TUESDAY (GROUP 1) POSTERS

This year, more than 450 posters are on display in the Exhibit Hall, Group 1 on Tuesday and Group 2 on Wednesday. These posters, many representing current and recently completed SERDP and ESTCP projects, highlight research within the SERDP and ESTCP focus areas (Environmental Restoration, Munitions Management, Sustainable Infrastructure, and Weapons Systems and Platforms). To help attendees find their areas of interest, posters are grouped to keep similar technologies together. In addition to the SERDP and ESTCP Partners in Environmental Technology exhibit booth, there are other exhibitors at this event with booths representing funding and partnering opportunities or information resources.

While many SERDP and ESTCP projects are showcased in the Exhibit Hall, more information about past and present SERDP and ESTCP research projects is available by visiting our websites (www.serdp.org and www.estcp.org). In addition, both sites enable you to access the SERDP/ESTCP Online Library (docs.serdp-estcp.org) where you can search for technical reports using criteria such as focus area, sub-focus, contaminant, or other specific environmental concerns.

The Exhibit Hall will be open throughout the Symposium. You are encouraged to tour the posters and exhibit booths during the hours noted below when presenters will be available for discussion. Technical session breaks on Tuesday and Wednesday will take place in the Exhibit Hall. Presenters may be available during these breaks.

**Tuesday Exhibit Hall Hours**

7:30 a.m. – 8:45 a.m.
12:30 p.m. – 1:45 p.m.
5:00 p.m. – 7:00 p.m.

<table>
<thead>
<tr>
<th>PRESENTER ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weapons Systems and Platforms (WP)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WP: Waste Reduction and Treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracy Carole&lt;br&gt;Naval Surface Warfare Center, Carderock Division</td>
<td>Solids Separation and Concentration of Shipboard Wastewaters and Residuals by a High Shear Rotary Membrane System</td>
<td>21</td>
<td>F-1</td>
</tr>
<tr>
<td>Denis Colahan&lt;br&gt;Naval Surface Warfare Center-Philadelphia</td>
<td>Elimination of Acid Cleaning of High Temperature Salt Water Heat Exchangers</td>
<td>22</td>
<td>F-2</td>
</tr>
<tr>
<td>Mr. Tom Torres&lt;br&gt;Naval Facilities Engineering Command-Engineering Service Center</td>
<td>Biological Treatment of Solvent-Based Paint</td>
<td>23</td>
<td>F-3</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms. Tina Lerke &lt;br&gt;Naval Surface Warfare Center, Carderock Division</td>
<td>Demonstration of Advanced Oxidation Treatment of Shipboard Blackwater and Graywater</td>
<td>24</td>
<td>F-4</td>
</tr>
<tr>
<td>Heath Himstedt &lt;br&gt;Colorado State University</td>
<td>Magneto-Responsive Nanofiltration Membranes for Treatment of Naval Bilge Waters</td>
<td>35</td>
<td>F-5</td>
</tr>
<tr>
<td>David Maribo &lt;br&gt;Naval Surface Warfare Center, Carderock Division, Code 633</td>
<td>Novel Membrane Treatment Systems for Shipboard Oily Wastewater</td>
<td>36</td>
<td>F-6</td>
</tr>
<tr>
<td>Mr. Sonny Maga &lt;br&gt;Naval Facilities Engineering Command-Engineering Service Center</td>
<td>Oily Sludge Biodetoxification</td>
<td>37</td>
<td>F-7</td>
</tr>
<tr>
<td>Mr. Andrew Rak &lt;br&gt;Noblis, Inc.</td>
<td>Research and Development Efforts to Reduce Risks from Emerging Contaminants</td>
<td>41</td>
<td>F-8</td>
</tr>
<tr>
<td>Mr. Wayne Ziegler &lt;br&gt;U.S. Army Research Laboratory</td>
<td>Improved Restricted Materials Tracking and Alternative Implementation Through Development of a Materials Selection and Analysis Tool (MSAT)</td>
<td>42</td>
<td>F-9</td>
</tr>
<tr>
<td>Mr. Theodore Knudson &lt;br&gt;Brush Wellman, Inc.</td>
<td>The Development of an Interactive Guide to Working Safely with Beryllium and Beryllium-Containing Materials</td>
<td>43</td>
<td>F-10</td>
</tr>
<tr>
<td>Mr. Wayne Patterson &lt;br&gt;U.S. Air Force</td>
<td>Low Temperature Powder Coatings</td>
<td>38</td>
<td>F-11</td>
</tr>
<tr>
<td>Dr. John L. Graham &lt;br&gt;University of Dayton Research Institute</td>
<td>A Fundamental Study of How Methylene Chloride and Phenol Interact with Epoxy and Polyurethane Coatings</td>
<td>39</td>
<td>F-12</td>
</tr>
<tr>
<td>Dr. Arunprakash Karunanithi &lt;br&gt;University of Colorado, Denver</td>
<td>Computer-Aided Molecular Design: A Novel Approach to Design Environmentally Friendly Replacement Solvents</td>
<td>40</td>
<td>F-13</td>
</tr>
<tr>
<td>Professor Dale W. Schaefer &lt;br&gt;University of Cincinnati</td>
<td>Structure and Composition of Non-Chromate Inhibitor Films</td>
<td>56</td>
<td>F-14</td>
</tr>
<tr>
<td>Dr. Jonathan McCrea &lt;br&gt;Integran Technologies, Inc.</td>
<td>Nanostructured Zn-Based Electrodeposits as Environmentally Benign Cd-Replacement Coatings for High-Strength Fasteners</td>
<td>57</td>
<td>F-15</td>
</tr>
<tr>
<td>Scott Grendahl &lt;br&gt;U.S. Army Research Laboratory</td>
<td>Hydrogen Re-Embrittlement DOE</td>
<td>58</td>
<td>F-16</td>
</tr>
<tr>
<td>Mr. Mark Miller &lt;br&gt;Benet Laboratories</td>
<td>Chromium Replacement and Erosion Mitigation Technology for Medium Caliber Gun Barrels</td>
<td>59</td>
<td>F-17</td>
</tr>
<tr>
<td>Marta A. Jakab &lt;br&gt;Southwest Research Institute</td>
<td>Scientific Understanding of the Mechanisms of Non-Chromate Corrosion Inhibitors</td>
<td>60</td>
<td>F-18</td>
</tr>
<tr>
<td>Professor Michael R. Kessler &lt;br&gt;Ames Laboratory and Iowa State University</td>
<td>Environmentally Benign Repair of Composites Using High Temperature Cyanate Ester Nanocomposites: Repair System Evaluation</td>
<td>61</td>
<td>F-19</td>
</tr>
<tr>
<td>Dr. Peter Zarras &lt;br&gt;Naval Air Warfare Center Weapons Division</td>
<td>Validation of Novel Electroactive Polymers as Environmentally Compliant Coatings for Replacement of Hexavalent Chromium Pretreatments</td>
<td>73</td>
<td>F-20</td>
</tr>
</tbody>
</table>
### PRESENTER ORGANIZATION

