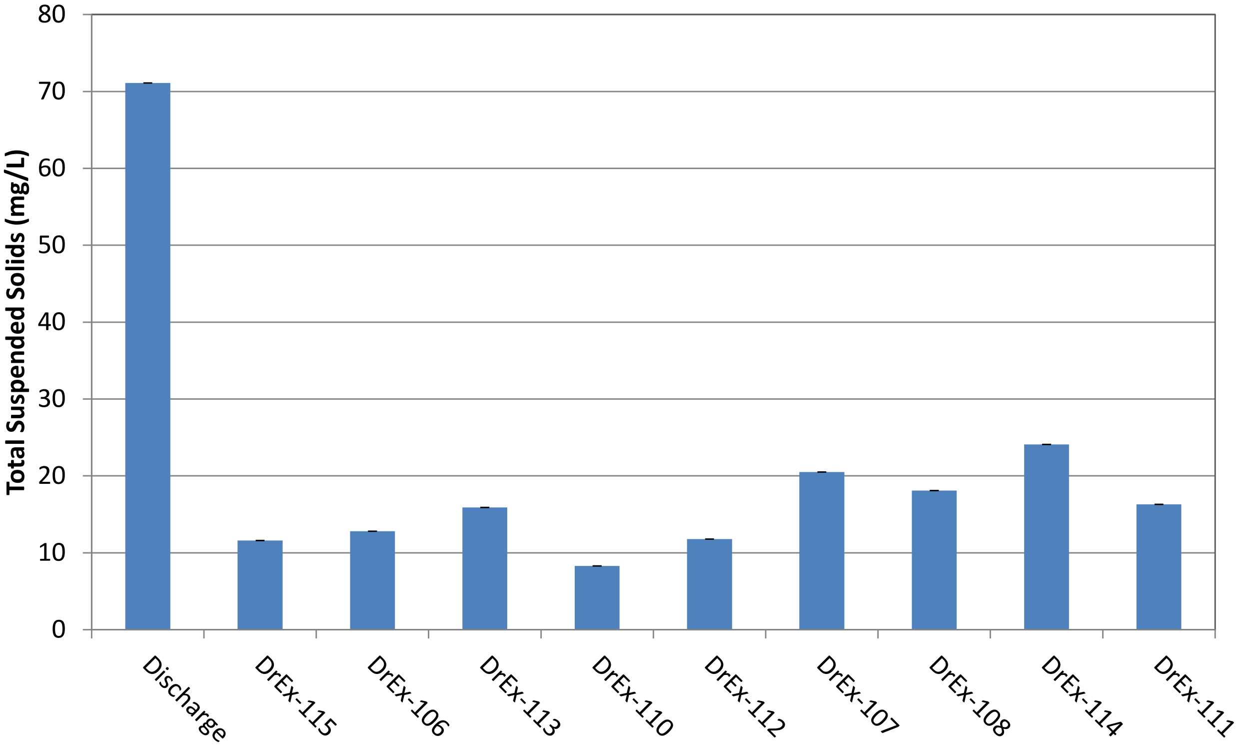

Figure 25. TSS Concentrations in the First-flush Discharge Water at the Mouth of Paleta Creek, and for the DrEx 7-hour Composite Samples from the Stormwater Plume During the Feb 1, 2016 Event.

Chronic toxicity for the purple sea urchin was also evaluated in the discharge and DrEx composite samples from this event. For the Feb 1 storm event, significant decreases from controls were observed for Drifters 106, 107, 108, 110, 111, and 112 (Table 7), while Drifters 113, 114, and 115 showed no observable adverse effects. Statistical analyses using the TST found adverse effects relative to controls in Drifters 106, 107, 108, and 112 (Table 7). Based on the available chemistry data, it appeared that measured levels of organic contaminants were generally too low to cause toxicity. Dissolved copper and zinc levels were also generally relatively low, but in some instances were approaching levels that could cause chronic toxicity.

Overall, the composite samples from the Feb 1, 2016 event provided an effective means for characterizing exposure conditions within the first flush portion of the discharge plume from both a chemical and toxicological perspective.

Table 7. Summary of Toxicity Results for the Discharge Sample and DrEx Composite Samples from the Jan 5-6, 2016 Event.

Test Concentration (%)	Sea Urchin										
	Mean 96-hr Development (% normal)										
	Ambient Sample	**Drifter 106**	**Drifter 107**	**Drifter 108**	**Drifter 109**	**Drifter 110**	**Drifter 111**	**Drifter 112**	**Drifter 113**	**Drifter 114**	**Drifter 115**
Lab Control	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3
Brine Control	99.3	99.3	99.3	99.3	99.3	99.3	99.3	99.3	99.3	99.3	99.3
10	99.3	**92.5**^{a}	**68.3**^{a}	98.8	99	99.5	99.8	97.8	97	99	100
100*	96.8	**0.0**^{c}	**2.8**^{c}	**0.0**^{c}	**59.3**^{a}	**92.0**^{a}	**90.5**^{a}	**88.8**^{a}	97.3	96.5	94.8
TST Results	Not Toxic	Toxic	Toxic	Toxic	Toxic	Not Toxic	Not Toxic	Toxic	Not Toxic	Not Toxic	Not Toxic

Values in **bold** indicate a statistically significant decrease compared to the brine control as determined with the student's one tailed t-test.

Level of statistical significance: a - <0.05, b - <0.01, c - ≤0.001.

*Indicates the highest concentration possible to test was <100% effluent, due to the addition of hypersaline brine; Actual values tested are as follows: Ambient (83.1%), 106 (84.0%), 107 (78.2%), 108 (78.6%), 109 (74.8%), 110 (82.6%), 111 (76.3%), 112 (84.10%), 113 (84.3%), 114 (77.2%), 115 (87.0%)

DrEx Passive Samplers: DGT samplers were recovered from all ten DrEx units. Duplicate DGT samplers were analyzed for cadmium, copper, lead, and zinc. Post-evaluation of the zinc results indicated that there was contamination of the DGT samples for zinc, most likely either by the acid used in the digestion, or in the DGT resin itself. For this reason, the zinc results have a high degree of uncertainty. Labile copper concentrations represented on average about 54% of the dissolved fraction while labile zinc represented on average about 87% of the dissolved fraction. The reduction in the labile copper fraction is consistent with the observation of significantly higher DOC in the discharge water. However, there was no clear relationship between labile copper and zinc concentrations and the observed toxicity in the samples. Cadmium, nickel, and lead levels were all relatively low and uniform across the ten DrEx samples. SPME samplers were recovered from all ten DrEx units. SPME samplers were analyzed for PCBs, PAHs, and chlorinated pesticides. The short exposure time (roughly seven hours) associated with the deployment, and some malfunctions of the circulation pumps, impacted the utility of the data. The concentration of Performance Reference Compound (PRC) PCBs for the average of the blanks was greater than field exposed samples except for Drifters 113 and 114, which indicated either these pumps were not functioning, or the pumps did not increase the elimination rate of PRCs from the Polydimethylsiloxane (PDMS) for these DrEx units.

Overall, while still developmental, the passive sampler results indicated a potential for their application on these drifting exposure systems. The DGT samplers are better suited to the application because the exposure time scale is more in line with the standard DGT method. The SPME samplers have potential, but the application is not truly passive because it requires pumping, and more work is needed to better refine the method and improve the response time.

5.6.2 DPS and SeDep Demonstration Results

The DPS and SeDep demonstration included two events. The first event was conducted at the Oscar Pier site in Pearl Harbor during the period Mar 12 – Apr 26, 2016 and included application of both systems. The second event was conducted at the Waiau Generating Station site in Pearl Harbor and focused only on the DPS technology.

Primary data from the DPS deployments included the three-dimensional DPS trajectories, the bottom-detection locations, and onboard temperature and salinity. Position data from the surface float, and depth data from the drogue winch were combined to construct the three-dimensional trajectories. Bottom-detection locations were compiled from all of the drifter releases to develop an overall map of the deposition footprint linked to the outfall discharge location. This footprint was calculated using geostatistical mapping techniques to construct a footprint map for subsequent deployment of SeDep systems. Verification data for the DPS demonstration included sub-meter resolution GPS data and water depths collected at DPS locations over the course of the survey. Differences between the paired samples from the drifter and verification GPS data sets were analyzed to evaluate the accuracy of the DPS trajectory data. Reliability of the communications link was analyzed to determine the percent of time the communications link was maintained during the survey period. The survivability of the units was calculated as the percent of units that successfully completed the mission, accounting for units that were lost, disabled, malfunctioned, etc.

Primary data from the SeDep system included time series of sediment mass, sediment trap samples, and surface sediment samples from above the deposition sensor at the end of the deployment period. Time series data from the deposition sensor were averaged to one-hour intervals and plotted to visualize the time trend in deposition at each station. Sediment trap sample results were evaluated in the context of the time-series observations from the deposition sensors. Deposition mass in the traps was compared to the time-integrated results from the sensors. Chemistry results from the traps and surface sediment samples were used to estimate mass loading to the sediment bed via ongoing deposition. Verification data for the SeDep demonstration included deposition detection sensitivity, measurement reliability, system survivability, and ease of use. Detection sensitivity was analyzed from field measurements based on the variability measured during quiescent periods of the deployment when no storm events, ship movements, or other significant sediment transport processes were active. Evaluation of the pressure sensor response was also analyzed based on the placement of calibration mats on top of the sensors at the end of the deployment to check the response to a known loading. Survivability in the field was analyzed based on successful mission completion. Ease of use data were summarized based on diver interviews following the deployment and retrieval phases of the demonstration.

5.6.2.1 Mar 12-13, 2016 DPS Event – Oscar Pier

<u>Tides and Winds</u>: In the absence of strong freshwater discharges, the primary influences on the circulation in Pearl Harbor are tides and winds. The DPS survey at Oscar Pier was conducted during the period from Mar 12-13, 2016. Tide and wind conditions for the deployment period are shown in Figure 26 relative to the DPS release and tracking period. The tracking took place over a complete diurnal tide cycle with a tidal range of about 0.5 m which is typical for Pearl Harbor.

Wind conditions were also typical trade winds for the area with wind speeds ranging from about ten miles per hour (mph) during the night to about 20 mph during the day and generally blowing from the ENE direction. Release times for the DPS units started during a period of ebb flow, and continued through successive flood and ebb periods. There was no precipitation during the event.

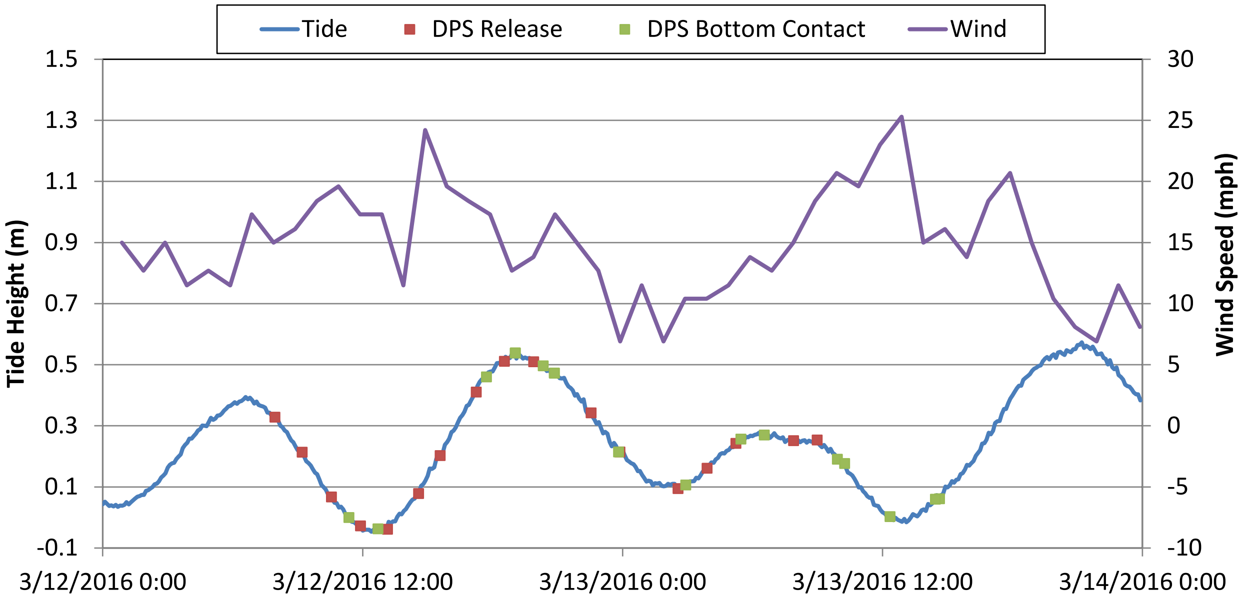

Figure 26. Tide and Wind Conditions for the Mar 12-13, 2016 DPS Survey Event.

DPS Tracking: During the Mar 12-13, 2016 event, a total of 17 DPS releases from the Oscar Pier area were successfully tracked to bottom contact. Three-dimensional trajectories for the DrEx systems showed a strong tidal dependence. During slack high water and early ebb tide conditions, DPS units generally stayed close to the shoreline and traveled southward toward the mouth of the harbor, often looping back and making bottom contact near the release point. During the latter ebb and slack low water conditions, DPS units tended to transit along the shoreline to the north and further into the harbor along the main channel. During the late flood condition, DPS units often traveled out into the channel away from the shoreline, and then traveled either north or south along the channel. The tidal influence on the DPS units led to strong spreading and dispersion for units released over the tidal cycle and a correspondingly large deposition footprint that was strongly strained to the north and south along the channel and the Oscar Pier shoreline area (Figure 27).

