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USING SEDMENT TOXICITY IDENTIFICTION EVALUATIONS TO IMPROVE THE DEVELOPMENT OF REMEDIAL GOALS FOR AQUATIC HABITATS

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PROJECT BACKGROUND AND OBJECTIVES

TIE BACKGROUND

Naval Facilities Engineering Service Center (NFESC), in a cooperative effort with Engineering Field Activity Northeast (EFANE), contracted Science Applications International Corporation (SAIC) to demonstrate and develop guidance for the use of sediment toxicity identification evaluations (TIEs) to isolate the causes of toxicity in contaminated sediments. Remedial goals for reduction of ecological risk often rely upon sediment screening values that are not intended to serve as regulatory limits (e.g. NOAA screening values; NOAA, 1999). Remedial plans are also frequently driven by site-specific correlations between contaminant concentrations and biological effects (e.g., sediment toxicity). While these data do serve as flags for potential actionable risks, they are not direct evidence that the suspected contaminants of concern (CoCs) have actually caused toxicity. Normally, there is a substantial degree of uncertainty in the link between cause and effect, particularly when confounding factors (e.g., ammonia) are involved in the toxic response. Without knowledge of causative factors driving toxicity, cleanup goals may be set to satisfy overly conservative or inappropriate assumption. Consequently, decisions to conduct time-consuming and costly remedial actions can be errant, and the results may do little to remediate the principal risks at the site.

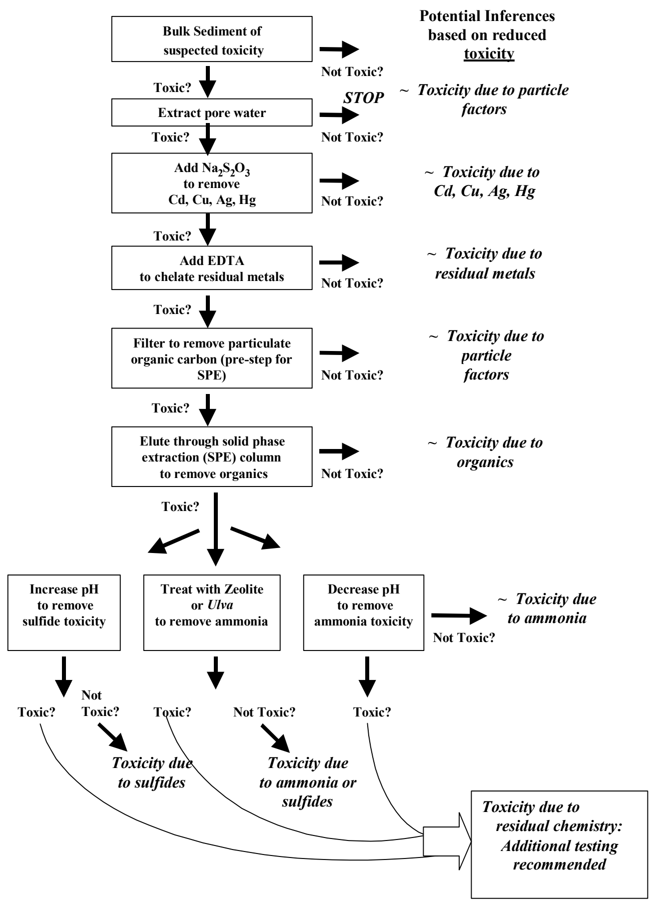
Toxic Sediment: Cause unknown

The selection of appropriate cleanup goals can be greatly improved by identifying the risk-causing chemicals through TIE studies. In TIE investigations with sediments, physical/chemical properties of sediment pore waters can be manipulated to deduce which chemical constituents are toxic in the site-specific matrix (U.S. EPA, 1991a; U.S. EPA, 1991b; U.S. EPA, 1996). The responses of aquatic organisms to each manipulated sample provide evidence relating toxic effects to specific classes of toxicant(s) as the causative agents. Depending upon the responses, the toxicant(s) can be tentatively categorized as heavy metals, organic compounds including pesticides and polycyclic aromatic hydrocarbons (PAHs), and/or confounding factors such as ammonia or sulfides (U.S. EPA, 1996).