<table>
<thead>
<tr>
<th>PRESENTER ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dr. El Sayed Arafat</strong>&lt;br&gt;Naval Air Systems Command (NAVAIR)</td>
<td>Demonstration/Validation of High Performance Corrosion Preventive Compound (CPC) for Interior Aircraft Applications</td>
<td>74</td>
<td>F-21</td>
</tr>
<tr>
<td><strong>D. Facchini</strong>&lt;br&gt;Integran Technologies, Inc.</td>
<td>Nanocrystalline Cobalt-Alloy Coatings for Chrome Replacement Applications</td>
<td>75</td>
<td>F-22</td>
</tr>
<tr>
<td><strong>Dr. Becky L. Treu</strong>&lt;br&gt;Missouri University of Science and Technology</td>
<td>Corrosion Protection Mechanisms of Rare Earth-Based Coatings</td>
<td>76</td>
<td>F-23</td>
</tr>
<tr>
<td><strong>Professor Matt O’Keefe</strong>&lt;br&gt;Missouri University of Science and Technology</td>
<td>Multifunctional UV (MUV) and Cerium-Based Corrosion Coatings</td>
<td>77</td>
<td>F-24</td>
</tr>
<tr>
<td><strong>Professor Christopher K. Ober</strong>&lt;br&gt;Cornell University</td>
<td>Environmentally Benign Multilayer Polymer Coatings with Controlled Surface Properties for Marine Antifouling Applications</td>
<td>78</td>
<td>F-25</td>
</tr>
<tr>
<td><strong>Mr. Jim Tankersley</strong>&lt;br&gt;Battelle</td>
<td>Final Report: Qualification, Demonstration, &amp; Validation of Compliant Removers for Aircraft Sealants and Specialty Coatings</td>
<td>93</td>
<td>F-26</td>
</tr>
<tr>
<td><strong>Mr. Corey Bliss</strong>&lt;br&gt;U.S. Air Force Research Laboratory</td>
<td>Ultraviolet Cure Powder Coatings for Military Systems</td>
<td>94</td>
<td>F-27</td>
</tr>
<tr>
<td><strong>Mr. Corey Bliss</strong>&lt;br&gt;AFRL/RXSSO Coatings Technology Integration Office</td>
<td>Dynamic Multivariate Accelerated Corrosion Test Protocol</td>
<td>95</td>
<td>F-28</td>
</tr>
<tr>
<td><strong>Dr. Chang-Yu Wu</strong>&lt;br&gt;University of Florida</td>
<td>Innovative Welding Technologies to Control HAP Emissions Using Silicon Additives</td>
<td>96</td>
<td>F-29</td>
</tr>
<tr>
<td><strong>Dr. Craig Price</strong>&lt;br&gt;Naval Air Systems Command (NAVAIR)</td>
<td>Evaluation of Improved Metal-Rich Primers for Chromate-Free Corrosion Protection</td>
<td>97</td>
<td>F-30</td>
</tr>
<tr>
<td><strong>Matthew Campbell</strong>&lt;br&gt;Concurrent Technologies Corporation</td>
<td>Ultraviolet (UV)-Curable Coatings for Aerospace Applications</td>
<td>98</td>
<td>F-31</td>
</tr>
<tr>
<td><strong>Dr. Thomas Phely-Bobin</strong>&lt;br&gt;QinetiQ North America, Foster-Miller Inc.</td>
<td>UV Curable Non-Chrome Primer and Advanced Topcoat System</td>
<td>99</td>
<td>F-32</td>
</tr>
<tr>
<td><strong>Dr. John La Scala</strong>&lt;br&gt;U.S. Army Research Laboratory</td>
<td>Demonstration of Composites with Low Hazardous Air Pollutant Contents for Military Applications</td>
<td>100</td>
<td>F-33</td>
</tr>
<tr>
<td><strong>Dr. Lee Magness</strong>&lt;br&gt;U.S. Army Research Laboratory</td>
<td>Demonstration of Nanoscale Tungsten Alternatives to Depleted Uranium in Anti-Armor Penetrators</td>
<td>101</td>
<td>F-34</td>
</tr>
<tr>
<td><strong>Mr. Matthew Scott</strong>&lt;br&gt;PPG Industries, Inc.</td>
<td>Zinc Rich Coatings for High-Strength Fasteners</td>
<td>102</td>
<td>F-35</td>
</tr>
<tr>
<td><strong>Dr. Gerald Frankel</strong>&lt;br&gt;The Ohio State University</td>
<td>Scientific Understanding of Non-Chromated Corrosion Inhibitors Function</td>
<td>103</td>
<td>F-36</td>
</tr>
<tr>
<td><strong>Moshe Moked</strong>&lt;br&gt;Distek North America, LLC</td>
<td>ArmorGalV® Thermal Diffusion – Environment-Friendly, Cost Effective</td>
<td>104</td>
<td>F-37</td>
</tr>
<tr>
<td><strong>Timothy Hoehman</strong>&lt;br&gt;Tinker Air Force Base</td>
<td>Robotic Laser Coating Removal System</td>
<td>105</td>
<td>F-38</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP: Energetic Materials and Munitions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Trevor Griffiths QinetiQ</td>
<td>Formulation and Performance Testing of Novel Pyrotechnic Incendiary Compositions</td>
<td>106</td>
<td>F-39</td>
</tr>
</tbody>
</table>