Settling Rate and Bottom Contact: The DPS units were programmed to simulate silt-sized particle transport with an effective settling rate of 34 mm/min. Results showed that all of the DPS units followed this rate closely. Bottom contact depths ranged from about 6.8 m for DPS1-1, to a high of 16.9 m for DPS9-1, with an average of 11.8 m. These results suggest that the DPS units can function effectively over the expected range of depths for harbor environments. Because the settling rates were uniform, bottom contact times varied as a function of the contact depth. The spatial distribution and footprint of bottom contacts are shown in Figure 28. Two qualitative footprint areas were defined including the footprint that encompassed only the bottom contact locations, and a broader footprint that encompassed the trajectories and the bottom contacts.

The first footprint is descriptive of the likely deposition area for silt-sized particles released from the outfall near Oscar Pier. The second footprint is representative of silt and large (faster settling) size particles based on the assumption that these particles would settle somewhere along the trajectory leading to the bottom contact location for silt.

Overall, the GPS tracking and bottom contact data collected using the DPS systems provided a clear visualization of the area of the harbor with connectivity to the outfall, the depth, spatial and time scales of the transport area, and the spatial location and size characteristics of the deposition footprint. These are all key aspects in understanding the complex nature and extent of the particle transport associated with discharge from a given outfall location.

DPS Sensor Data: Sensors mounted on the DPS units recorded temperature and salinity continuously during the Mar 12-13, 2016 survey event. Although the temperature and salinity data would be more relevant during an actual storm event, the primary purpose of the sensor measurements was to document conditions during the deployments and demonstrate that the system can accommodate sensors of this type. In addition, sensors such as transmissometers or optical backscatter sensors would also be useful during storm event deployments. For the non-storm deployments that were conducted, the sensors primarily provide background information on site conditions.

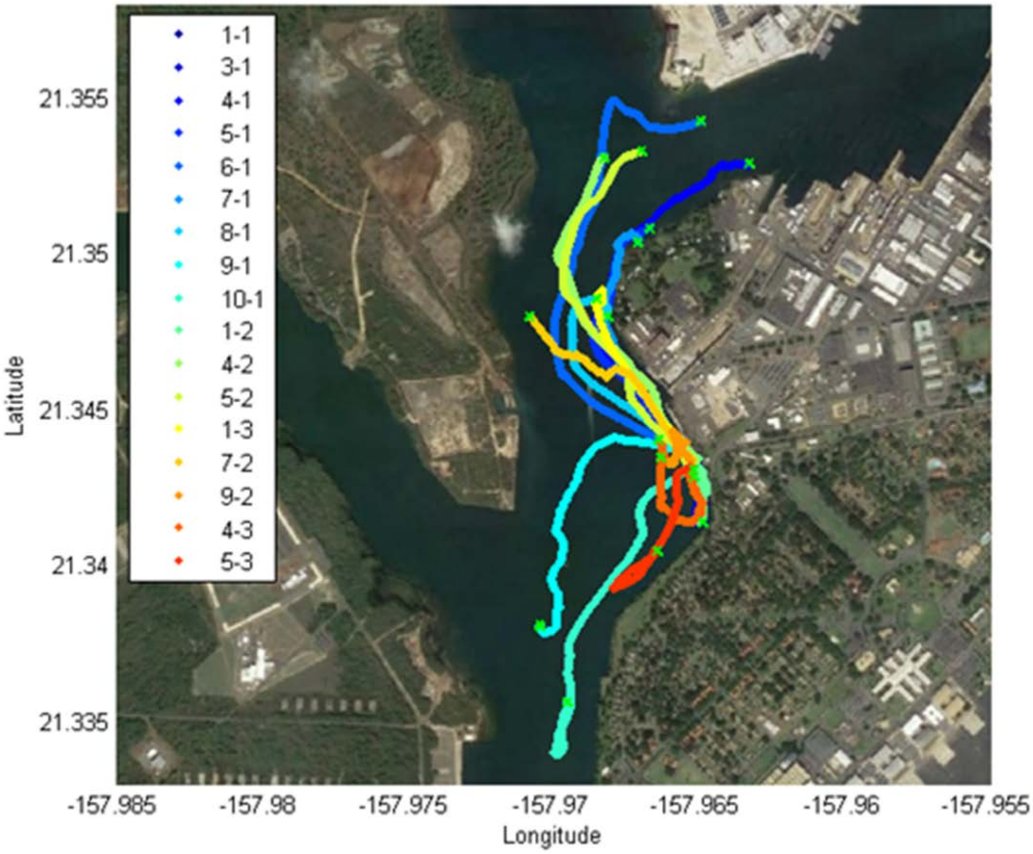

Figure 27. Complete DPS Trajectory Map Showing Individual Trajectories for the 17 DPS Units (colored lines) and Bottom Contact Locations (green x's).

Figure 28. Deposition Footprint with Connectivity to the Stormwater Discharge Outfall Near Oscar Pier. The Light Shaded Area Indicates the Area Encompassed by the Actual Bottom Contacts for the Target 34 mm/min (silt) Settling Rate Particles. The Darker Shaded Area Encompasses the Trajectories and Bottom Contacts and is Representative of the Potential Deposition of Particles Sinking at ≤34 mm/min (Silts and Sands). The Green x's Are the Actual Bottom Contact Locations.

5.6.2.2 Mar 15 – Apr 26, 2016 SeDep Event – Oscar Pier

Tides, Winds, and Precipitation: Environmental conditions including tides, winds, and precipitation have the potential to influence the rates and patterns of particle deposition at the Oscar Pier site. Tidal variations followed typical semi-diurnal and spring-neap patterns of variability. Tidal range varied from a low of about 0.4 m during neap tides, to a high of about 0.8 m during spring tides. Winds were generally from the northeast consistent with trade wind patterns for the area but varied in other directions during some portions of the event. Wind speed varied on a daily basis, with stronger winds during the day and weaker winds at night. Wind speed was generally in the range of 5-20 mph, but sustained periods of lower wind speeds also occurred, and these generally corresponded to periods of inconsistent trade winds or storms.

The goal for the SeDep deployment was to span sufficient time to capture multiple storm events discharging from the outfall near Oscar Pier. The precipitation record shows that two moderate storm events and several smaller events took place during the deployment period, totaling about 13 mm (Figure 29). This was more limited than would have been ideal, but provided some level of discharge to evaluate stormwater related deposition in the area. The primary events occurred on Mar 25, 2016 (Julian day 84; approximately 6.6 mm) and Apr 17, 2016 (Julian day 107; approximately 3.3 mm). The drainage area for the outfall is about 506000 meters squared (m^2) (125 acres) and extends inland about 1500 m. The land cover in the area is primarily impermeable and the land use is primarily industrial. Although the discharge from the outfall is not monitored, assuming an impermeable surface over the entire area, the discharge for the two storm events would have been on the order of 3340 meters cubed (m^3) and 1670 m^3, respectively. For the entire period, the rainfall total of 12.7 mm would have resulted in a total discharge of about 6430 m^3. Given typical stormwater particulate concentrations on the order of about 100 milligrams per liter (mg/L), this would translate to a total particulate load of about 643 kg discharged from the outfall over the monitoring period.

SeDep Sensor Data: Based on the DPS deposition footprint results from the Mar 12-13, 2016 event, ten SeDep units were deployed in Pearl Harbor for the period of Mar 15 – Apr 26, 2016. The deployments were focused in the nearfield area of the footprint with an additional unit deployed further into the harbor and further out toward the entrance to characterize the far field areas of the footprint (Figure 30). Deposition data were collected continuously over the 42-day period of the deployment, and the data were averaged to hourly readings.

Results for the SeDep deposition sensor data are shown in Figure 29. The SeDep results reflect direct measurements of cumulative deposition for in-water mass of sediment as calibrated against known weights placed on the pressure plates. The results indicated cumulative deposition ranging from a low of about 69 grams (g) at SeDep1 to a high of about 323 g at SeDep9. In general, SeDep units placed close to the outfall and to the south of the outfall showed lower deposition, while systems placed to the north of the outfall showed higher deposition. The deposition sensors placed closer to the outfall showed temporal patterns that appeared to be more closely correlated to stormwater discharge events. While all of the stations showed net deposition over the deployment period, some stations showed periods of erosion as well. This seemed to be more prevalent at the stations to the north of the outfall. Three of the SeDep units (3, 7, and 10) failed to work for the entire duration of the deployment due to an adhesive failure on the pressure plate that caused a loss in the pressure integrity of the system. Overall, the SeDep sensor systems provided a unique temporal quantification of cumulative sediment deposition under conditions that are representative of DoD harbors subject to stormwater and other sediment transport processes.

SeDep Sediment Trap Mass: As part of the integrated SeDep system, each station (Figure 30) included a sediment trap for the quantification of total deposited mass, and to determine the chemical characteristics of the depositing particles. Particles collected in the sediment traps over the 42-day deployment were separated from the water phase, weighed to determine wet weight, and sub-sampled for moisture content and chemistry analyses. Based on the wet weights and the moisture content measurements, the total deposited mass and deposition rate at each station were determined. The results show that total deposited mass ranged from a low of about 17.2 g at station SeDep1 to a high of 78.2 g at station SeDep9.

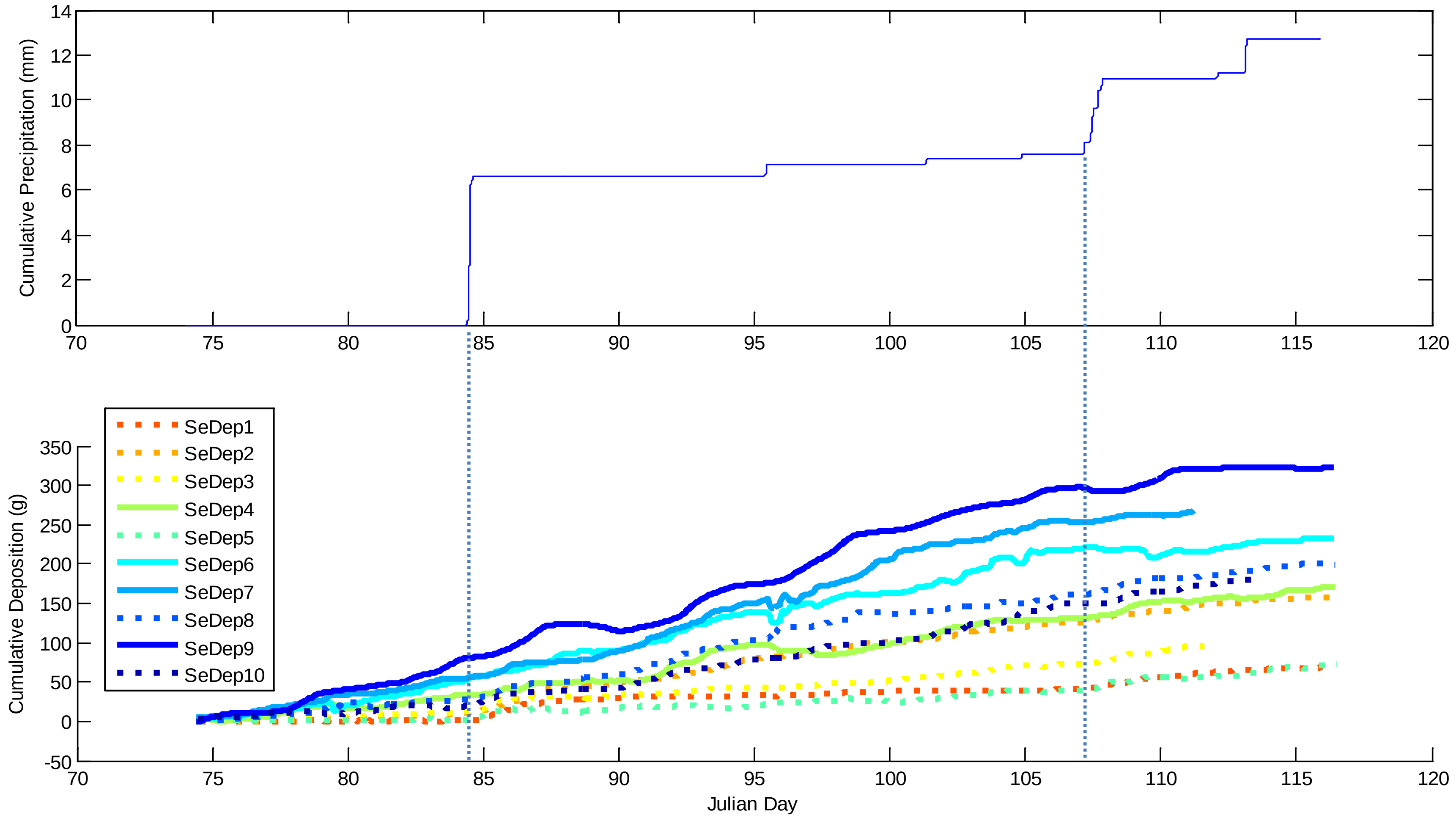

Figure 29. Cumulative Precipitation and Sediment Deposition for the SeDep Deployment Event in Pearl Harbor from Mar 15 – Apr 26, 2016 (Julian Day 74-116). Vertical Dotted Lines Indicate the Two Significant Precipitation Events During the Deployment. Solid SeDep Lines Are for Sensors That Were Placed to the North (Further into the Harbor) and Dashed Lines Are for Sensors that Were Near the Outfall or to the South (Further Toward the Harbor Entrance).