Currently, there is no single standardized approach for conducting sediment TIE procedures. Guidance is also lacking for application of TIE findings to resolve issues raised through standard risk assessments and for use in remedial planning. Typically, TIE studies involve several separate procedures to identify each class of contaminants and then the results from each procedure are compared. This effectiveness of this approach is often limited because some toxicity typically remains after each treatment. The resulting uncertainty is believed to be partially responsible for poor transition of this technology into the standard toolbox of tests used in ecological risk assessments.

SEQUENTIAL TIE APPROACH

Flow Diagram for Sequential TIE: Fractionation, Testing and Interpretation



In SAIC's sequential TIE approach (Figure, left) each step treats a chemical 'fraction' that could potentially cause toxicity, and through consecutive binding or removal of these fractions the result is ultimately a non-toxic sample. Using this approach, a reduction in toxicity at each step is expected wherever CoCs or confounding factors are present in sufficient concentrations to cause acute effects. If at some point in the treatment process a non-toxic sample is produced, then this demonstrates that all the sources for adverse effects have been identified and associated with one or more classes of chemicals or confounding factors.

A sequential approach should be considered in preference to traditional parallel testing, particularly in cases where little is known regarding the sources of toxicity, where multiple classes of toxicants are suspected or when confounding factors (e.g.. ammonia) are involved. This is because the sequential procedures are carefully ordered (serial as well as parallel) to remove the chemical fractions in a manner that reduces treatment bias (i.e., one treatment affecting multiple CoC classes), masking (one CoC class of high toxicity preventing the detection of lesser toxicity sources) and non-additivity (synergistic or antagonistic effects from CoC class mixtures).

> ***The TIE sequence isolates and tests for the presence of the principal classes of contaminants***

This consecutive testing approach was recently demonstrated with sediment pore water samples from the Naval Submarine Base-New London, CT at an Installation Restoration (IR) site (Goss Cove) for Northern Division (SAIC, 1999). Prior remedial investigation and risk assessment studies for the site had suggested actionable risk although considerable uncertainty existed as to the CoCs responsible for risk. The application of the improved TIE process revealed that ammonia (a ubiquitous non-CoC sediment constituent) and not the conventional sediment contaminants (PAHs, metals) was responsible for the risk. As a result, a finding of "No Further Action" was granted by EPA, saving approximately $2M in remediation costs (Navy RPM News, 1999).

CURRENT USE OF TIES FOR ASSESSING SEDIMENT SITES

In order to develop 'state of the science' guidance for conducting and applying sediment TIEs, SAIC has reviewed recent TIE applications as case studies. TIE methods are in a dynamic stage of development, and the EPA, USACE, and NAVFAC have recently sponsored TIE applications for several sites (Besser et al., 1998; Carr and Nipper, 2000; SAIC, 1999; SAIC, 2000; SAIC, 2001). A study recently conducted with sediments from the Calcasieu Estuary Superfund site for the U.S. EPA Region VI provided some valuable insights regarding TIE procedures (SAIC, 2001). In that study SAIC's sequential TIE method was used to determine that mixtures of organic and metal contaminants as well as excess minerals at one site were jointly responsible for acute toxicity (SAIC, 2001). The Calcasieu data will be used in establishing and supporting Total Maximum Daily Load (TMDL) limits for industrial and domestic effluent permits. Another sediment TIE study that was recently co-sponsored by EFANW and NFESC used EPA methods to demonstrate that at a contaminated site in Puget Sound, risks to aquatic life were not due to ordnance compounds (Carr and Nipper, 2000). Organics, metals and ammonia were associated with toxicity at the site, avoiding the misplacement of $9 million for ordnance cleanup by the U.S. Navy (NFESC, 2001).

The regulatory acceptance of TIE results for these pioneer programs at Navy sites has been high; now it is critical to establish a working protocol for future tests based on numerous TIE studies that have been effective. It is also important to continue to refine TIE methodologies to better target specific risk management issues. Some of these issues, such as discordance between bulk sediment test results and pore water test results, and varying results from different methods of pore water extraction, along with the absence of standard published methods were highlighted in a recent SETAC workshop on pore water testing (Adams et al., 2001). The freshwater and marine site studies chosen for the NFESC TIE Project have been designed as prototypes to demonstrate recommended protocols and also to incorporate research objectives.