**Sustainable Infrastructure (SI)**

<table>
<thead>
<tr>
<th>SI: Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Aniket Sawant O’Brien &amp; Gere</td>
</tr>
<tr>
<td>Ms. Kathleen Moxley NASA Goddard Space Flight Center (GSFC)</td>
</tr>
<tr>
<td>Mr. Jeremy Alcorn Concurrent Technologies Corporation (CTC)</td>
</tr>
<tr>
<td>Mr. Jeremy Alcorn Concurrent Technologies Corporation (CTC)</td>
</tr>
<tr>
<td>Dr. Igor Linkov U.S. Army Engineer Research and Development Center</td>
</tr>
<tr>
<td>Dr. Bart Chadwick Space and Naval Warfare Systems Center Pacific (Code 17150)</td>
</tr>
<tr>
<td>I. Sam Higuchi NASA</td>
</tr>
<tr>
<td>Dr. Joseph F. Donoghue Florida State University</td>
</tr>
<tr>
<td>Dr. Paul Kirshen Battelle</td>
</tr>
</tbody>
</table>

**SI: Energy**

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. John M. Liu Naval Surface Warfare Center Carderock Division</td>
</tr>
<tr>
<td>Saiful Rahman Virginia Tech - Advanced Research Institute</td>
</tr>
<tr>
<td>Manisa Pipattanasomporn Virginia Tech - Advanced Research Institute</td>
</tr>
<tr>
<td>Shengnan Shao Virginia Tech - Advanced Research Institute</td>
</tr>
<tr>
<td>PRESENTER ORGANIZATION</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td><strong>SI: Cultural Resources</strong></td>
</tr>
</tbody>
</table>
| Mr. Chris Inaba  
Naval Facilities Engineering Service Center | Performance-Based Non-Destructive Load Assessment Tools for Historic Buildings and Structures | 52 | F-55 |
| Dr. Eileen Ernenwein  
University of Arkansas | Streamlined Archaeogeophysical Data Processing and Integration for DoD Field Use: Results of Large-Area Geophysical Survey at Presidio Los Adaes, Louisiana | 53 | F-56 |
| Jeffrey H. Altschul  
SRI Foundation | Formal Predictive Models of Archaeological Site Location | 54 | F-57 |
| Thomas Boothby  
The Pennsylvania State University | A Combined Dynamic Method for Non-Destructive Evaluation of Concrete Beams | 55 | F-58 |
| **SI: Environmental Noise** | | | |
| Dr. Adam M. Fincham  
University of Southern California | Ocean Sonic Boom Models for Environmental Impact of Space Launch Vehicles, Space Reentry and Supersonic Overflight: Theoretical and Experimental Results | 62 | F-59 |
| Matthew Rhudy  
University of Pittsburgh | Real-Time Military Impulse Noise Classifier | 63 | F-60 |
| Mr. Edward T. Nykaza  
U.S. Army ERDC-CERL | Community Attitudes Toward Military Blast Noise | 64 | F-61 |
| **SI: Natural Resources** | | | |
| Ms. Sara Zeigler  
University of Maryland | The Use of Population Viability Analysis in the Recovery of Plant Species Listed under the U.S. Endangered Species Act | 49 | F-62 |
| Dr. Maile Neel  
University of Maryland | An Ecoinformatic Approach to Developing Recovery Goals and Objectives | 50 | F-63 |
| Carl Qualls  
University of Southern Mississippi | Intrinsic and Extrinsic Causes of Low Hatching Success of Gopher Tortoise Eggs | 51 | F-64 |
| Dr. Richard Lance  
U.S. Army ERDC Environmental Lab | Habitat Degradation and Impacts on Population Genetics in Two Endangered Songbirds | 65 | F-65 |
| Dr. Richard Lance  
U.S. Army ERDC Environmental Lab | Genetic Structuring Among Hibernacula Populations of the Endangered Gray Bat (Myotis Grisescens) | 66 | F-66 |
| Dr. Mary Calebk  
Desert Research Institute | Operational Standards for Deployment of Desert Tortoise Detection Dog Teams | 67 | F-67 |
| Dawn M. Lawson  
NAVFAC Southwest | Developing Management Strategies for Multiple Species Using Population Viability Models in a Highly Fragmented Landscape in the Context of Climate Change | 68 | F-68 |
| Dr. Brian Hudgens  
Institute for Wildlife Studies | Using Movement Behaviors to Determine Connectivity in Complex Landscapes | 69 | F-69 |
| Dr. Jeff Walters  
Virginia Tech | A Decision Support System for Identifying and Ranking Critical Habitat Parcels for Red-Cockaded Woodpeckers on and Around Department of Defense Installations | 70 | F-70 |
| Dr. R. Todd Jobe  
The University of North Carolina | A Test of Umbrella Species for Habitat Connectivity | 71 | F-71 |
| Anne Trainor  
University of North Carolina - Chapel Hill | Estimating the Connectivity of Red-Cockaded Woodpecker (Picoides Borealis) by Incorporating Prospecting Behavior and Landscape Features at North Carolina’s Fort Bragg Military Installation | 72 | F-72 |
<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Pamela Reid</td>
<td>University of Miami-RSMAS</td>
<td>Landscape Mosaics of Coral Reefs: Powerful Tools for Community Assessment and Monitoring</td>
<td>79</td>
<td>F-73</td>
</tr>
<tr>
<td>Robert Mitchell</td>
<td>Joseph W. Jones Ecological Research Center</td>
<td>Dynamic References in Ecological Restoration: Accounting for Temporal</td>
<td>80</td>
<td>F-74</td>
</tr>
<tr>
<td>Elizabeth K. Mojica</td>
<td>College of William and Mary</td>
<td>Use of Satellite Telemetry to Inform Management of Bald Eagles at Aberdeen Proving Ground, Maryland</td>
<td>81</td>
<td>F-75</td>
</tr>
<tr>
<td>Dr. Henriette Jager</td>
<td>Oak Ridge National Laboratory</td>
<td>Model Experiments to Evaluate Factors Limiting Shortnose Sturgeon in the Ogeechee River</td>
<td>82</td>
<td>F-76</td>
</tr>
<tr>
<td>Bernd Blossey</td>
<td>Cornell University</td>
<td>Understanding and Managing Multiple Stressors that Impact Threatened and Endangered Plant Species</td>
<td>83</td>
<td>F-77</td>
</tr>
<tr>
<td>Dr. Katherine Strickler</td>
<td>University of Idaho</td>
<td>Modeling Population Viability of Species of Concern using Count Data</td>
<td>84</td>
<td>F-78</td>
</tr>
<tr>
<td>Dr. Doug Bruggeman</td>
<td>Michigan State University</td>
<td>Development of Habitat Trading Programs for Military Installations and their Neighbors Through Adaptive Management</td>
<td>85</td>
<td>F-79</td>
</tr>
<tr>
<td>Dr. Michael J. Blum</td>
<td>Tulane University</td>
<td>Development and Use of Genetic Methods for Assessing Aquatic Environmental Condition on Pacific Islands</td>
<td>86</td>
<td>F-80</td>
</tr>
<tr>
<td>Dr. Leslie Ries</td>
<td>University of Maryland</td>
<td>Using Edge Response Information to Choose the Best Sites for Management Action</td>
<td>87</td>
<td>F-81</td>
</tr>
<tr>
<td>Ms. Marissa Brand</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Integration and Validation of Avian Radars</td>
<td>88</td>
<td>F-82</td>
</tr>
<tr>
<td>Dr. Betsy A. Bancroft</td>
<td>University of Washington</td>
<td>Exploring the Effects of Climate Change and Disease on Desert Tortoises</td>
<td>89</td>
<td>F-83</td>
</tr>
<tr>
<td>Mr. Chad Wilsey</td>
<td>University of Washington</td>
<td>The Potential Effects of Military Training Activities, Habitat Management, and Climate-Induced Vegetation Change on Black-Capped Vireo Populations at Fort Hood, TX</td>
<td>90</td>
<td>F-84</td>
</tr>
<tr>
<td>Dr. Nathan Schumaker</td>
<td>U.S. Environmental Protection Agency</td>
<td>HexSim: A Flexible Simulation Model for Forecasting Wildlife Responses to Multiple Interacting Stressors</td>
<td>91</td>
<td>F-85</td>
</tr>
<tr>
<td>Dr. Anna Pidgeon</td>
<td>University of Wisconsin-Madison</td>
<td>Mapping the Abundance and Occurrence of Birds at Fort Bliss and Fort McCoy Using Landsat TM/ETM+ Imagery</td>
<td>92</td>
<td>F-86</td>
</tr>
</tbody>
</table>