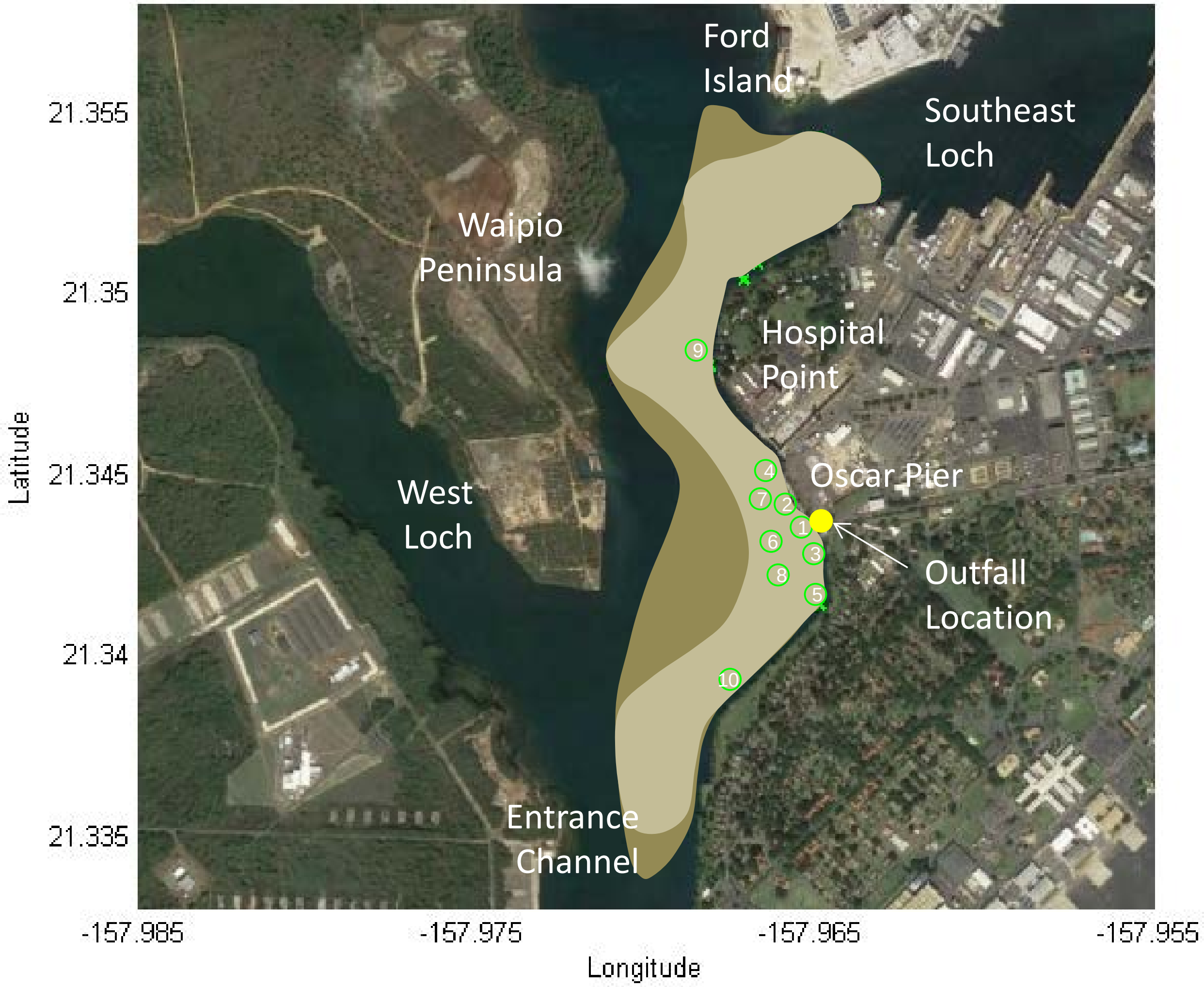

Figure 30. Location Map for the SeDep Systems in Pearl Harbor During the Mar 15 – Apr 26, 2016 Event.

Cumulative deposition measurements from the sediment traps were also used to calculate deposition rates based on the total deposition, the deployment duration, and the area of the sediment trap. These deposition rates ranged from a low of 0.82 grams per centimeter squared per year (g/cm^2/y) at SeDep1 to a high of 3.73 g/cm^2/y at SeDep9. These rates are generally consistent with rates measured by the SeDep sensors (Figure 30; $R^2 = 0.93$), as well as previously measured rates in the harbor (US Navy, 2015). Both measurements showed similar overall spatial patterns, with higher deposition rates to the north and offshore of the outfall, and lower deposition rates near the outfall and to the south. Station SeDep3 showed the largest difference between the sediment traps and the deposition sensors. Overall the sediment traps that were co-located with the SeDep sensors provided an effective means of collecting deposited sediments, and the deposition rates were consistent with expectations regarding the typical rates in Pearl Harbor.

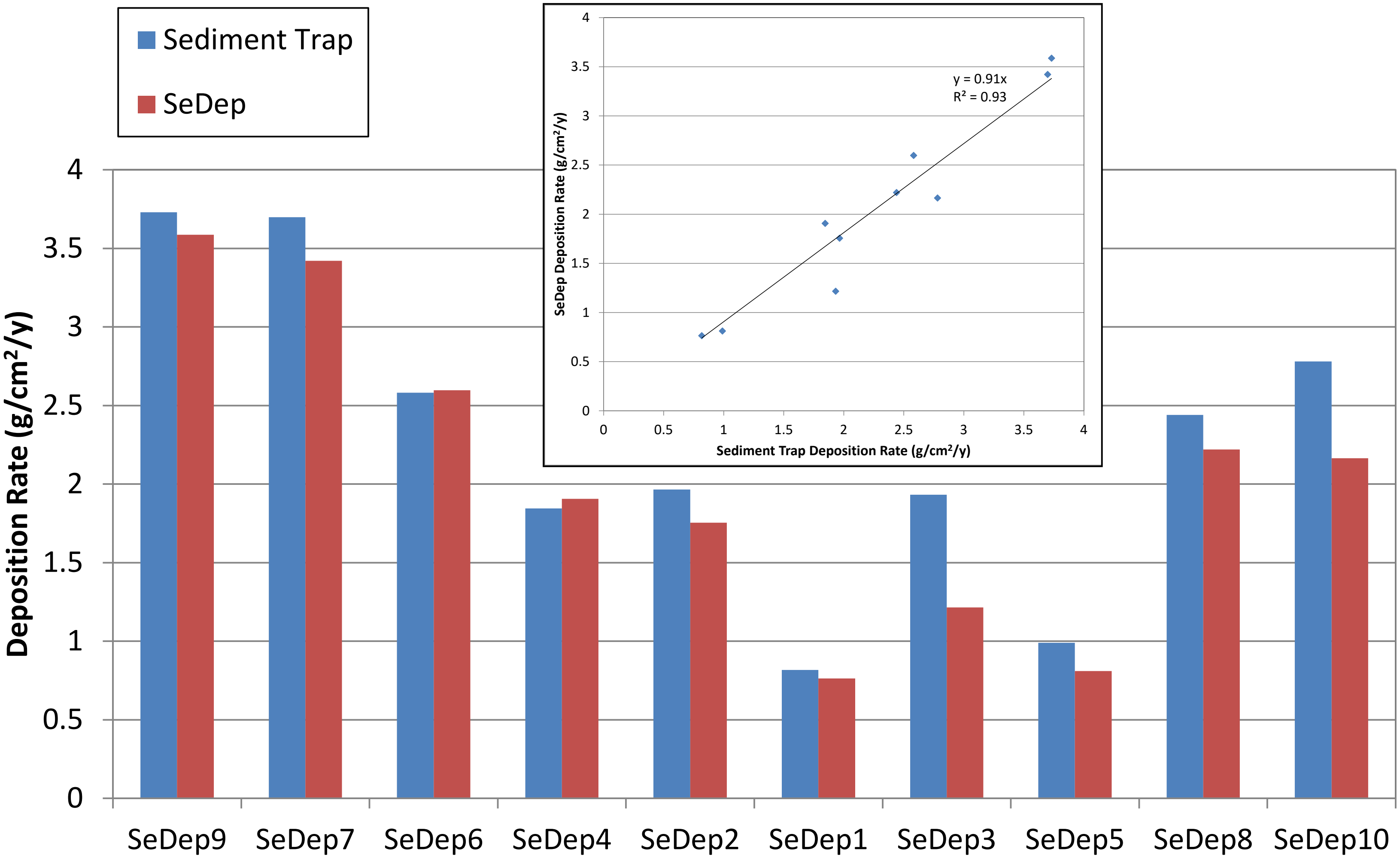

Figure 30. Comparison of Overall Deposition Rates Measured by the Sediment Traps and the SeDep Sensors. The Inset Plot Shows a Regression of the Deposition Rates Measured by the Two Methods ($R^2 = 0.93$; Slope = 0.91).

SeDep Sediment Trap and Surface Sediment Chemistry: Samples collected in the sediment traps were analyzed for a subset of chemicals that were determined based on the known risk drivers for the sediments in the vicinity of Oscar Pier. In addition, surface sediment samples from the top 2 cm of the sediment column were collected by divers directly adjacent to the sediment traps and SeDep sensors at the stations shown in Figure 30. For both sets of samples, analytes included TOC, mercury, copper, lead, and PCBs.

Depositing particles at three of the stations (SeDep3, SeDep5, and SeDep10) exceeded the site Preliminary Remediation Goal (PRG) for mercury (0.71 mg/kg), suggesting that there is still potential for recontamination of mercury in the area. Spatially, northern and offshore stations generally had lower concentrations while outfall and southern stations general had higher concentrations. Copper concentrations were generally below the PRG for copper (214 mg/kg) at all stations, indicating that copper input levels in the area are not likely to be driving recontamination. Lead concentrations followed similar patterns as copper and mercury and were generally below the PRG at all stations, indicating that lead input levels in the area are not likely to be driving recontamination. Concentrations of total PCBs in the sediment traps were also highest at the stations with lowest deposition rates, and particularly high at SeDep1 directly off the outfall (Figure 31). This was the only station with PCB trap concentrations that exceeded the PRG (170 μg/kg), suggesting that recontamination was only likely in close proximity to the outfall for PCBs.

Mercury levels in surface sediments were generally similar to or higher than sediment trap levels, suggesting that even though incoming particulate levels exceeded the PRGs in some areas, they are still exerting downward pressure on the surface sediment concentrations. Similarly, copper concentrations in surface sediments were generally similar to or higher than sediment trap levels, suggesting that incoming particulate levels are still exerting downward pressure on the surface sediment concentrations. Lead concentrations in surface sediments were also generally similar to or higher than sediment trap levels. As with metals, total PCB levels in surface sediments were generally similar to or higher than sediment trap levels, suggesting that incoming particulate levels are still exerting downward pressure on the surface sediment concentrations. A clear exception to this was at the outfall station SeDep1 where the sediment trap concentration significantly exceeded the surface sediment concentration (Figure 32). Spatially, highest concentrations in surface sediments were generally found in the vicinity of the outfall and to the south of the outfall, particularly at the furthest southern station SeDep10.

Overall, the sediment trap and surface sediment chemistry indicated incoming sediment particles generally had lower contaminant concentrations than surface sediments, indicating that they should tend to improve conditions over time. However, some chemicals including mercury and PCBs had particle input concentrations that still exceeded their respective PRGs. Spatial distributions of trap and surface sediments suggest the chemicals of concern may have different sources that are driving conditions at the site, with some chemicals showing gradients to the south (mercury and PCBs), some showing gradients to the north (copper), and some being fairly evenly distributed off the outfall (lead).