TIE PROJECT OBJECTIVES

In keeping with the Navy's objective to efficiently and effectively assess and manage risks at its aquatic sites, the NFESC TIE Project was initiated to demonstrate and improve sediment TIE procedures for sites that have identified potential ecological risks. The goal of the demonstration is to increase the utility and acceptability of TIEs within the regulatory community for use in supporting the risk assessment and/or the evaluation of remedial options/actions. Upon completion of Phase I evaluations for the individual sites, a guidance document will be prepared to include:

- Guidance on when to use the TIE- how to determine if your site is a good candidate;
- A protocol for running the TIE methodology;
- Utility of the TIE findings in providing clarification/enhanced certainty with respect to causes of site-related risks; and
- Examples of cost/benefits resulting from performance of the TIE demonstration.

TIE PROJECT DEMONSTRATION AND GUIDANCE

The current TIE Demonstration Project involves two Navy sites: 1) Indian Head Naval Surface Warfare Center on a tributary of the Potomac River in Maryland, and 2) Hunters Point Naval Shipyard in San Francisco Bay. The sites were chosen using two principal criteria: 1) A clear need to resolve regulatory uncertainties and site management decisions, and 2) representation of unique issues associated with assessments of sediment toxicity.

The Indian Head study has been successfully completed with the site report in its final review stage and the Hunters Point study is currently underway. Close collaboration with the technical team for each site has assured successful and efficient study designs and sampling efforts. The demonstration project is scheduled for completion by 31 March 2002. It is important to emphasize that these TIE studies do not supersede or replace the role that the ecological risk assessment (ERA) plays in determining whether some "actionable" risk exists at the site. Rather, TIE information is used to clarify the causes of actionable risk that were determined as part of a weight-of-evidence approach.

SAIC's recommended approach to TIE studies includes the collection of sediment chemistry and toxicity data even when sediment characterization information is available from ERA studies. This is to assure concordance among the sediment toxicity, chemical concentrations in sediments and pore waters and TIE results. This recommended TIE approach, if consistency implemented, will provide the Navy with a reliable, standardized method to supplement traditional risk assessment approaches in determining the principal sources of sediment toxicity.

KEY ELEMENTS FOR A SUCCESSFUL TIE PROGRAM

Completion of a comprehensive TIE study involves the design and coordination of three principal phases leading to the development of sound conclusions regarding factors contributing to toxicity: 1) Planning (scheduling, site review, study design, and coordination); 2) Field sampling and laboratory activities, including chemical and biological testing; 3) Data integration (weight-of-evidence). The existing guidance for TIEs has primarily focused on sample manipulation procedures and approaches for interpretation of laboratory test results on a per-sample basis. Through the current program of TIE site demonstrations and guidance document preparation, NFESC intends to emphasize the need for a much broader framework that incorporates planning, execution and interpretation in addition to refined testing procedures for effective application of TIE studies.

TIE PLANNING

Schedule. Planning and coordination must include the development and distribution of a detailed, but flexible schedule. While each TIE study is unique, as a general rule three to six months should be allowed for the completion of a sediment pore water TIE, from planning to final reporting. Timelines for completion of each phase of a typical TIE study are presented below. Often the success of a sediment TIE is dependent on coordination amongst multiple organizations that contribute to the total effort, and in these cases it is especially important to incorporate flexibility into the planning, data collection and review processes.

Site Review. The principal objective of a TIE study is generally to refine remedial planning based on new site-specific information. The first step is to evaluate the site to see if it is actually one that will benefit from a TIE study. Each case is unique, but the sites where projected remedial costs are high and the factors contributing to toxicity are uncertain are generally the best candidates for TIE testing. Conversely, if the contaminated area of concern is small, if minimal toxicity has been observed, or if there is a clear link between a point source of contamination and observed adverse effects, a TIE may not be warranted. Similarly, where remedial alternatives would be the same regardless of the cause of toxicity (e.g., metals or organics) then TIE information would not necessarily further the planning process. Existing toxicity data and chemical characterizations should be evaluated in making the determination of TIE applicability. Bulk sediment toxicity should be demonstrated prior to the development of plans for pore water TIE testing, because the intent of the TIE tests is to resolve the nature of sediment toxicity. Other types of data that may be used to determine the potential utility of a TIE study include sediment and pore water chemistry, pore water toxicity, AVS/SEM, ammonia and sulfide concentrations. Care must be taken in reviewing the data to assure its current relevance, especially with regard to the fate and transport processes of the system that may affect contaminant depth, or seasonal factors that may affect the nature of exposure conditions. Some of the types of information that are useful in the preliminary site evaluation are summarized below.