**Munitions Management (MM)**

<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Brian Houston</td>
<td>Naval Research Laboratory</td>
<td>Broadband, Multi-Aspect Scattering from UXO</td>
<td>107</td>
<td>F-87</td>
</tr>
<tr>
<td>Dr. Michael DeWeert</td>
<td>BAE Systems Spectral Solutions</td>
<td>REVEAL LiDar for High-Resolution 3D Underwater UXO Detection</td>
<td>108</td>
<td>F-88</td>
</tr>
<tr>
<td>Dr. Gregory Schultz</td>
<td>Sky Research, Inc.</td>
<td>Underwater Ordnance Characterization Using AUV Technology</td>
<td>109</td>
<td>F-89</td>
</tr>
<tr>
<td>Dr. Roland Gritto</td>
<td>Array Information Technology</td>
<td>Detection and Classification of Underwater UXO Using Resonance Scattering Sonar</td>
<td>111</td>
<td>F-90</td>
</tr>
<tr>
<td>Mike Putnam</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Demonstration of the Laser Line Scan System for Underwater UXO Characterization</td>
<td>112</td>
<td>F-91</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
</table>
| Mr. Andrew Schwartz  
U.S. Army Corps of Engineers | High Accuracy Positioning and Navigation for Underwater MEC Operations | 113 | F-92 |
| Dr. Raymond Lim  
Naval Surface Warfare Center  
Panama City Division | Pond Measurements to Investigate Sonar Detection and Classification of Underwater UXO | 114 | F-93 |
| Professor Fridon Shubitidze  
Dartmouth College/Sky Research, Inc. | 3D Numerical Modeling of Underwater Electromagnetic Induction Phenomena: Assessing EMI Noise Due to the Marine Environment | 115 | F-94 |
| Professor Shahriar Negahdaripour  
University of Miami | Belief Theoretic Multi-Sensory Data Fusion for Underwater UXO Identification | 116 | F-95 |
| Robert Siegel  
SAIC | Underwater Simultaneous EMI and Magnetometer System (USEMS) | 130 | F-96 |
| Mr. William Wild  
SPAWAR Systems Center Pacific  
(Code 17151) | Mitigation of U/W UXO Blow-In-Place Explosions with Bubble Curtains | 131 | F-97 |
| Eugene Lavely  
BAE Systems AIT | RVM Classifier Performance for Buried Munitions Using Buried Object Sonar System (BOSS) Low-Frequency Data | 132 | F-98 |
| Richard Funk  
Tetra Tech, Inc. | Bringing the Full Dual-Coil EM61-MKII High Power Underwater for MEC Detection | 133 | F-99 |
| Dr. Steven G. Kargl  
University of Washington | Underwater UXO Detection and Classification via Synthetic Aperture Sonar and Acoustic Templates | 134 | F-100 |
| Jong Ki Lee  
The Ohio State University | Handheld Geolocation System (HGS) for UXO Detection and Discrimination Using Low-Cost IMU | 110 | F-101 |
| Professor Dorota Grejner-Brzezinska  
The Ohio State University | Performance Assessment of Quadruple Sensor Integration Based Geolocation Technology for Geophysical Sensors for Detection and Discrimination of Unexploded Ordnance | 135 | F-102 |
| Dr. Bruce Barrow  
SAIC | Field Demonstration of an EMI/IMU System to Locally Interrogate Buried UXO | 136 | F-103 |
| Mr. Larry Tinney  
TerraSpectra Geomatics | Improved Use of Historical Photography for FUDS Assessments | 137 | F-104 |
| Dr. William Doll  
Battelle | Examination of Airborne FDEM System Attributes for UXO Mapping and Detection | 138 | F-105 |
| Dr. William Doll  
Battelle | Demonstration of the Battelle TEM-8 Airborne Electromagnetic System for Mapping and Detection of UXO | 139 | F-106 |
| Burton Bridge  
Tetra Tech, Inc. | Wide Area Assessment for Marine Munitions and Explosives of Concern | 140 | F-107 |
| Ms. Victoria Kantsios  
URS Corporation | Wide Area Assessment Cost-Benefit Analysis - Active Army MMRP | 141 | F-108 |
| Mr. Dale Bennett  
URS Corporation | LiDAR and Orthophotos in UXO/MEC Wide Area Assessment: Lessons Learned | 153 | F-109 |
| Dr. Roelof Versteeg  
Idaho National Laboratory | Development of Autonomous Magnetometer Rotorcrafts for Wide Area Assessment | 154 | F-110 |