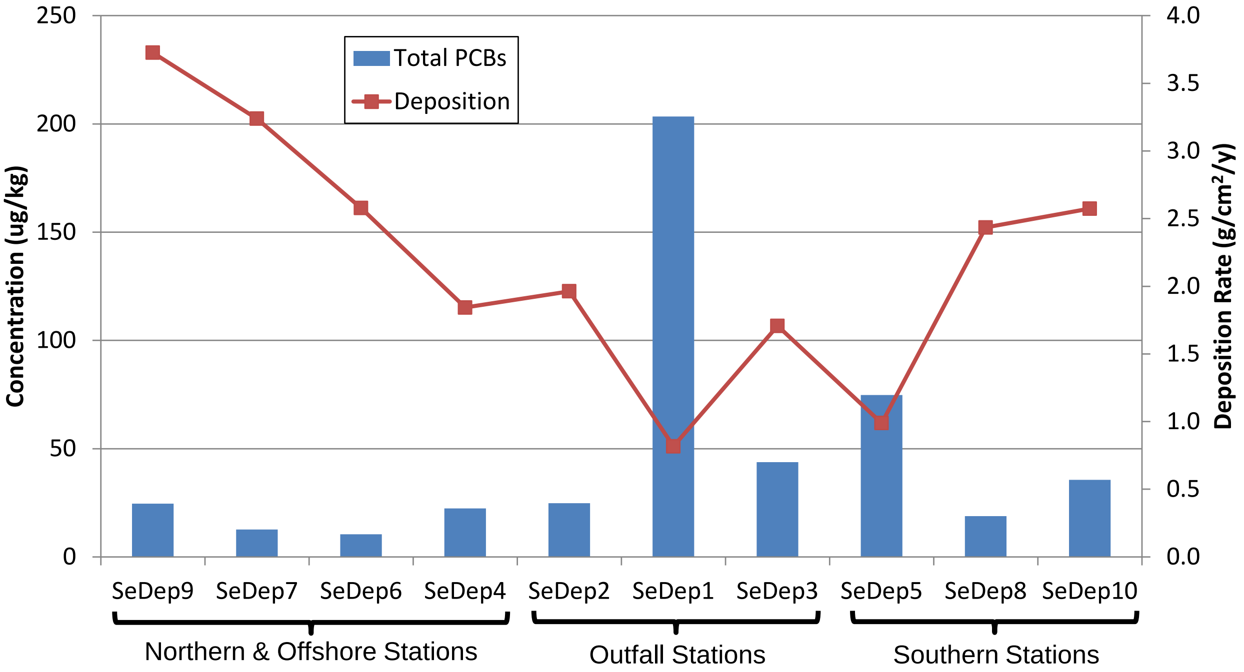

Figure 31. **Total PCB Concentrations in Deposited Sediments and Deposition Rates Based on the SeDep Sediment Traps.**

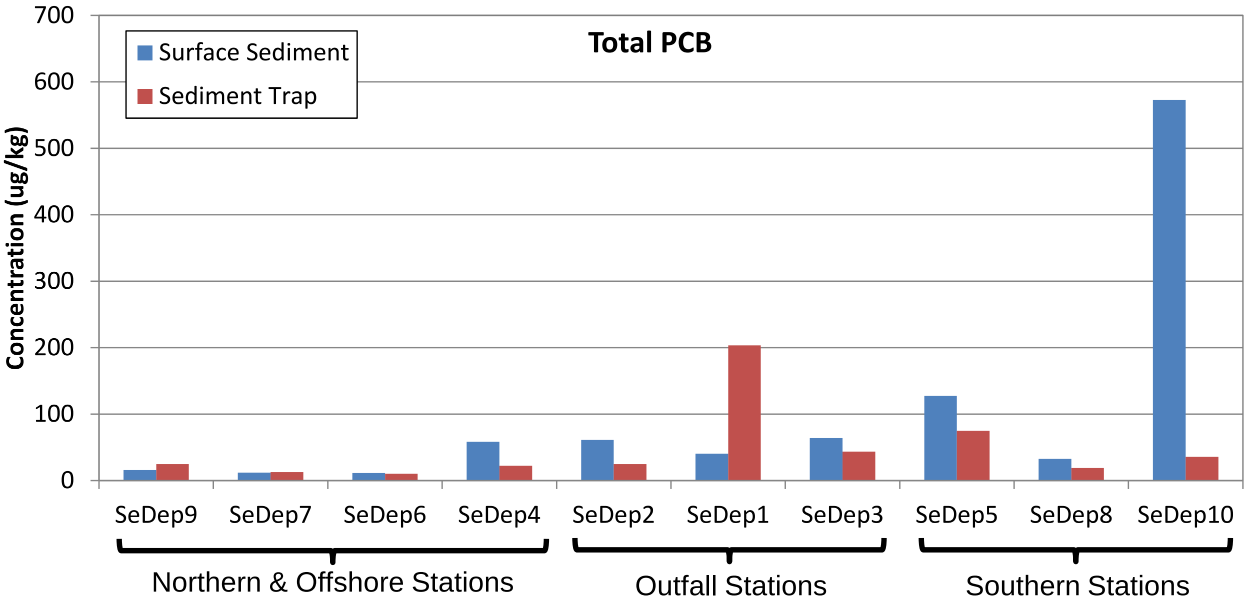

Figure 32. **Total PCB Concentrations in Surface Sediments and Sediment Traps at the SeDep Stations.**

5.6.2.3 Oct 28-29, 2016 DPS Event – Waiau

<u>Tides and Winds</u>: The DPS survey at Waiau was conducted during the period from Oct 28-29, 2016. The tracking took place over a complete diurnal tide cycle with a tidal range of about 0.7 m which is typical for Pearl Harbor. Wind conditions were characterized by relatively weak trade winds with wind speeds ranging from about 5 mph during the night to about 10-15 mph during the day and generally blowing from the ENE direction. Release times for the DPS units started during a period of flood flow, and continued through successive ebb and flood periods. There was no measurable precipitation at the Honolulu gage during the event, however there was precipitation observed at the site during the night of Oct 28, and likely precipitation in the watershed that fed some flow to the local streams in the area.

<u>DPS Tracking</u>: A total of 20 DPS units were released during the tidal period extending from 10/28/2016 09:00 – 10/29/2016 08:45. Two of the units malfunctioned and did not provide useful data. A total of 18 units successfully completed the full trajectory and bottom contact cycle. The DPS units were all released from approximately the same location off the suspected OWS discharge pipe location at a water depth of about 1.5 m. The releases occurred at 75-minute intervals with the exception of the two units that malfunctioned resulting in intervals of 150 minutes.

The first four DPS units (DPS1-1, DPS2-1, DPS3-1, and DPS4-1) followed a relatively similar trajectory, traveling S or SSW toward the deeper water channel area, and then turning W or WNW in the deeper water where they made bottom contact. The next six units (DPS5-1, DPS6-1, DPS7-1, DPS8-1, DPS1-2, and DPS3-2) also followed a relatively similar trajectory with the exception of DPS8-1. These units all generally traveled S for a short distance before making bottom contact in the shallow water prior to reaching the channel. DPS8-1 followed a similar trajectory but continued S to the channel, and then turned WNS before making bottom contact. The next three DPS units (DPS2-3, DPS4-2, and DPS5-2) followed similar trajectories, traveling initially to the S or SSE to the deeper water, and then turning W or WNW before making bottom contact. The subsequent four units (DPS7-2, DPS8-2, DPS6-3, and DPS3-3) had similar trajectories, first traveling SSE, and then turning SW before making bottom contact near the edge of the channel. The final DPS unit (DPS1-3) followed a similar pattern to DPS3-2, traveling S for a short distance before making bottom contact in the shallow water prior to reaching the channel. The complete map of trajectories and bottom contact locations is shown in Figure 33. Overall, the trajectories show a consistent pattern of southward travel toward the deeper water in the channel. For the DPS units that reached the channel, the trajectories generally turned toward the west. The overall average speed was 3.9 cm/s, the overall average distance traveled was about 672 m, and the overall average bottom contact depth was about 9.2 m.

<u>Settling Rate and Bottom Contact</u>: The DPS units were programmed to simulate silt-sized particle transport with an effective settling rate of 34 mm/min. Results showed that all of the DPS units followed this rate closely. Bottom contact depths ranged from about 4.5 m for DPS3-2, to a high of 11.6 m for DPS2-1, with an average of 9.2 m. These results suggest that the DPS units can function effectively over the expected range of depths for harbor environments. Because the settling rates were uniform, bottom contact times varied as a function of the contact depth. Settling times varied from a low of 2.2 hours for DPS3-2, to a high of 5.7 hours for DPS9-1, with an average of 4.5 hours.

The spatial distribution and footprint of bottom contacts are shown in Figure 33 and Figure 34 respectfully. Two qualitative footprint areas were defined including the footprint that encompassed only the bottom contact locations, and a broader footprint that encompassed the trajectories and the bottom contacts. The first footprint is descriptive of the likely deposition area for silt-sized particles released from the Waiau release point. The second footprint is representative of silt and large (faster settling) size particles based on the assumption that these particles would settle somewhere along the trajectory leading to the bottom contact location for silt.

Overall, the GPS tracking and bottom contact data collected using the DPS systems provided a clear visualization of the area of the harbor with connectivity to the outfall, the depth, spatial and time scales of the transport area, and the spatial location and size characteristics of the deposition footprint. These are all key aspects in understanding the complex nature and extent of the particle transport associated with discharge from a given outfall location.

<u>DPS Sensor Data</u>: Sensors mounted on the DPS units recorded temperature and salinity continuously during the Oct 28-29, 2016 survey event. Although the temperature and salinity data would be more relevant during an actual storm event, the primary purpose of the sensor measurements was to document conditions during the deployments and demonstrate that the system can accommodate sensors of this type. In addition, sensors such as transmissometers or optical backscatter sensors would also be useful during storm event deployments. For the non-storm deployments that were conducted, the sensors primarily provided background information on site conditions.

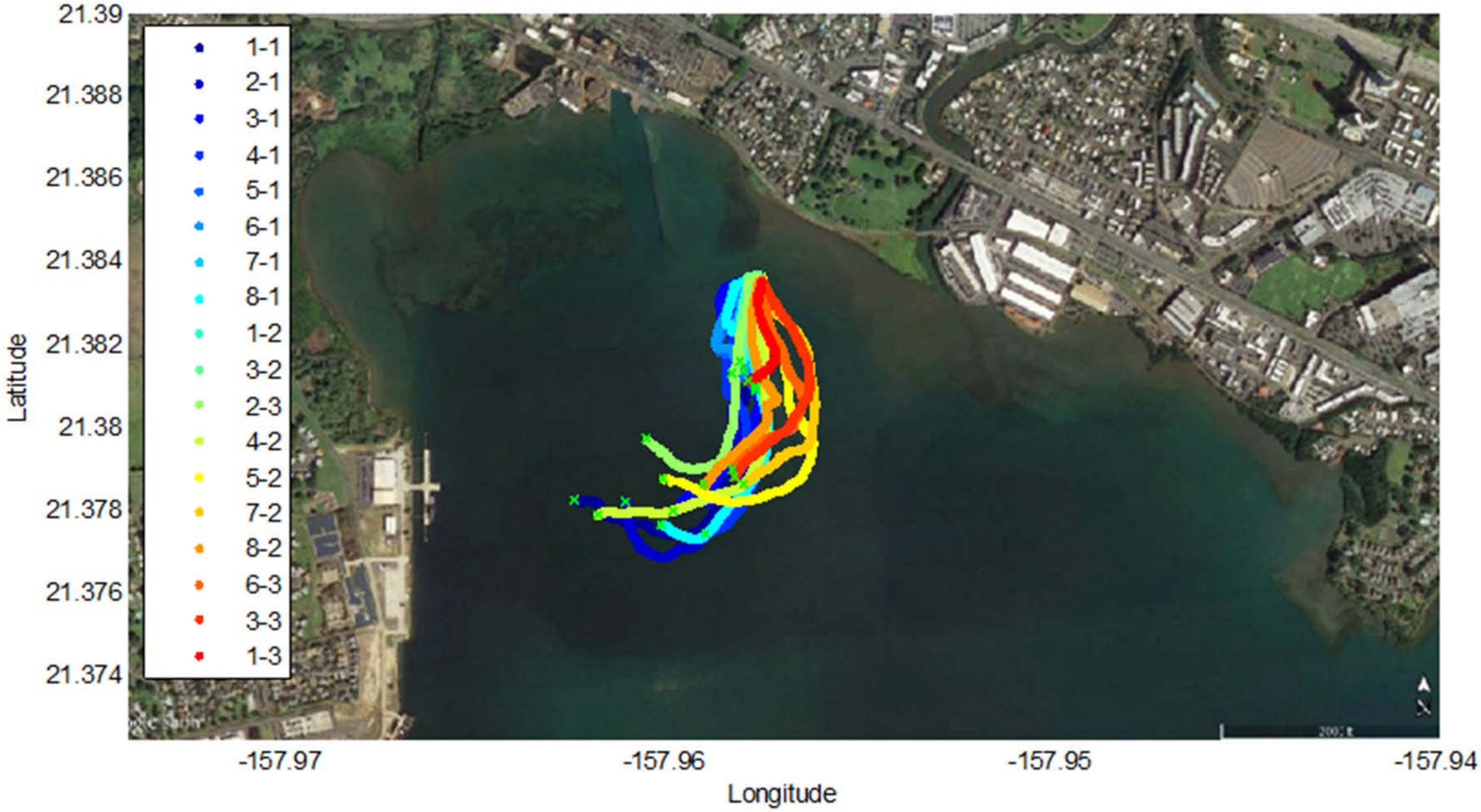

Figure 33. **Complete DPS Trajectory Map Showing Individual Trajectories for the 18 DPS Units (colored lines) and Bottom Contact Locations (green ×'s).**