INFORMATION USEFUL IN EVALUATING THE APPLICABILITY OF A TIE STUDY	
GENERAL INFORMATION	ANCILLARY INFORMATION (CO-FACTORS FOR TOXICITY ASSESSEMNT)
• Previously Demonstrated Toxicity • Results of Bulk Sediment Toxicity Tests • Results of Porewater or Elutriate Tests (if completed) • Chemist Data • Bulk Sediment Chemistry Data • Porewater Chemistry Data (if completed) • Past Sampling Locations to Evaluate Spatial Variability • Knowledge of Upland IR Related Sources • COPCs at Upland IR Sites	• Total Organic Carbon (TOC) Measurements • Ammonia or Sulfide Concentrations Measured During Toxicity Tests • pH • Simultaneously Extractable Metal:Acid Volatile Sulfide (SEM:AVS) Measurements • Previous Sampling Depths

The freshwater Indian Head site and the saltwater Hunters Point site were chosen for the demonstration project because analysis of data from previous toxicity testing and chemical analyses revealed adverse effects but considerable uncertainty regarding the principal factors driving toxicity remained. Clean-up activities are planned for both sites and costly remedial alternatives have been proposed. Also, each site presented unique issues to demonstrate TIE methods and applications.

In a Remedial Investigation (RI) report (Tetra Tech NUS, 1999a) on Indian Head Site 42, silver had been identified as the Contaminant of Concern (CoC). Clean-up goals for freshwater sediments adjacent to the Indian Head site had been based on exceedances of NOAA sediment screening values for silver. Remedial options developed for Site 42 had estimated costs ranged from $613,000 to $2,875,000 to contain or remove contaminants, including trichloroethelene (TCE) which posed potential risks to groundwater, and silver which posed potential risks to sediments (Sadorra, 2000). However, it is known that site-specific factors such as organic carbon and acid volatile sulfides (AVS) concentrations largely restrict the bioavailability of silver. Furthermore, silver has not been demonstrated to be the principal cause of toxicity in any field-collected sediments studied to date (Call et al., 1999). Also, sediment chemistry data from the RI included values for other cationic metals that would contribute to toxicity. Overall, the data supporting remediation for silver in Indian Head sediments were relatively sparse and inconclusive and hence the site was deemed a good candidate for TIE.

For Hunters Point, concentrations reported for sediment samples in a Phase I ERA (Battelle et al., 1999) exceeded screening levels for copper, chromium, lead, zinc and PCBs. Nevertheless, toxicity was most strongly correlated to total ammonia. The demonstration TIE, in this case, would be particularly useful in determining the associations between acute toxicity and metal concentrations, versus ammonia or other confounding factors.

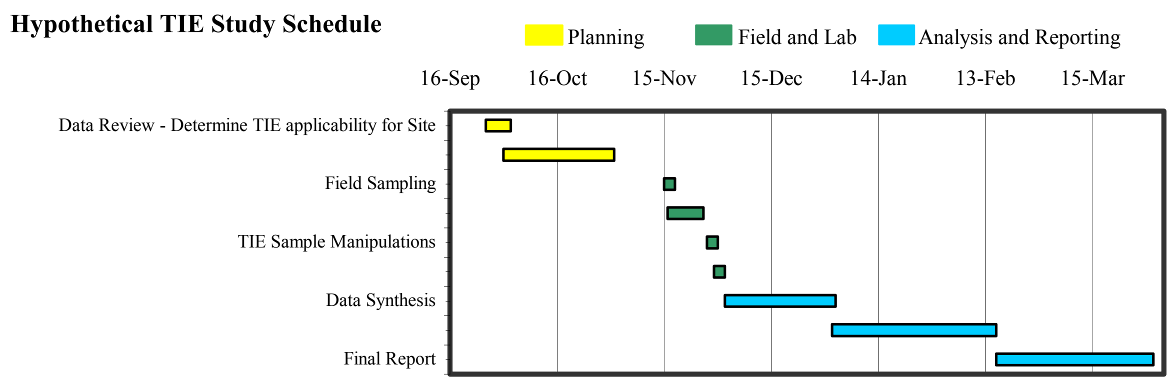
Quantico Embayment, located at the Marine Corps Combat Development Command (MCCDC) station, was also evaluated as a potential TIE study site for the demonstration project. It was considered less suitable than Indian Head and Hunters Point, principally because sediment toxicity had not been demonstrated to occur as constantly or to the same degree as it had been in studies of the other two sites. Also, DDT and PCBs were the greatest ecological risk contributors at Quantico, and for these bioaccumulative contaminants the exposure pathway responsible for the highest risks would occur through trophic transfer not direct sediment contact. The acute tests employed in pore water TIEs would not address the exposure pathway of concern. Additionally, high oxygen demand had been reported for some sediments from the Quantico Embayment, and the TIE methodologies have not yet been developed to effectively isolate hypoxia as a confounding factor. The site selection factors that resulted in the selection of Indian Head and Hunters Point are summarized in the Table below.