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs. Amy Walker</td>
<td>U.S. Army Engineering &amp; Support Center, Huntsville</td>
<td>Integration of UXO Software Suite</td>
<td>155</td>
<td>F-111</td>
</tr>
<tr>
<td>Mr. Bill Harmon</td>
<td>Michigan Department of Environmental Quality</td>
<td>Quality Considerations for Munitions Response Projects</td>
<td>156</td>
<td>F-112</td>
</tr>
<tr>
<td>Mrs. Janine Latham</td>
<td>Weston Solutions</td>
<td>GIS and RDMS Integration During a Multi-Phase Munitions and Explosives of Concern (MEC) Removal Action</td>
<td>157</td>
<td>F-113</td>
</tr>
<tr>
<td>Mr. John Hathaway</td>
<td>Pacific Northwest National Laboratory</td>
<td>When Can I Stop Digging? A Bayesian Method for Quantifying the Probability of No UXO Remaining as Remediation Progresses</td>
<td>158</td>
<td>F-114</td>
</tr>
<tr>
<td>Mr. M. Andy Kass</td>
<td>Colorado School of Mines</td>
<td>Enhancement of TEM Data and Noise Characterization by Principal Component Analysis</td>
<td>159</td>
<td>F-115</td>
</tr>
<tr>
<td>Dr. Paul Hatzinger</td>
<td>Shaw Environmental, Inc.</td>
<td>Evaluating the Origin of Natural Perchlorate Using Stable Isotope Analysis</td>
<td>117</td>
<td>F-116</td>
</tr>
<tr>
<td>Neil C. Sturchio</td>
<td>University of Illinois at Chicago</td>
<td>Chlorine-36 as a Tracer of Perchlorate Origin</td>
<td>118</td>
<td>F-117</td>
</tr>
<tr>
<td>Dr. Marc Deshusses</td>
<td>Duke University</td>
<td>Perchlorate Reduction in a Bioreactor Packed with Zero-Valent Iron</td>
<td>119</td>
<td>F-118</td>
</tr>
<tr>
<td>Gregory Harvey</td>
<td>U.S. Air Force</td>
<td>A Survey of European Soil Perchlorate Levels</td>
<td>120</td>
<td>F-119</td>
</tr>
<tr>
<td>Reema Bansal</td>
<td>University of Idaho</td>
<td>Quantification of Perchlorate and Chlorate Reducing Enzymes Using Liquid Chromatography and Mass Spectrometry (LC-MS/MS) Based Methods</td>
<td>121</td>
<td>F-120</td>
</tr>
<tr>
<td>Dr. Patrick Evans</td>
<td>CDM</td>
<td>Field Demonstration of the Membrane Biofilm Reactor for Perchlorate Treatment in Drinking Water</td>
<td>126</td>
<td>F-121</td>
</tr>
<tr>
<td>Dr. Patrick Evans</td>
<td>CDM</td>
<td>Perchlorate and Nitrate Bioremediation in Vadose Zone Soil by Gaseous Electron Donor Injection Technology (GEDIT)</td>
<td>127</td>
<td>F-122</td>
</tr>
<tr>
<td>Dr. Don Cropek</td>
<td>U.S. Army Corps of Engineers Construction Engineering Research Laboratory</td>
<td>Lab-on-a-Chip Sensor for Monitoring Perchlorate in Ground and Surface Water</td>
<td>128</td>
<td>F-123</td>
</tr>
<tr>
<td>Andrea Davis</td>
<td>Applied Research Associates, Inc.</td>
<td>Large-Scale Demonstration of Weak Base Anion Resin: Removing Perchlorate from Drinking Water</td>
<td>129</td>
<td>F-124</td>
</tr>
<tr>
<td>Pei-Fang Wang</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Defining Munition Constituent (MC) Source Terms in Aquatic Environments on DoD Ranges</td>
<td>142</td>
<td>F-125</td>
</tr>
<tr>
<td>Marianne Walsh</td>
<td>U.S. Army ERDC-CRREL</td>
<td>Multi-Increment Sampling to Estimate the Accumulation of Propellant Residues at Firing Points</td>
<td>143</td>
<td>F-126</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Fanny Monteil-Rivera</td>
<td>National Research Council of Canada, Biotechnology Research Institute</td>
<td>Dissolution and Photodegradation of a New Propellant Formulation Containing HMX and TEGDN</td>
<td>144</td>
<td>F-127</td>
</tr>
<tr>
<td>Sylvie Rocheleau, M.SC.A.</td>
<td>National Research Council Canada, Biotechnology Research Institute</td>
<td>Benchmark Toxicity Data for Energetic Materials for Developing the Terrestrial Plant-Based Ecological Soil Screening Levels (ECO-SSL)</td>
<td>145</td>
<td>F-128</td>
</tr>
<tr>
<td>Dr. Mark Johnson</td>
<td>U.S. Army Center for Health Promotion and Preventive Medicine</td>
<td>Development of Toxicity Data for Munition Compounds to Support Toxicity Reference Value Derivations for Wildlife</td>