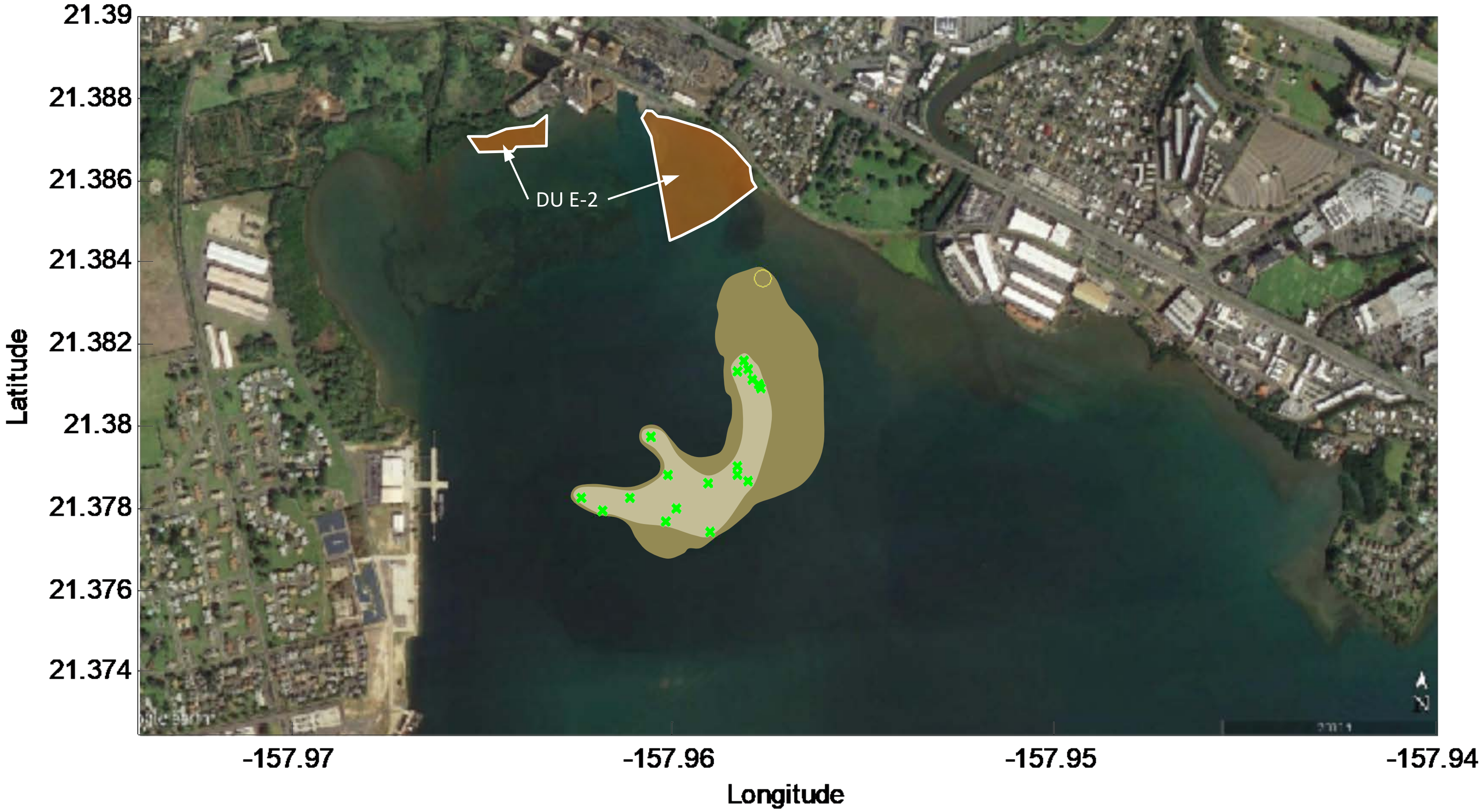

Figure 34. Deposition Footprint with Connectivity to the Suspected OWS Discharge Outfall Near Waiau. The Light Shaded Area Indicates the Area Encompassed by the Actual Bottom Contacts for the Target 34 mm/min (silt) Settling Rate Particles. The Darker Shaded Area Encompasses the Trajectories and Bottom Contacts and is Representative of the Potential Deposition of Particles Sinking at ≥34 mm/min (silts and sands). The Green ×'s Are the Actual Bottom Contact Locations.

6.0 PERFORMANCE ASSESSMENT

Performance analysis focused on the ability of the systems to provide improved exposure, transport, and fate assessment for stormwater sources in a cost-effective manner. A key aspect of this performance was the ability to improve the understanding of the linkage between the ongoing sources and potential recontamination of sediment. This requires the ability to accurately track the trajectory of the plume and associated particle-bound contaminants, and establish reliable measures of event-based depositional footprints. Performance was measured against the performance criteria established in the demonstration plan. Performance objectives and metrics for the three technologies are summarized in Table 1 – Table 2 respectively.

6.1 DRIFTING EXPOSURE SYSTEM

For the DrEx system, a series of quantitative and qualitative performance objectives were established. Quantitative objectives focused on tracking accuracy, communications reliability, water sampler operation, and system survivability under field conditions. The primary qualitative performance objective for the DrEx was that the drifters reliably track the surface plume of a stormwater discharge release.

6.2 DRIFTING PARTICLE SIMULATOR

For the DPS system, a series of quantitative and qualitative performance objectives were established similar to the DrEx but adapted to the particle tracking capability of the system. Quantitative objectives focused on tracking accuracy, communications reliability, settling rate performance, and system survivability under field conditions. The primary qualitative performance object for the DPS is that the drifters reliably track the particle plume of a stormwater discharge release.

6.3 SEDIMENT DEPOSITION DETECTOR

For the SeDep system, a series of quantitative and qualitative performance objectives were established. Quantitative objectives focused on deposition detection sensitivity, measurement reliability, and system survivability under field conditions. The primary qualitative performance objective for the SeDep is that the system be reasonably easy to install and use in the field.

6.4 QUANTITATIVE PERFORMANCE OBJECTIVES – DRIFTING EXPOSURE SYSTEM

6.4.1 Tracking Accuracy

The goal of this performance objective was to demonstrate the tracking accuracy was <5 m for >90% of the deployment period provided that the SBAS differential system was active. The data were interpreted by first determining if the drifter status indicated a differential GPS fix, and then time-matching the data from the DrEx GPS and the verification GPS. Position differences were then calculated for each verification point. A difference histogram was then developed and the position difference at the 90th percentile of the histogram was used to compare to the performance objective. The results are summarized in Table 8.

Results based on the Trimble GeoXT GPS measurements showed 90th percentile differences of 4.9 m and 6.4 m for the Jan 5-6, 2016 event and Feb 1, 2016 event, respectively. Results from the BadElf Global Navigation Satellite System (GNSS) GPS measurements showed 90th percentile differences ranging from 5.4-5.5 m for the Jan 5-6, 2016 event, and 5.0-5.6 m for the Feb 1, 2016 event. While these values and ranges generally slightly exceeded the performance objective, the objective was considered to be met because the results were generally both very consistent and also very close to the objective. The 5 m objective was originally chosen on the basis that this was an approximate level at which the drifter tracking accuracy would be suitable for small-scale plume tracking around outfalls and urban embayment's. The ranges of tracking accuracy measured during the survey events appears to consistently be adequate to achieve this original objective.

6.4.2 Communications Reliability

The goal of this performance objective was to demonstrate reliable position data transmitted for >90% of the deployment period. The data were interpreted by determining the total number of possible data transmissions at the specified data transmission interval for each deployment. The actual number of data transmissions was then determined from the final data files that were downloaded from the server. The transmission success rate was then calculated as the actual transmissions divided by the possible transmissions for comparison to the performance objective. To accommodate typical variability in the transmission time, the transmission was considered to be successful if the period between transmissions was less than twice the specified transmission period.

Results for communications reliability were evaluated for each of the two survey events (Table 9). During the Jan 5-6, 2016 event, communications reliability ranged from a low of 59% to a high of 94%, with an overall average of 81%. During the Feb 1, 2016 event, reliability ranged from a low of 34% to a high of 100% with an overall average of 77%. While these levels fall somewhat short of the performance goal, experience during the events indicated that the communications reliability was generally sufficient to provide adequate information on the locations of the drifters throughout the deployments, as well as providing accurate information on the location for the retrieval. In general, drifters with low communications reliability had often become trapped near the pier structures, or between a ship and the pier, and thus satellite communications were hampered by interfering structures. Overall, it appears that a realistic expectation for communications reliability under these types of conditions is in the range of 80%, and that performance in this range should be adequate to support the requirements of the system.

6.4.3 Water Sampler Operation

The goal of this performance objective was to demonstrate reliable composite sample with total volume within 10% of the user specified target. The data were interpreted by calculating the cumulative pumping volume based on the DrEx recorded data, and the total volume based on the pre- and post-deployment weights. The difference between these volumes was then divided by the actual volume to determine the percent difference, and this was compared to the performance objective.

Results for water sampler operations were evaluated for each of the two survey events (Table 10). For the Jan 5-6, 2016 event, percent differences between the pump estimated volume and the measured volume ranged from a low of 14% to a high of 100% with an overall average of 41%. Large differences were primarily attributable to leaks that developed in the sampling bags after retrieval of the drifters. These leaks resulted in water loss prior to the weighing of the bags for the final volume determinations. In addition, one of the bags inadvertently became disconnected from the sampling tube and so no volume flowed into the bag. Considering only the units that were operational and had no leaks, the percent difference had an average of 14%. For the Feb 1, 2016 event, percent differences ranged from a low of 1% to a high of 91% with an overall average of 20%. Prior to this event, outer sleeves were added to protect and support the sampling bags. Only one sampling bag developed a leak during this event (DrEx 109). Eliminating this unit from the analysis, the average percent difference was found to be 12%. In general, for operational units with no leaks, the performance of the sampling system provided good agreement with the post-survey volume measurements within the range of about 12-14%. While this is slightly higher than the 10% target, it is still adequate to achieve the sampling requirements for the system.

6.4.4 System Survivability

The goal of this performance objective was to demonstrate system survivability >80% under field conditions. Two different levels of survivability were evaluated including systems that were successfully retrieved but had significant damage (repair >50% of the system value), and systems that were completely lost or suffered complete loss damage (repair >100% of the system value). The difference between the number of deployed systems and the number of successful systems was divided by the number of deployed systems to calculate the success rate. The success rate was then compared to the performance objective.

Results for system survivability were evaluated for both survey events. Results are summarized in Table 11. For the Jan 5-6, 2016 event, no drifters were lost or sustained major damage. One drifter (109) failed due to a faulty electronic mounting bracket that caused the magnetic switch to deactivate and shutdown the system. This only required a minor repair. For the Feb 1, 2016 event, no drifters were lost or sustained major damage. One drifter (112) lost its conductivity/temperature (C/T) sensor. The same drifter also had some saltwater flooding to the pump housing for the water sampler. The total damage was estimated to be less than 25% of the drifter value. Overall, the performance objective for system survivability was met because no drifters were lost or sustained major damage.

Table 8. Summary of Results for DrEx Tracking Accuracy.

Survey Event	Trimble GeoXT		BadElf GNSS Surveyor	
	Drifter	90th Percentile Delta (m)	Drifter	90th Percentile Delta (m)
Jan 5-6, 2016	All	4.9	107	5.5
			110	5.4
			113	5.4
Feb 1, 2016	All	6.4	106	5.1
			107	5.5
			108	5.6
			112	5.4
			113	5.0

Table 9. Summary of Results for DrEx Communications Reliability.

Jan 5-6, 2016 Event		Feb 1, 2016 Event	
Drifter	Comms Reliability (%)	Drifter	Comms Reliability (%)
106	94%	106	100%
107	94%	107	96%
108	85%	108	97%
109	NA	109	86%
110	79%	110	70%
111	59%	111	48%
112	76%	112	34%
113	66%	113	81%
114	84%	114	75%
115	91%	115	86%
Average	81%	Average	77%

Table 10. Summary of Results for the DrEx Water Sampler Operation.

Jan 5-6, 2016 Event				Feb 1, 2016 Event			
Drifter	Pump Volume (ml)	Measured Volume (ml)	Percent Difference	Drifter	Pump Volume (ml)	Measured Volume (ml)	Percent Difference
106[a]	5002	3750	25%	106	3346	3050	9%
107[a]	5001	2708	46%	107	2932	2838	3%
108	5002	4318	14%	108	2777	2994	8%
109[b]	NA	NA	NA	109[a]	3180	302	91%
110[a]	5002	2846	43%	110	3148	3190	1%
111[a,d]	4502	2602	42%	111[d]	2781	3044	9%
112[a]	5001	3789	24%	112	3939	4027	2%
113	5001	4239	15%	113	3047	2310	24%
114[a]	5002	2038	59%	114	3626	2927	19%
115[c]	5002	0	100%	115	4166	2862	31%
Average			41%	Average			20%
Average of intact/operational			14%	Average of intact/operational			12%

a. Sample bag leaked following retrieval.

b. Drifter was non-operational.

c. Sampling bag was disconnected from sampler.

d. Sampler was inadvertently programmed for 4500 ml instead of 5000 ml.

Table 11. Summary of Results for DrEx System Survivability.

Jan 5-6, 2016 Event				
Drifter	Minor Damage (<50%)	Major Damage (>50%)	Lost (Y/N)	Note
106	N	N	N	
107	N	N	N	
108	N	N	N	
109	Y	N	N	Faulty electronics mounting bracket
110	N	N	N	
111	N	N	N	
112	N	N	N	
113	N	N	N	
114	N	N	N	
115	N	N	N	
Percent of Total	10%	0%	0%	
Feb 1, 2016 Event				
Drifter	Minor Damage (<50%)	Major Damage (>50%)	Lost	Note
106	N	N	N	
107	N	N	N	
108	N	N	N	
109	N	N	N	
110	N	N	N	
111	N	N	N	
112	Y	N	N	Lost C/T sensor; Pump flooded
113	N	N	N	
114	N	N	N	
115	N	N	N	
Percent of Total	10%	0%	0%	

6.5 QUALITATIVE PERFORMANCE OBJECTIVES – DRIFTING EXPOSURE SYSTEM

6.5.1 Surface Plume Tracking Effectiveness

The goal of this qualitative performance objective was to demonstrate the DrEx units generally tracked the stormwater plume based on the onboard salinity and temperature signature being consistent with plume characteristics. The data were interpreted based on best professional judgement to determine the extent to which the DrEx units appeared to track the surface plume of the stormwater following discharge.

For the Jan 5-6, 2016 event, plume tracking was evaluated based on the onboard sensors and vertical profiles collected along axial transects through the plume at three different time points during the storm. Analysis focused on the salinity data because it provided the clearest indicator of the stormwater plume. Onboard sensor data were available for all ten drifters (including 109 which did not record position data). Salinity data from the onboard sensors indicated that the drifters generally stayed within the plume. Values were generally low and then rose within the first hour of transport. Values were then stabilized for the drifters that traveled to the next pier area to the south. For the drifters that stayed within the Paleta Creek pier area, the salinities tended to drop again as the drifters re-entered the area of the creek mouth. These variations were explained by the plume dynamics and tidal influences. The vertical profile transects also indicated the drifters generally stayed within the plume.