Summary of Site Selection Criteria for the TIE Demonstration.			
SITE SELECTION CRITERIA	**Indian Head, MD[1]**	**Hunters Point, CA[2]**	**Quantico Embayment, MD[3]**
Acutely toxic sediments?	✓	✓	**?**
CoCs above screening benchmarks?	✓	✓	✓
Pore water data available?		✓	
Field survey planned?		✓	
Type of aquatic environment	**Fresh to tidal fresh**	**Marine**	**Brackish**
EPA Region	**3**	**9**	**3**
NAVFAC Component	**EFA Chesapeake**	**EFD Southwest**	**EFA Chesapeake**
Types of contaminants	**Silver; other cationic metals; ordnance; organics**	**Cationic metals; organics**	**Pesticides, PCBs**
Confounding factor identified	**Ammonia**	**Ammonia**	**Low D.O.**

[1] Source of site data for Indian Head (including Sites 42 and 39/41): Tetra Tech, NUS, 1999a; 1999b.
[2] Source of site data for Hunters Point: Battelle, ENTRIX Inc. and Neptune and Co. 1999.
[3] Source of site data for Quantico: Pinkney, A.A., D.R. Murphy, P.C. McGowan, B.L. McGee, K.N. Johnson, L.Domico. 1999.

Study Design and Coordination. The design of a successful TIE study involves a high degree of collaborative effort, with coordination between the contractor, NFESC, Navy site representatives, and the regulatory community. Working with all parties concerned with identifying the limitations of the existing assessment of toxicity sources is critical, such that the specific goals of the study can be agreed upon. After determining the goals, the choice of station locations should be made and reviewed by all members of the site team to assure that all of the potential chemical exposure issues are well represented.

Generally, more than one research team is involved in the study, and coordinated planning and scheduling are key to a successful outcome. For the Indian Head study, SAIC conducted all field and laboratory tasks but additional support for relocating prior stations and vessel support for field sampling was highly beneficial. For Hunters Point, field collection efforts were coordinated with a planned site investigation (Battelle, 2000) such that coordination for the TIE involved input into chemical analytical lists, sharing of test organisms, sample shipment and data delivery. Each demonstration study was designed with regard for the site-specific issues identified during the RI and/or FS for the site. Both studies were scheduled in accordance with existing time frames for site management. Some of the key components of a typical TIE study, with realistic time frames for completion are presented in the hypothetical schedule provided below.



Test species for the TIEs were chosen to be consistent with ERA assessment endpoints (i.e. ecologically relevant and representative), but also to include species at the more sensitive end of the spectrum of acute susceptibility to the stressors of concern such that the tests would be responsive to the TIE treatments where appropriate. For Indian Head, the amphipod, *Hyalella azteca*, was chosen because it had previously demonstrated reduced survival in bulk sediment tests. Newly hatched fathead minnows (*Pimepheles promelas*) were tested to represent the potential vulnerability of a second taxonomic group. Also, each species was chosen to represent somewhat unique sensitivities to different classes of contaminants. For Hunters Point, the echinoderm (*Strongylocentrotus purpuratus*) larval development test was selected because it was used in the Phase I ERA studies, and because it is known to be highly sensitive to ammonia as well as potential CoCs at the site. The second TIE bioassay tested survival of newly hatched Atherinid fish, *Menidia menidia*. This species is more sensitive to ammonia than most saltwater fishes, and hence protective in the prediction of ammonia effects but still less sensitive than the echinoderm larval development endpoint such that other CoC-related effects might be discerned. Embryos of both of the chosen fish species are demersal, and thus represent direct exposure risks from contaminated sediments.