<td>148</td>
<td>F-129</td>
</tr>
<tr>
<td>Dr. Roman G. Kuperman</td>
<td>U.S. Army Edgewood Chemical Biological Center</td>
<td>The Effects of 2,4-DNT, 2-ADNT, 4-ADNT, and NG on Soil Biological Processes</td>
<td>149</td>
<td>F-130</td>
</tr>
<tr>
<td>Dr. Roman G. Kuperman</td>
<td>U.S. Army Edgewood Chemical Biological Center</td>
<td>Benchmark Toxicity Data for Energetic Materials for Developing the Soil Invertebrate-Based Ecological Soil Screening Levels (ECO-SSL)</td>
<td>150</td>
<td>F-131</td>
</tr>
<tr>
<td>Dr. Emmanuela Diaz</td>
<td>Defence Research and Development Center – Valcartier</td>
<td>Residual Dinitrotoluenes from Open Burning of Gun Propellant</td>
<td>151</td>
<td>F-132</td>
</tr>
<tr>
<td>Dr. Sonia Thiboutot</td>
<td>Defence Research and Development Center – Valcartier</td>
<td>Prototype Table for the Burning of Excess Artillery Propellant Bags</td>
<td>152</td>
<td>F-133</td>
</tr>
<tr>
<td>Mr. Alan D. Hewitt</td>
<td>U.S. Army ERDC-CRREL</td>
<td>Method 8330B and Multi-Increment Sampling</td>
<td>167</td>
<td>F-134</td>
</tr>
<tr>
<td>Jared Johnson</td>
<td>U.S. Army Corps of Engineers-Engineer Research and Development Center</td>
<td>Development of a Continuous Electrochemical Reactor for the Destruction of Munitions Constituents in Water</td>
<td>168</td>
<td>F-135</td>
</tr>
<tr>
<td>Carlton T. Phillips</td>
<td>U.S. Army Edgewood Chemical Biological Center</td>
<td>Toxicity to Folsomia Candida of Energetic Materials Weathered-and-Aged in a Natural Sandy Soil</td>
<td>169</td>
<td>F-136</td>
</tr>
<tr>
<td>Ghalib Bardai</td>
<td>National Research Council Canada, Biotechnology Research Institute</td>
<td>Role of Nitrite in Nitroglycerin (NG) Induced Microphthalmia in Quail Embryos</td>
<td>170</td>
<td>F-137</td>
</tr>
<tr>
<td>Dr. Ronnie Britto</td>
<td>Tetra Tech, Inc.</td>
<td>Full-Scale Alkaline Hydrolysis of Explosives-Contaminated Soil</td>
<td>171</td>
<td>F-138</td>
</tr>
<tr>
<td>Dr. Anthony Bednar</td>
<td>U.S. Army Corps of Engineers-Engineers Research and Development Center-Environmental Laboratory</td>
<td>Field Portable GC-MS for Semi-Volatile Compound Analysis in Groundwater</td>
<td>174</td>
<td>F-139</td>
</tr>
<tr>
<td>Dr. Stuart Strand</td>
<td>University of Washington</td>
<td>Enhancing Bacterial Degradation of RDX in the Rhizosphere</td>
<td>175</td>
<td>F-140</td>
</tr>
<tr>
<td>Steve Muffler, P.G., C.G.W.P.</td>
<td>Tetra Tech, Inc.</td>
<td>Remediation Challenges and Successes for RDX and TNT in Soil: Field-Scale Biotreatment and Chemical Treatment at the Iowa Army Ammunition Plant</td>
<td>176</td>
<td>F-141</td>
</tr>
<tr>
<td>Dr. Jerald Schnoor</td>
<td>The University of Iowa</td>
<td>Phytoremediation for the Containment and Treatment of Energetic and Propellant Material on Testing and Training Ranges</td>
<td>177</td>
<td>F-142</td>
</tr>
<tr>
<td>PRESENTER</td>
<td>ORGANIZATION</td>
<td>POSTER TITLE</td>
<td>POSTER</td>
<td>PAGE</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>Neil C. Bruce</td>
<td>University of York</td>
<td>Engineering Transgenic Grasses for In Situ Treatment of RDX and TNT</td>
<td>190</td>
<td>F-143</td>
</tr>
<tr>
<td>Neil C. Bruce</td>
<td>University of York</td>
<td>Detoxification of the Explosive TNT by Endogenous Enzymes in Arabidopsis</td>
<td>191</td>
<td>F-144</td>
</tr>
<tr>
<td>Mrs. Deborah Walker</td>
<td>U.S. Army Engineering Support Center Huntsville</td>
<td>Real World Munitions Constituents Results for Your Research Consideration</td>
<td>192</td>
<td>F-145</td>
</tr>
<tr>
<td>Dan Badulescu</td>
<td>University of British Columbia</td>
<td>Genomic Technologies for RDX Remediation: Charting Social Acceptability in North America</td>
<td>193</td>
<td>F-146</td>
</tr>
<tr>
<td>Mrs. Carmen Lebrón</td>
<td>Naval Facilities Engineering Command-Engineering Service Center</td>
<td>Verification of Methods for Assessing the Sustainability of Monitored Natural Attenuation (MNA)</td>