For the Feb 1, 2016 event, plume tracking was evaluated based on the onboard sensors and surface water mapping conducted at one point in time during the storm event. Analysis focused on the salinity data because it provided the clearest indicator of the stormwater plume. Onboard sensor data were available for nine out of ten drifters (drifter 112 sensor was lost). Salinity data from the onboard sensors indicated that the drifters generally stayed within the plume. Values were generally low and then rose gradually over the first 1-3 hours of transport. Values then stabilized for several of the drifters, but showed variability. These variations were explained by the plume dynamics and tidal influences. The surface water mapping transects also indicated the drifters generally stayed within the plume (Figure 35).

Overall, the performance evaluation for the surface plume tracking effectiveness indicated that the success criteria were met. Multiple lines of evidence during multiple storms of different magnitudes consistently showed that the drifters stayed within the stormwater plume.

Figure 35. **DrEx Drifter Locations Relative to the Stormwater Plume Surface Salinity as Mapped During the Feb 1, 2016 Storm Event.**

6.6 QUANTITATIVE PERFORMANCE OBJECTIVES – DRIFTING PARTICLE SIMULATOR

6.6.1 Tracking Accuracy

The goal of this performance objective was to demonstrate the tracking accuracy was <5 m for >90% of the deployment period. The data were interpreted by first time-matching the data from the DrEx GPS and the verification GPS. Position differences were then calculated for each verification point. A difference histogram was then developed and the position difference at the 90th percentile of the histogram was used to compare to the performance objective.

For the Mar12-13, 2016 event at Oscar pier, a total of 62 verification measurements were collected with the Trimble GeoXT. The 90th percentile difference in the position between the DPS and the Trimble was 3.4 m. For the Oct 28-29, 2016 event at Waiau, a total of 28 verification measurements were collected with the Trimble GeoXT. The 90th percentile difference in the position between the DPS and the Trimble was 4.8 m. The results indicate the success criteria for the DPS tracking accuracy performance objective was met. Results are summarized in Table 12.

6.6.2 Communications Reliability

The goal of this performance objective was to demonstrate reliable position data was transmitted for >90% of the deployment period. The data were interpreted by determining the total number of possible data transmissions at the specified data transmission interval for each deployment. The actual number of data transmissions was then determined from the final data files that were downloaded from the server. The transmission success rate was then calculated as the actual transmissions divided by the possible transmissions for comparison to the performance objective. Results for communications reliability are shown in Table 13. For both DPS survey events, the communications reliability averaged 100%. Thus, the success criteria for this performance objective was met.

6.6.3 Settling Rate

The goal of this performance objective was to demonstrate accurate settling rates within 10% of the target rate. The actual settling rate was calculated from the DPS micro winch pressure sensor as the slope of the time versus depth relationship prior to the unit making bottom contact. The percent difference from the target was then calculated by calculating the difference between the two rates, dividing by the target rate, and multiplying by 100%.

Results for the settling rate measurements are shown in Table 14. The target settling rate for both survey events was 34 mm/min. For both events, the average percent difference from the target settling rate was less than or equal to 0.1%. Thus, the success criteria for the settling rate performance objective was met.

6.6.4 System Survivability

The goal of this performance objective was to demonstrate system survivability >80% under field conditions. Two different levels of survivability were evaluated including systems that were successfully retrieved but had significant damage (repair >50% of the system value), and systems that were completely lost or suffered complete loss damage (repair >100% of the system value).

The difference between the number of deployed systems and the number of successful systems was divided by the number of deployed systems to calculate the success rate. The success rate was then compared to the performance objective.

Results for system survivability were evaluated for both the Mar 12-13, 2016 and Oct 28-29, 2016 events (Table 15 and Table 16, respectfully). For the Mar 12-13, 2016 event, no DPS units were lost, and one DPS unit sustained major damage. The damaged unit (DPS 3) resulted from an operator error associated with failing to replace the vent plug on the winch. This resulted in flooding of the winch electronics, requiring a complete rebuild of the winch. Thus, system survivability for the Mar 12-13, 2016 event was 90%. For the Oct 28-29, 2016 event, no drifters were lost or sustained major or minor damage. Thus, system survivability for this event was 100%. Overall, the performance objective for system survivability was met.

Table 12. Summary of Results for DPS Tracking Accuracy.

Survey Event	Trimble GeoXT	
	DPS	90th Percentile Delta (m)
Mar 12-13, 2016	All	3.4
Oct 28-29, 2016	All	4.8

Table 13. Summary of Results for DPS Communications Reliability.

Mar 12-13, 2016 Event		Oct 28-29, 2016 Event	
DPS	Comms Reliability (%)	DPS	Comms Reliability (%)
DPS1-1	100%	DPS1-1	100%
DPS1-2	100%	DPS1-2	100%
DPS1-3	100%	DPS1-3	100%
DPS3-1	100%	DPS2-1	100%
DPS4-1	99%	DPS2-3	100%
DPS4-2	100%	DPS3-1	100%
DPS4-3	100%	DPS3-2	100%
DPS5-1	100%	DPS3-3	100%
DPS5-2	100%	DPS4-1	100%
DPS5-3	100%	DPS4-2	100%
DPS6-1	100%	DPS5-1	100%
DPS7-1	100%	DPS5-2	100%
DPS7-2	100%	DPS6-1	100%
DPS8-1[a]	100%	DPS6-3	100%
DPS9-1	100%	DPS7-1	100%
DPS9-2	100%	DPS7-2	100%
DPS10-1	100%	DPS8-1	100%
		DPS8-2	100%
Average	100%	Average	100%

a. Communications with DPS8-1 were lost when the float went under water at bottom contact time

Table 14. Summary of Results for DPS Settling Rate.

Mar 12-13, 2016 Event		Oct 28-29, 2016 Event	
DPS	Settling Rate (% Diff)[a]	DPS	Settling Rate (% Diff)[a]
DPS1-1	0.0%	DPS1-1	0.0%
DPS1-2	0.0%	DPS1-2	0.0%
DPS1-3	0.0%	DPS1-3	0.0%
DPS3-1	0.0%	DPS2-1	0.1%
DPS4-1	0.0%	DPS2-3	0.0%
DPS4-2	0.0%	DPS3-1	0.0%
DPS4-3	0.0%	DPS3-2	0.0%
DPS5-1	0.0%	DPS3-3	0.0%
DPS5-2	0.0%	DPS4-1	0.0%
DPS5-3	0.0%	DPS4-2	0.0%
DPS6-1	0.0%	DPS5-1	0.0%
DPS7-1	0.0%	DPS5-2	0.0%
DPS7-2	0.0%	DPS6-1	0.0%
DPS8-1	0.0%	DPS6-3	0.0%
DPS9-1	0.0%	DPS7-1	0.0%
DPS9-2	0.0%	DPS7-2	0.0%
DPS10-1	0.0%	DPS8-1	0.0%
		DPS8-2	0.0%
Average	0.0%	Average	0.0%

a. Settling rate calculated as percent difference from target rate of 34 mm/min.

Table 15. Summary of Results for DPS System Survivability During the Mar 12-13, 2016 Event.

Mar 12-13, 2016 Event				
DPS Unit	Minor Damage (<50%)	Major Damage (>50%)	Lost (Y/N)	Note
DPS1	N	N	N	
DPS2	N	N	N	Not used
DPS3	N	Y	N	DPS winch flooded due to operator error
DPS4	N	N	N	
DPS5	N	N	N	
DPS6	N	N	N	
DPS7	N	N	N	
DPS8	N	N	N	
DPS9	N	N	N	
DPS10	N	N	N	
Percent of Total	0%	10%	0%	

Table 16. Summary of Results for DPS System Survivability During the Oct 28-29, 2016 Event.

Oct 28-29, 2016 Event				
DPS Unit	Minor Damage (<50%)	Major Damage (>50%)	Lost	Note
DPS1	N	N	N	
DPS2	N	N	N	
DPS3	N	N	N	
DPS4	N	N	N	
DPS5	N	N	N	
DPS6	N	N	N	
DPS7	N	N	N	
DPS8	N	N	N	
DPS9	N	N	N	Not used
DPS10	N	N	N	Not used
Percent of Total	0%	0%	0%	

6.7 QUALITATIVE PERFORMANCE OBJECTIVES – DRIFTING PARTICLE SIMULATOR SYSTEM

6.7.1 Particle Plume Tracking Effectiveness

The goal of this performance objective was to show that DPS units provide a qualitatively similar estimate of particle trajectories and deposition footprints as other available approaches. The hydrodynamic model CH3D or Environmental Fluid Dynamics Code (EFDC) was used to perform simulations for the two demonstrations (Mar 12-13, 2016 and Oct 28-29, 2016) and the resulting distributions were compared to the DPS results to determine if there was a qualitative agreement in the patterns of deposition resulting from the two methods.

Results for the comparison between the CH3D modeled deposition pattern and the DPS bottom contact locations are shown in Figure 36 for the Mar 12-13, 2016 event. The two methods show good agreement, with the DPS bottom contacts generally falling within the areas where the CH3D model showed the majority of deposition associated with silt particle release from Oscar Pier. While the model showed some deposition at distances beyond the observed bottom contact locations, the magnitude of deposition in those areas was generally quite low. Thus, the DPS units appear to be in good qualitative agreement with the modeled results. Similar results were found for the Oct 28-29, 2016 event (public release of the model results was not available at the time of publication of this report). On the basis of these qualitatively similar results, it can be concluded that the success criteria for this performance objective was met.

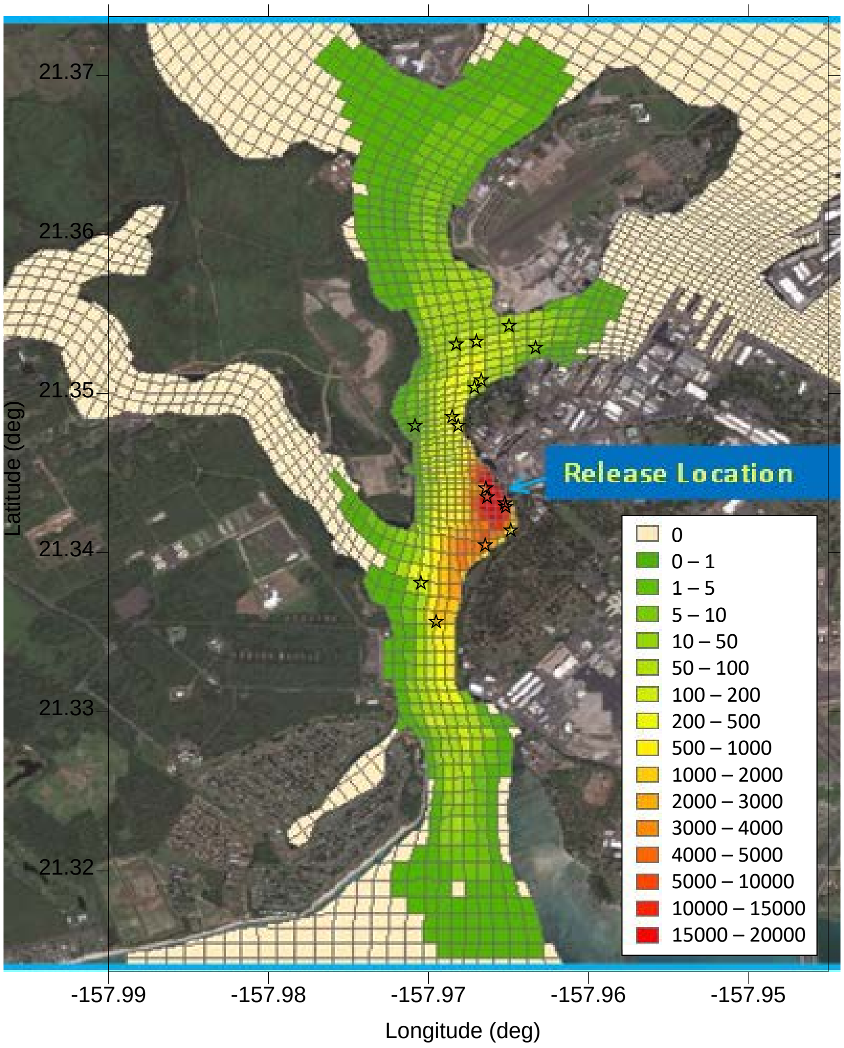

Figure 36. Comparison of Modeled Deposition and DPS Bottom Contact Locations for the Mar 12-13 Event at Oscar Pier. Model Deposition Units Are in Grams.

6.8 QUANTITATIVE PERFORMANCE OBJECTIVES – SEDIMENT DEPOSITION DETECTOR

6.8.1 Deposition Detection Sensitivity

The goal of this performance objective was to demonstrate the sensitivity of the SeDep was equivalent to <1 mm of sediment deposition. The controlled laboratory data were compiled and evaluated to determine the sensitivity of the system. For each unit, calibration curves were developed to convert voltage into added wet weight using the wet weights calculated for the rubber sheets based on their air weight and volume. Wet weights were also converted to approximate dry weight values for sediments using an estimated density of sediment particles of 2.65 g/cm^3, and subsequently to thicknesses using an estimated dry bulk density of 1.3 g/cm^3. Standard deviations for each weight measurement were then compiled for wet weight, dry weight, and thickness. Detection limits were then calculated, and the resulting detection limits were averaged across the measured weights and compared to the goal.