FIELD SAMPLING AND LABORATORY TESTING

Field Sampling. The success of the TIE study requires not only a design strategy that addresses the goals of the study, but also a logistic plan that provides for effective execution of the strategy. The components that have proven to drive the logistic plan at Navy sites include site access, seasonal considerations, and availability of adequate sample quantities and sampling equipment. The logistic aspects of the work plan must include details associated with:

- Scheduling
- Permits
- Mobilization of Supplies and Equipment
- Site Access
- Station Positioning
- Sediment Collection and Handling
- Chain of Custody Procedures and Forms

Photo (Above): Sediment collection often involves multiple modes of collection and transport. Five-gallon samples are collected to provide sufficient volumes for bulk sediment tests, chemical and physical analyses, and for extraction of one-two liters of pore water for TIE tests.

Laboratory Testing. Logistic plans for laboratory chemical analyses and toxicity testing are required and also depend on successful coordination with the entire study team. Foremost is the recommendation that all analyses be performed on collocated samples. Toxicity testing methods apply well-established test protocols (e.g. ASTM, 1980) with minimal modifications to accommodate low sample volumes. EPA recommended methods for TIE fractionation procedures are incorporated in the sequential testing approach (U.S.EPA, 1991a, 1991b, 1996). The following elements must be addressed in detail in the work plan:

- Scheduling of chemical analyses and TIE tests to coordinate with field sampling;
- Sediment homogenization and subsampling procedures;
- Pore water extraction;
- Bulk sediment and pore water toxicity procedures;
- Screening TIE sample selection;
- TIE fractionation and sub-sampling procedures; and
- QA/QC and documentation.

Photo (above): A series of TIE-treated pore water samples prepared for animal exposures.

DATA INTEGRATION

In TIE studies, it is always true that the sum of the acquired data is worth more than the individual components. The weight-of-evidence approach requires that each of the risk-characterizing components (e.g., bulk sediment toxicity, TIE results and chemical analysis results) should be conducted on the same (split) sediment samples. When the independent assessments yield concordant results, then the identification of specific CoCs as the source of toxicity is far more technically defensible. Another potential outcome from the integrated analysis is that TIE results may exhibit levels of toxicity similar to bulk sediment tests, but the fractionation procedures confirm that the source of toxicity is not site related (e.g., ammonia). In such cases, TIEs provide the technical basis to revise remedial goals (including no further action). For some samples, there may be residual effects indicating that the TIE did not remove all constituent toxicity. Through the process of elimination, this type of result can serve to suggest classes of toxicants other than those that standard TIE manipulations effectively remove.

Analysis and Interpretation of Biological and Chemical Data. TIE results and those from chemical analyses must be synthesized through a series of parallel processes that ultimately facilitate a complete weight-of-evidence evaluation. The standard set of evaluations that should be performed are included below.

<u>Biological Results from TIE Testing</u>

- Review acceptability of TIE performance control data and other laboratory quality assurance performance measures;
- Compare TIE pore water results with bulk sediment toxicity test results to evaluate representativeness of the TIE;

- Synthesize TIE results by developing statistically meaningful response to TIE treatments
- (e.g., significant differences and LC50s with confidence limits); and
- Establish which treatments resulted in changes in response due to fractionation procedures; and
- Identify classes of contaminants or confounding factors that caused toxicity.

Chemical Characterization

- Analyze sediment chemistry data using screening values for acute effects (e.g. NOAA ERMs) to derive sediment based Hazard Quotients;
- Analyze pore water metals data including non-CoC data (pH, ammonia, dissolved oxygen, sulfide, hardness, etc.) in terms of known effect concentrations from testing with single toxicants (Water Quality Criteria and others) to derive pore water based Hazard Quotients; and
- Evaluate sediment organics data using fugacity models such as equilibrium partitioning to incorporate organic carbon binding and for metals cationic binding to acid volatile sulfides (AVS) in sediments, and use the synthesized data to derive 'normalized' Hazard Quotients.

Evaluation of Concordance

- For each station, summarize the classes of contaminants found to contribute to toxicity;
- For each station, list Hazard Quotients > 1 and the associated analyte;
- Evaluate the concordance or discordance between the two estimators of risk by contaminant class; and
- Describe potential explanations if discordance occurs, and recommend further studies to resolve uncertainties.