<td>122</td>
<td>F-147</td>
</tr>
<tr>
<td>Mrs. Carmen Lebrón</td>
<td>Naval Facilities Engineering Command-Engineering Service Center</td>
<td>Improving Effectiveness of Bioremediation at DNAPL Source Zone Sites by Applying Partitioning Electron Donors (PEDs)</td>
<td>123</td>
<td>F-148</td>
</tr>
<tr>
<td>Mrs. Carmen Lebrón</td>
<td>Naval Facilities Engineering Command-Engineering Service Center</td>
<td>Standardized Procedures for Use of Nucleic Acid-Based Tools for Microbial Monitoring</td>
<td>124</td>
<td>F-149</td>
</tr>
<tr>
<td>Dr. Michael Kavanaugh</td>
<td>Malcolm Pirnie, Inc.</td>
<td>Diagnostic Tools for Performance Evaluation of Innovative In-Situ Remediation Technologies at Chlorinated Solvent Contaminated Sites</td>
<td>125</td>
<td>F-150</td>
</tr>
<tr>
<td>Ms. Yujie Men</td>
<td>University of California, Berkeley</td>
<td>Application of Molecular and Analytic Tools to Track Enrichment of Reductive Dechlorination Cultures from a TCE Contaminated Groundwater Site</td>
<td>146</td>
<td>F-151</td>
</tr>
<tr>
<td>Dr. Rick Johnson</td>
<td>Oregon Health and Science University</td>
<td>Depth-Resolved Molecular Biological Analysis of Groundwater Contaminant Plumes: Advantages of Cryogenic Core Collection</td>
<td>195</td>
<td>F-152</td>
</tr>
<tr>
<td>Kaneen Christensen</td>
<td>Colorado School of Mines</td>
<td>Bench-Scale Fracture Network Experiments: Evaluating DNAPL Dissolution Rates as a Function of DNAPL-Water Interfacial Area and DNAPL Dissolution Kinetics During Chemical Oxidation</td>
<td>211</td>
<td>F-153</td>
</tr>
<tr>
<td>Paul G. Tratnyek</td>
<td>Oregon Health and Science University</td>
<td>Injection of Nano Zero-Valent Iron for Subsurface Remediation: A Field Scale Test of Materials, Methods, and Models</td>
<td>218</td>
<td>F-154</td>
</tr>
<tr>
<td>Ms. Amanda Struse</td>
<td>CH2M Hill</td>
<td>Use of Mobile Injection Trailers to Complete Large-Scale Permanganate Injection</td>
<td>219</td>
<td>F-155</td>
</tr>
<tr>
<td>Pamela Dugan</td>
<td>Carus Corporation</td>
<td>Enhancing ISCO of DNAPL Using Encapsulated Permanganate: Selective Oxidation and Controlled Release Studies</td>
<td>220</td>
<td>F-156</td>
</tr>
<tr>
<td>Jeff A. K. Silva</td>
<td>Colorado School of Mines</td>
<td>Optimizing Fluid Formulations and Design Simulations for Implementing Polymer-Amended Permanganate Treatment at the Field-Scale</td>
<td>221</td>
<td>F-157</td>
</tr>
<tr>
<td>Mr. Ki Young Cha</td>
<td>North Carolina State University</td>
<td>A Spreadsheet Tool for Designing ISCO Systems with Permanganate</td>
<td>222</td>
<td>F-158</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Vijay John</td>
<td>Tulane University</td>
<td>Multifunctional Nanocolloids for Environmental Remediation of Chlorinated Hydrocarbons</td>
<td>227</td>
<td>F-159</td>
</tr>
<tr>
<td>Mr. Joey Trotsky</td>
<td>Naval Facilities Engineering Command-Engineering Service Center</td>
<td>A Low Cost Passive Approach for Large-Scale Source Area Bioaugmentation</td>
<td>228</td>
<td>F-160</td>
</tr>
<tr>
<td>Mr. Richard Wice</td>
<td>Shaw Environmental, Inc.</td>
<td>Post ERH Bioaugmentation at Air Force Plant 4</td>
<td>229</td>
<td>F-161</td>
</tr>
<tr>
<td>Dr. Kent S. Sorenson, Jr.</td>
<td>CDM</td>
<td>Demonstration of Enhanced Mass Transfer During Bioremediation of TCE DNAPL</td>
<td>232</td>
<td>F-162</td>
</tr>
<tr>
<td>Kimberly A. Wilson</td>
<td>South Carolina Department of Health and Environmental Control</td>
<td>ITRC’S Permeable Reactive Barrier Technology Update</td>
<td>233</td>
<td>F-163</td>
</tr>
<tr>
<td>Dr. Robert J. Steffan</td>
<td>Shaw Environmental, Inc.</td>
<td>Factors Affecting the Success of Bioaugmentation Applications</td>
<td>235</td>
<td>F-165</td>
</tr>
<tr>
<td>Mr. Mark Kluger</td>
<td>Dajak, LLC</td>
<td>Enhancing Abiotic Reaction Rates Using ERH as a Sustainable Remediation Solution at Two DoD Sites</td>
<td>236</td>
<td>F-166</td>
</tr>
</tbody>
</table>