Results for the laboratory detection limit testing are shown in Table 17. Testing of the original SeDep systems using the Omega sensors showed minimum detection limits (MDLs) for thickness ranging from 0.008 to 0.014 mm with an overall average of 0.012 mm. This level of detection sensitivity was well below the success criteria. However, the sensors were found to have two issues during longer deployments in the field. First, the sensors had a tendency to drift, requiring weight tests before and after the deployment and detrending of the field results. Second, the sensors were found to corrode, and several units became inoperable shortly after the first long field deployment. Based on these findings, an improved sensor (Validyne) was identified, tested, and incorporated into the system. Time constraints on the project limited the full integration and application of these new sensors. However, initial lab and field testing indicated the primary issues with the original sensors were resolved. Table 17 shows lab sensitivity testing results for one of these units which gave comparable sensitivity to the original sensors while also providing much improved stability and corrosion resistance. Overall, the success criteria for this performance objective was met.

6.8.2 Measurement Reliability

The goal of this performance objective was to demonstrate reliable pressure data collected >90% of the deployment period. Data from the SeDep logger were first evaluated for data quality based on best professional judgement, and then compiled for each system. To determine the measurement reliability, the number of acceptable data values was then divided by the total number of data values for the deployment period. This value was then compared to the goal of reliable pressure data collected >90% of the deployment period.

Measurement reliability based on the field deployment in Pearl Harbor are summarized in Table 18. Reliability ranged from 87-100% for the ten units, with an overall average of 97%. Reliability < 100% occurred for three units due to failure of the adhesive that was used to secure the pressure plate membrane. These failures generally occurred near the end of the deployment. The glued polycarbonate membranes have since been replaced with soldered stainless-steel membranes to eliminate the problem. On the basis of these results, the success criteria for the measurement reliability performance objective was concluded to be met.

6.8.3 System Survivability

The goal of this performance objective was to demonstrate system survivability >80% under field conditions. Two different levels of survivability were evaluated including systems that were successfully retrieved but had significant damage (repair >50% of the system value), and systems that were completely lost or suffered complete loss damage (repair >100% of the system value). The difference between the number of deployed systems and the number of successful systems was divided by the number of deployed systems to calculate the success rate. The success rate was then compared to the performance objective.

Results for SeDep system survivability are summarized in Table 19. During and following the Pearl Harbor deployment, two issues occurred that impacted the system survivability performance. During the deployment period, the pressure plate membrane on three of the units (3, 7, and 10) failed, leading to a loss of pressure difference signal. This failure was considered minor damage because replacement of the membrane is a relatively small cost as a percentage of the entire system (about 10%). As previously mentioned, the glued polycarbonate membranes were replaced with soldered stainless-steel membranes so that this problem should not occur in the future. After recovery, the units were tested, and post-survey weight calibrations were performed successfully. However, about five weeks after the recovery, it was discovered that five of the pressure sensors (1, 3, 4, 6, and 9) had failed, apparently due to corrosion that had taken place inside of the sensing element. Based on these failures, combined with the sensor drift issue identified for the Omega sensors, the Omega sensors were replaced with an improved sensor from Validyne. To further reduce potential issues with corrosion, the new sensors were also fully sealed in polyurethane. Initial pier-side testing indicates these improvements have successfully addressed the survivability and stability issues identified during the Pearl Harbor deployment, although long-term deployments are still needed to verify the robustness of the new configuration. Overall, the survivability success metric was not met; however, the issues that were identified have been addressed.

Table 17. Summary of Results for the Original SeDep Deposition Detection Sensitivity.

SeDep Unit	MDL (mV)	MDL Wet Wt (g)	MDL Dry Wt (g)	MDL Thick (mm)
SeDep1	1.78	0.77	0.46	0.009
SeDep2	2.07	1.07	0.67	0.013
SeDep3	1.93	0.98	0.61	0.012
SeDep4	2.20	1.01	0.63	0.012
SeDep5	1.63	0.97	0.60	0.012
SeDep6	3.28	1.21	0.73	0.014
SeDep7	2.00	1.11	0.66	0.013
SeDep8	2.81	0.66	0.39	0.008
SeDep9	1.88	0.77	0.46	0.009
SeDep10	1.95	1.04	0.63	0.012
			Overall Average	0.012
SeDep1 Validyne	1.01	0.77	0.46	0.009

Table 18. Summary of Results for SeDep Measurement Reliability.

SeDep Unit	Acceptable Data Values	Total Data Values	Reliability (%)	Notes
SeDep1	1829103	1829103	100%	
SeDep2	1829380	1829380	100%	
SeDep3	1611960	1829760	88%	Failed pressure plate membrance
SeDep4	1830741	1830741	100%	
SeDep5	1830908	1830908	100%	
SeDep6	1828694	1828694	100%	
SeDep7	1595212	1834612	87%	Failed pressure plate membrance
SeDep8	1832391	1832391	100%	
SeDep9	1834567	1834567	100%	
SeDep10	1691203	1831603	92%	Failed pressure plate membrance
Overall Average			97%	

Table 19. Summary of Results for SeDep System Survivability.

SeDep Unit	Minor Damage (<50%)	Major Damage (>50%)	Lost (Y/N)	Note
SeDep1	N	Y	N	Sensor failure post deployment
SeDep2	N	N	N	
SeDep3	N	Y	N	Sensor failure post deployment; membrane failure
SeDep4	N	Y	N	Sensor failure post deployment
SeDep5	N	N	N	
SeDep6	N	Y	N	Sensor failure post deployment
SeDep7	Y	N	N	Membrane failure
SeDep8	N	N	N	
SeDep9	N	Y	N	Sensor failure post deployment
SeDep10	Y	N	N	Membrane failure
Percent of Total	20%	50%	0%	

6.9 QUALITATIVE PERFORMANCE OBJECTIVES – SEDIMENT DEPOSITION DETECTOR

6.9.1 Ease of Installation and Retrieval

The goal of this performance objective was to demonstrate the ease of installation and retrieval for the SeDep systems, and the ability to install or retrieve a typical system array within a reasonable time period of 1-2 days.

The ease of installation and retrieval was evaluated during the Pearl Harbor demonstration. During the deployment, time on station and the overall deployment rate were monitored. On-station times ranged from 5-30 minutes with an average of about 12 minutes. Including transit times for the boat, the overall deployment rate was about ten stations in four hours or 2.5 stations/hour. The divers reported the deployments were straightforward and the only difficulty encountered was deployment in an area containing coral rubble mixed with sediment made it difficult to properly embed the SeDep unit into the bottom. Retrieval of the systems was also uneventful. The overall retrieval rate was ten stations in less than three hours for a retrieval rate of about 3.3 stations/hour. Locating the units sometimes took the divers a couple of tries, but all ten units were successfully located and retrieved. Overall, the success criteria for the ease of installation and retrieval performance objective was met.

7.0 COST ASSESSMENT

The focus of the cost assessment element of the demonstration was to develop an understanding of the expected operational costs of the technologies. Considerations for the cost assessment including cost drivers, cost modeling, and the cost analysis are summarized in Sections 7.1, 7.2, and 7.3 respectfully.

7.1 COST DRIVERS

Cost drivers for the application of the technologies following implementation will largely be driven by capital equipment and maintenance costs, labor and overhead costs associated with the field work, logistics costs, consumables, analytical costs associated with the sampling elements, and labor and overhead costs associated with the data analysis and reporting. Based on knowledge of these cost elements, the overall costs of fielding and operating the technologies can be scaled depending on the specific nature and scope of the site and the project.

7.2 COST MODEL

A cost model was developed for each of the technologies to estimate rental rates that would support capitalization of the equipment. It is expected that capital costs would be amortized over a fairly large number of site evaluations before the purchase of new equipment would be required, and that these costs would be recouped through equipment rental fees passed on to the customer.

7.2.1 DrEx Cost Model

The cost model for the DrEx system included the DrEx units and the main ancillary supporting equipment including the field kit, a field computer, and a temperature and conductivity sensor. Capital costs were estimated based on the data compiled for the equipment costs (Chadwick et al., 2017). Future replacement costs were estimated assuming a 4% inflation rate. A range of rental rates were then estimated assuming a 10% annual maintenance rate, 3-15 uses (days) per year, and a 5-10-year service life. The model results indicate required rental rates ranging from a low of $58 per day for the high use and long service life scenario, to a high of $497 per day for the low use, short service life scenario. For cost analysis, an intermediate rate of $145 per day corresponding to six uses per year and a ten-year service life was selected.

7.2.2 DPS Cost Model

The cost model for the DPS system included the DPS units and the main ancillary supporting equipment including the field kit, a field computer, and a temperature and conductivity sensor. Capital costs were estimated based on the data compiled for the equipment costs (Chadwick et al., 2017). Future replacement costs were estimated assuming a 4% inflation rate. A range of rental rates were then estimated assuming a 10% annual maintenance rate, 3-15 uses (days) per year, and a 5-10-year service life. The model results indicate required rental rates ranging from a low of $93 per day for the high use and long service life scenario, to a high of $800 per day for the low use, short service life scenario. For cost analysis, an intermediate rate of $233 per day corresponding to six uses per year and a ten-year service life was selected.

7.2.3 SeDep Cost Model

The cost model for the SeDep system included the SeDep units and the main ancillary supporting equipment including the field kit, a field computer, and a temperature sensor. Capital costs were estimated based on the data compiled for the equipment costs (Chadwick et al., 2017). Future replacement costs were estimated assuming a 4% inflation rate. A range of rental rates were then estimated assuming a 10% annual maintenance rate, 30-150 uses (days) per year, and a 5-10-year service life. The model results indicate required rental rates ranging from a low of $3 per day for the high use and long service life scenario, to a high of $29 per day for the low use, short service life scenario. For cost analysis purposes, an intermediate rate of $14 per day corresponding to 60 uses per year and a five-year service life was selected.

7.3 COST ANALYSIS

A cost analysis for each of the technologies was performed based on the assumptions and models summarized in the previous sections. The cost analysis was performed for each of the technologies independently, however it should be recognized that in actual applications they may be combined in various configurations, and that there are likely to be cost efficiencies associated with this in terms of reductions in mobilization and logistical costs. For each system, a range of different scales of application was assessed to provide insight into the potential costs associated with implementation at different sites.

7.3.1 DrEx Cost Analysis

The cost analysis for the DrEx system focused on application scenarios in which the system is deployed at one or more stormwater outfalls and used for plume tracking and exposure measurements over short periods of time. Costs for three application scenarios were analyzed. The small-scale application assumed the release of five DrEx units during first flush at a single outfall and tracking for a period of 12 hours. The mid-scale scenario assumed the release of five DrEx units during first flush at each of two outfalls and tracking for a period of 12 hours. The large-scale scenario assumed the release of five DrEx units during first flush at each of five outfalls and tracking for a period of 12 hours. All scenarios assumed samples would be collected for each unit that was released and that samples would be analyzed for TSS, metals, and organics. All events included temperature and conductivity sensors as well.

Overall application costs ranged from a low of $42,089 for the small-scale application (one outfall) to $125,466 for the large-scale application (five outfalls). There is some efficiency of scale as the costs of large applications are lower than just a linear scaling based on the number of outfalls. This appears to result from improved efficiencies in the labor costs for most categories. A significant cost driver for scale up is the analytical costs associated with the DrEx composite sample analysis. Overall, the largest components of the application cost tend to be the field operating cost and materials costs (15-30%), followed by planning costs, then analysis and reporting costs (10-15%). An example cost analysis for the mid-scale application is shown in Table 20.

7.3.2 DPS Cost Analysis

The cost analysis for the DPS system focused on application scenarios in which the system is deployed at one or more stormwater outfalls and used for determining the associated deposition footprint that is connectivity with the outfall(s) over typical tidal or other relevant short-term periods of variability. Costs for three application scenarios were analyzed.

The small-scale application assumed the release of five DPS units at a single outfall location repeatedly through an entire 24-hour tidal cycle period. The mid-scale application assumed the release of five DPS units at each of two outfall locations repeatedly through an entire 24-hour tidal cycle period. The large-scale application assumed the release of five DPS units at each of five outfall locations repeatedly through an entire 24-hour tidal cycle period. All scenarios included temperature and conductivity sensors as well.

Overall application costs ranged from a low of $36,995 for the small-scale application (one outfall) to $115,935 for the large-scale application (five outfalls). There is some efficiency of scale as the costs of large applications are lower than just a linear scaling based on the number of outfalls. This appears to result from improved efficiencies in the labor costs for most categories. A significant cost driver for scale up is the equipment costs associated with the higher use of DPS units and their relatively high rental. Overall, the largest component of the application cost tends to be the field operations (25-30%), followed by planning costs, analysis and reporting costs, and equipment costs (10-20%). An example cost analysis for the mid-scale application is shown in Table 21.

7.3.3 SeDep Cost Analysis

The cost analysis for the SeDep system focused on application scenarios in which the system is deployed at one or more stormwater outfalls and used for determining the associated deposition rates, mass loading, and chemical loading associated with particle deposition in the area. Costs for three application scenarios were analyzed. The small-scale application assumed the deployment and retrieval of five SeDep units at a single outfall location over a 30-day period. The mid-scale application assumed the deployment and retrieval of five SeDep units at each of two outfall locations over a 30-day period. The large-scale application assumed the deployment and retrieval of five SeDep units at each of five outfall locations over a 30-day period. All scenarios included sediment trap samples, surface sediment samples, and temperature sensors.

Overall application costs ranged from a low of $58,422 for the small-scale application (one outfall) to $211,909 for the large-scale application (five outfalls). Overall, the largest component of the application cost tends to be the field operating cost (30-35%), followed by material costs (20-25%). The relatively high field costs are driven by requirements for diver deployment and recovery of the equipment, while the material costs are driven primarily by analytical costs for the sediment trap and surface sediment samples. An example cost analysis for the mid-scale application is shown in Table 22.