CASE STUDY FINDINGS

At Indian Head Study Site 42, remedial options to address contamination affecting an adjacent stream were previously focused silver (based on RI findings). However, results from the TIE Study demonstrated that toxicity was not principally due to silver, because the silver-reducing agent, sodium thiosulfate, did not alter toxicity. Rather, as summarized in the Table below, a combination of metals (including unusually elevated levels of manganese and other factors) contributed to toxicity in this area. Zinc was identified as the principal CoC from the burn pit area sample collected in Mattawoman Creek. For sediments from Site 39/41, post-TIE residual effects were observed in one highly toxic sample, demonstrating the need for further study. Other samples from Site 39/41 produced responses attributable to both organic and metal sources.

Example Results for Indian Head Sediment TIE.

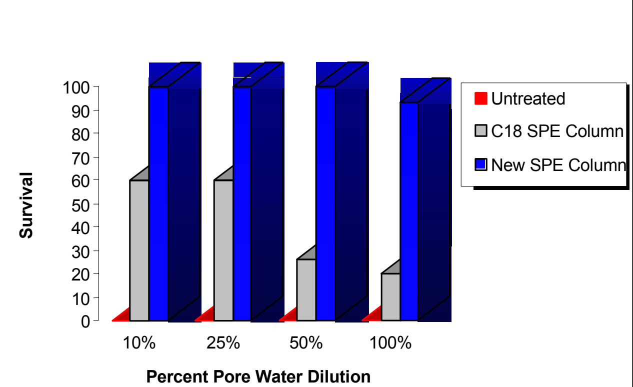
Site	Sample	*Hyalella* Survival		Toxicity Suggested by TIE and Chemistry	Potential Source of Unresolved Toxicity
		Bulk Sediment	Pore water TIE		
39/41	**IH-02**	+	+++	**Silver**	***b*-BHC, Nitrobenzene**
	IH-06	+	++	**b-BHC, Manganese, NH_4**	***b*-BHC**
	IH-08	++	++	**NH_4**	
	IH-15	+++	+++	**Zinc**	
42	**IH-11**	+++	++	**Manganese**	**SED**
	IH-13	++	+		**SED**

Toxicity rating from low (+) to high (+++).
SED = toxicity due to particulate fraction or longer duration of sediment exposures.

Reductions in toxicity were observed with filtration but the chemical source of toxicity associated with the particulate fraction was unknown. As a result, SAIC rearranged the testing sequence to determine whether metals are causing toxicity as the first steps in the sequential TIE protocol. Using this sequence, filtration and SPE steps more specifically identify toxicity due to organic contaminants. This method was applied for the second site demonstration at Hunters Point Shipyard. Another principal finding of the Indian Head investigation is that BHC pesticides and the ordnance compound nitrobenzene may have contributed to unresolved toxicity in a sediment sample from Mattawoman Creek (Site 39/41).

The effectiveness of the TIE in treating the more polar pesticides and ordnance compounds is relatively uncertain and highlights certain limitations in current TIE protocols. Here, SAIC has identified new and emergent technologies that may be useful in attributing toxicity associated with these compounds. In a trial application of a method to remove a much broader array of organics than the traditional C_{18} column, a sediment that was known to be heavily contaminated with ordnance compounds such as HMX, RDX and TNT was effectively treated (see Figure, right).

TIE results demonstrating removal of ordnance-associated toxicity in sediment



TIE GUIDANCE DOCUMENT

The Navy has developed a document entitled *Guide for Planning and Conducting Sediment Pore Water Toxicity Identification Evaluations (TIE) to Determine Causes of Acute Toxicity at Navy Aquatic Sites* (NFESC, 2003), that expands on the information contained within this white paper. The guide provides recommendations to optimize and facilitate the completion of TIE studies at Navy sediment IR sites including additional discussion on:

- Preliminary site evaluation to determine the potential utility of a TIE study;
- Study design and coordination;
- TIE methods, standard operating procedures and data collection, including preparation for field and laboratory activities;
- Data synthesis and evaluation;
- Interpretation of TIE findings; and
- Discussion of factors associated with regulatory acceptance of TIE findings.

This guide provides an approach for and investigative tool that can potentially be used at Navy sites that have been identified for possible remedial action or where previous risk assessment studies suggest adverse effects to the aquatic environment. The guide can be found at NFESC Environment Restoration Website (http://enviro.nfesc.navy.mil/erb/erb_a/restoration/fcs_area/con_sed/ug-2052-tie.pdf) or in the Navy related guidance section of the Navy Guidance for Conducting Ecological Risk Assessments Website (http://web.ead.anl.gov/ecorisk).

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