7.4 COST SUMMARY

The focus of these technology demonstrations was on the evaluation of new capabilities that expand the tool box for assessing stormwater and sediment recontamination beyond what is currently available. Thus, the cost analysis focused on providing a good definition of the costs associated with implementation over a range of scales. Overall, it appears that the costs associated with the technologies is within the range of typical field survey events for other aspects of sediment assessment and characterization. Assuming that the technologies would be incorporated and applied with other traditional characterization phases of a remedial investigation or stormwater monitoring program, significant efficiencies in costs could be expected.

Table 20. Cost Analysis for the Mid-scale DrEx Application.

Cost Category	**Sub Category**	**DrEx Rates and Units**				**Details**
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	1000		1	1000	Principal
	Preliminary budget	1000		1	1000	Principal
	Final budget	1000		2	2000	Principal
	Contract Agreement	1000		2	2000	Principal
	Sampling Plan	1000		3	3000	Principal
	Material Orders	600		2	1200	Technician
Sub-total					10200	
Mobilization Costs	Equipment checkout	600		1	600	Technician
	Calibration	600		0.5	300	Technician
	Pre-clean	600		0.5	300	Technician
	Packing	600		2	1200	Technician
	Shipping	600		1	600	Technician
Sub-total					3000	
Field Operating Costs	Travel and return travel	2200		2	4400	1 Principal & 2 Techician
	On-site setup/testing	2200		1	2200	1 Principal & 2 Techician
	DrEx field survey	2800		2	5600	1 Captain, 1 Principal, & 2 Technicians
	Data downloads	2200		0.5	1100	1 Principal & 2 Techician
	Sample handling and shipping	2200		1	2200	1 Principal & 2 Techician
Sub-total					15500	
Demobilization Costs	Post-clean	2200		0.5	1100	1 Principal & 2 Techician
	Breakdown	2200		0.5	1100	1 Principal & 2 Techician
	Packing	2200		0.5	1100	1 Principal & 2 Techician
	Shipping	2200		0.5	1100	1 Principal & 2 Techician
Sub-total					4400	
Analysis and Reporting	Post-survey data analysis	1000		5	5000	Principal
	Reporting	1000		5	5000	Principal
Sub-total					10000	
Project Management		1000		3.45	3450	@ 10% of labor days
Total Labor Costs					**46550**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	DrEx + Ancillary	145	20		2900	Estimated per day charge
	Boat rental	500	2		1000	Estimated per day charge
Sub-total					3900	
Materials Costs	Calibration standards	25	2		50	For C/T sensor
	Sample tubing	10	10		100	1/8 teflon
	Pump tubing	8	10		80	Per Brightwaters
	Sampling bags/containers	18	10		180	5 liter Tedlar
	Batteries	65	10		650	For drifters
	Log books/sheets	7	1		7	
	Fuel	3.5	40		140	For boats and vehicles
	Iridium services	54	10		544	40 monthly, 0.10/mess, 5-min
	DrEx composite samples	800	12		9600	TSS, metals, and organics
	Other Misc Supplies	500	1		500	
Sub-total					11851	
Indirect Activity Costs	Investigation Derived Waste (IDW)	100	1		100	Decon and cleaning water disposal
Sub-total					100	
Travel Costs	Airfare	500	3		1500	3 Roundtrip
	Per diem	200	12		2400	4 days, 3 people
	Truck/Van	150	4		600	4 days
Sub-total					4500	
Total non-labor cost					**20351**	
Project Sub-total					**66901**	
Fee/Markup @ 8%					**5352**	
Project Total					**72253**	

Table 21. Cost Analysis for the Mid-scale DPS Application.

Cost Category	**Sub Category**	**DPS Rates and Units**				**Details**
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	1000		1	1000	Principal
	Preliminary budget	1000		1	1000	Principal
	Final budget	1000		2	2000	Principal
	Contract Agreement	1000		2	2000	Principal
	Sampling Plan	1000		3	3000	Principal
	Material Orders	600		2	1200	Technician
Sub-total					10200	
Mobilization Costs	Equipment checkout	600		1	600	Technician
	Calibration	600		0.5	300	Technician
	Packing	600		2	1200	Technician
	Shipping	600		1	600	Technician
Sub-total					2700	
Field Operating Costs	Travel and return travel	2200		2	4400	1 Principal & 2 Techician
	On-site setup/testing	2200		1	2200	1 Principal & 2 Techician
	DPS field survey	2800		2	5600	1 Captain, 1 Principal, & 2 Technicians
	Data downloads	2200		0.5	1100	1 Principal & 2 Techician
Sub-total					13300	
Demobilization Costs	Breakdown	2200		0.5	1100	1 Principal & 2 Techician
	Packing	2200		0.5	1100	1 Principal & 2 Techician
	Shipping	2200		0.5	1100	1 Principal & 2 Techician
Sub-total					3300	
Analysis and Reporting	Post-survey data analysis	1000		5	5000	Principal
	Reporting	1000		5	5000	Principal
Sub-total					10000	
Project Management		1000		3.25	3250	@ 10% of labor days
Total Labor Costs					**42750**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	DrEx + Ancillary	233	20		4660	10 units, 2 days
	Boat rental	500	2		1000	2 days
Sub-total					5660	
Materials Costs	Calibration standards	25	2		50	For C/T sensor
	Batteries	80	5		400	For drifters
	Log books/sheets	7	1		7	
	Fuel	3.5	40		140	For boats and vehicles
	Iridium services	66	10		660	30 monthly, 0.125 mess, 5-min
	Other Misc Supplies	500	1		500	
Sub-total					1757	
Travel Costs	Airfare	500	3		1500	3 Roundtrip
	Per diem	200	12		2400	4 days, 3 people
	Truck/Van	150	4		600	4 days
Sub-total					4500	
Total non-labor cost					**11917**	
Project Sub-total					**54667**	
Fee/Markup @ 8%					**4373**	
Project Total					**59040**	

Table 22. Cost Analysis for the Mid-scale SeDep Application.

Cost Category	Sub Category	SeDep Rates and Units				Details
Labor Costs		Rate	Units	Days	Cost	
Planning	Preliminary study design	1000		1	1000	Principal
	Preliminary budget	1000		1	1000	Principal
	Final budget	1000		2	2000	Principal
	Contract Agreement	1000		2	2000	Principal
	Sampling Plan	1000		3	3000	Principal
	Material Orders	600		2	1200	Technician
Sub-total					10200	
Mobilization Costs	Equipment checkout	600		1	600	Technician
	Calibration	600		2	1200	Technician
	Pre-clean	600		0.5	300	Technician
	Packing	600		2	1200	Technician
	Shipping	600		1	600	Technician
Sub-total					3900	
Field Operating Costs	Travel and return travel	2200		6	13200	1 Principal & 2 Techician
	On-site setup/testing	2200		1	2200	1 Principal & 2 Techician
	SeDep field survey - deploy	4400		2	8800	1 Captain, 1 Principal, 2 Tech, 2 Dive
	SeDep field survey - retrieve	4400		2	8800	1 Captain, 1 Principal, 2 Tech, 2 Dive
	Data downloads	2200		0.5	1100	1 Principal & 2 Techician
	Sample handling and shipping	2200		1	2200	1 Principal & 2 Techician
Sub-total					36300	
Demobilization Costs	Post-clean	2200		0.5	1100	1 Principal & 2 Techician
	Breakdown	2200		0.5	1100	1 Principal & 2 Techician
	Packing	2200		0.5	1100	1 Principal & 2 Techician
	Shipping	2200		0.5	1100	1 Principal & 2 Techician
Sub-total					4400	
Analysis and Reporting	Post-survey data analysis	1000		5	5000	Principal
	Reporting	1000		5	5000	Principal
Sub-total					10000	
Project Management		1000		4.2	4200	@ 10% of labor days
Total Labor Costs					**69000**	
Non-Labor Costs		Rate	Units	Days	Cost	
Equipment Costs	SeDep + Ancillary	14	300		4200	10 units, 30 days
	Boat rental	500	4		2000	4 days
	Dive gear rental	100	8		800	4 days, 2 sets
Sub-total					7000	
Materials Costs	Batteries	15	10		150	For SeDep
	Log books/sheets	7	1		7	
	Fuel	3.5	40		140	For boats and vehicles
	Sed Trap Samples	800	12		9600	TOC, metals, and organics
	Surf Sed Samples	800	12		9600	TOC, metals, and organics
	Other Misc Supplies	500	1		500	
Sub-total					19997	
Indirect Activity Costs	IDW Disposal	100	1		100	Decon and cleaning water
Sub-total					100	
Travel Costs	Airfare	500	6		3000	6 Roundtrip
	Per diem	200	24		4800	3 people, 4 days, 2 trips
	Truck/Van	150	8		1200	4 days, 2 trips
Sub-total					9000	
Total non-labor cost					**36097**	
Project Sub-total					**105097**	
Fee/Markup @ 8%					**8408**	
Project Total					**113505**	

8.0 IMPLEMENTATION ISSUES

Through experience with a large number of demonstration projects, an over-arching strategy has been developed for implementation based on several key components including:

- The technology is well demonstrated and documented
- Standard operating procedures are developed and available
- Equipment is available on the open market
- Technology service providers are available to DoD users
- Regulators have visibility of the technology

To the extent possible, progress has been attempted to made on each of these components through the course of this project.

8.1 TECHNOLOGY DEMONSTRATION

The DrEx technology has undergone limited demonstration at one site for two storm events. These field events have provided a high level of confidence that the technology can achieve the defined objectives of tracking and sampling stormwater plumes to better define potential for exposure and recontamination. Technical issues identified during these field events have been corrected. Logistical challenges associated with working in and around an active DoD facility were found to be manageable. The demonstrations were well documented through the ESTCP Site Selection Memorandum, Demonstration Plan, and this Technical Report, as well as through a series of conference presentations and publications. The technology would still benefit from further demonstration by early adopters under a broader range of facilities, discharge conditions, environmental settings, and regulatory applications.

The DPS technology has undergone limited demonstration at one site for two deposition mapping events. These field events have provided a high level of confidence that the technology can achieve the defined objectives of tracking particle trajectories and mapping deposition footprints for potential recontamination associated with particle releases from specific outfalls. Technical issues identified during these field events have been corrected. Logistical challenges associated with working in and around an active DoD facility were found to be manageable. The demonstrations were well documented through the ESTCP Site Selection Memorandum, Demonstration Plan, and this Technical Report, as well as through a series of conference presentations and publications. As with the DrEx system, the DPS technology would still benefit from further demonstration by early adopters under a broader range of facilities, discharge conditions, environmental settings, and regulatory applications.

The SeDep technology has undergone limited demonstration at one site for one extended monitoring event. This field event provided a moderate level of confidence that the technology can achieve the defined objectives of monitoring and sampling deposition in areas of interest to characterize recontamination potential. Technical issues identified during the field event have been corrected, but there has been limited testing of the system following the improvements. Logistical challenges associated with working in and around an active DoD facility were found to be manageable. The demonstration was well documented through the ESTCP Site Selection Memorandum, Demonstration Plan, and this Technical Report, as well as through a series of conference presentations and publications. The SeDep technology would benefit from more rigorous testing and demonstration prior to use by early adopters. However, direct transition to users is also possible, but would likely require some investment by the service provider to assure that the new systems will perform as expected under a range of application conditions.

8.2 STANDARD OPERATING PROCEDURES

Standard operating procedures have been developed for all of the technologies. These are well documented in manuals provided by the equipment companies, as well as in the procedural documents contained in the ESTCP Demonstration Plan. It is expected that these procedures could be refined and improved over time based on experience, and that this would help to improve the implementation process and potentially reduce the application costs.

8.3 EQUIPMENT AVAILABILITY

The DrEx equipment, described in this document, is currently available from vendors. Similarly, the DPS equipment is fully available from the commercial vendor that participated in the project. For the SeDep system, a relationship with a commercial vendor was not finalized, although the system is based directly on the commercially available system. The improvements incorporated into the SeDep system are essential to improving the performance to the level where it can meet the objectives specified for the technology, particularly with respect to sensitivity and operation in deeper water. The SeDep technology would benefit from further effort toward commercialization to ensure the equipment would be widely available.

8.4 SERVICE PROVIDERS

During the equipment development and demonstration, there were ongoing collaborations with potential technology service providers. The primary partner, as a service provider, on the project was with Ramboll and Geosyntec Consultants who supported various aspects of the development, testing, and demonstration of the technology. These consultants would be well positioned to support the technologies as service providers in the future. In addition, the technologies are suitably documented and straightforward enough that any experienced environmental consulting company could provide the required support after a relatively short learning curve. The DrEx and DPS technologies are currently in patent pending status, and there may be future opportunities for service providers to license the technology. Implementation of the technology would be well served by having the technology be picked up and promoted by a commercial consulting firm for future applications at DoD sites.

8.5 REGULATORY VISIBILITY

To date, the technologies have had some limited regulatory exposure. The technology was briefed and toured to staff from the San Diego Regional Water Quality Control Board during the period of the demonstrations in San Diego Bay. Results from the demonstrations in Pearl Harbor have also been briefed to the regulatory team associated with the Pearl Harbor sediment cleanup. The Remedial Project Manager (RPM) at Pearl Harbor has been actively involved in the project and in implementing the technology at the site, and represents a key early adopter for the technology. The technology would benefit from further exposure to regulatory agencies that have oversight over stormwater and/or sediment cleanups.

9.0 REFERENCES

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