**ER: Chlorinated Solvents — Site Characterization, Monitoring, and Processing**

<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. Evan Cox</td>
<td>Geosyntec Consultants</td>
<td>The Truth Is Out There: Unraveling the Mystery of the Missing DCE, Vinyl Chloride &amp; Ethene</td>
<td>172</td>
<td>F-167</td>
</tr>
<tr>
<td>M. Hope Lee</td>
<td>Idaho National Laboratory</td>
<td>Enzyme Activity Probes (EAP) for Estimating TCE Degradation Rates</td>
<td>173</td>
<td>F-168</td>
</tr>
<tr>
<td>Dr. Rick Johnson</td>
<td>Oregon Health and Science University</td>
<td>A New Core Sampler for Cryogenic Collection of Complete Subsurface Samples for Molecular Biological Tools Analysis</td>
<td>194</td>
<td>F-169</td>
</tr>
<tr>
<td>Dr. Natuschka M. Lee</td>
<td>Technical University of Munich</td>
<td>Comparison of PCR and Fish for Detection of Bacteria in Dechlorinating Samples</td>
<td>196</td>
<td>F-170</td>
</tr>
<tr>
<td>Dr. Frank Löeffler</td>
<td>Georgia Institute of Technology</td>
<td>Microarrays for Reductive Dechlorination Biomarker Identification and Dehalococcoides Monitoring</td>
<td>197</td>
<td>F-171</td>
</tr>
<tr>
<td>Paul J. McMurdie</td>
<td>Stanford University</td>
<td>Elucidating the Role of Horizontal Gene Transfer in Vinyl Chloride Respiration of Dehalococcoides Through Comparative Genomics</td>
<td>198</td>
<td>F-172</td>
</tr>
<tr>
<td>Ms. Kimberlee A. West</td>
<td>University of California, Berkeley</td>
<td>Transcriptome Analyses of Unsequenced Dehalococcoides Strains in Dechlorinating Enrichment Cultures Using a Genus-Wide Microarray</td>
<td>199</td>
<td>F-173</td>
</tr>
<tr>
<td>Professor Lewis Semprini</td>
<td>Oregon State University</td>
<td>Comparison of Lactate, Formate, and Propionate as Substrates for TCE Reductive Dehalogenation in a Continuous-Flow Column</td>
<td>200</td>
<td>F-174</td>
</tr>
</tbody>
</table>

**ER: Chlorinated Solvents — Plume Remediation and Management**

<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Michael Lepuil</td>
<td>Tetra Tech, Inc.</td>
<td>Comparison of Fish Versus PCR-Based Quantification of Dehalococcoides Cells in PCE/TCE-Contaminated Groundwater</td>
<td>147</td>
<td>F-175</td>
</tr>
<tr>
<td>PRESENTER</td>
<td>ORGANIZATION</td>
<td>POSTER TITLE</td>
<td>POSTER</td>
<td>PAGE</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>Dr. Allen Shapiro</td>
<td>U.S. Geological Survey</td>
<td>Designing Monitoring Locations in Fractured Rock for Remediation of Chloroethene Contaminated Groundwater</td>
<td>212</td>
<td>F-176</td>
</tr>
<tr>
<td>Ms. Julie Kirstein</td>
<td>U.S. Geological Survey</td>
<td>Monitoring Microbial Community Structure Before and During Bioaugmentation at the Former Naval Air Warfare Center (NAWC) Site</td>
<td>213</td>
<td>F-177</td>
</tr>
<tr>
<td>Corinne Marks, P.E.</td>
<td>URS Corporation</td>
<td>Solid Potassium Permanganate Emplacement Using Hydraulic Fracturing</td>
<td>215</td>
<td>F-179</td>
</tr>
<tr>
<td>James F. Fein</td>
<td>ECC</td>
<td>Sodium Persulfate Activated with Modified Fenton’s Reagent for the Treatment of Carbon Tetrachloride</td>
<td>216</td>
<td>F-180</td>
</tr>
<tr>
<td>James F. Fein</td>
<td>ECC</td>
<td>Sodium Permanganate for the Treatment of Trichloroethylene</td>
<td>217</td>
<td>F-181</td>
</tr>
<tr>
<td>Bruce M. Henry</td>
<td>Parsons</td>
<td>Loading Rates and Impacts of Substrate Delivery for Enhanced In Situ Anaerobic Bioremediation</td>
<td>230</td>
<td>F-182</td>
</tr>
<tr>
<td>Bruce M. Henry, PG</td>
<td>Parsons</td>
<td>Challenges to Enhanced In Situ Bioremediation of Chlorinated Solvents in a Cold Temperature Environment</td>
<td>231</td>
<td>F-183</td>
</tr>
<tr>
<td>Mr. Prashant Jha</td>
<td>Stony Brook University</td>
<td>Novel Chitosan-Based Processes for Toxic Metal Ion Removal from Acidic Environments</td>
<td>237</td>
<td>F-184</td>
</tr>
<tr>
<td>Mr. Carl Spreng</td>
<td>Colorado Department of Public Health and Environment</td>
<td>A Decision Framework for Applying Attenuation Processes to Metals and Radionuclides</td>
<td>238</td>
<td>F-185</td>
</tr>
<tr>
<td>Ms. Yvette Wieder Lowney</td>
<td>Exponent, Inc.</td>
<td>Validation of an In Vitro Bioaccessibility Test Method for Estimation of the Bioavailability of Arsenic from Soil</td>
<td>239</td>
<td>F-186</td>
</tr>
<tr>
<td>Dr. Lisa Axe</td>
<td>New Jersey Institute of Technology</td>
<td>Assessing Speciation: Beneficial Reuse of Phosphate and Thermal Treated Sediments and the Potential for Metal Leaching into Groundwater</td>
<td>240</td>
<td>F-187</td>
</tr>
<tr>
<td><strong>ER: Heavy Metals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Susan Hubbard</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Geophysical Imaging for Investigating the Delivery and Distribution of Amendments in the Heterogeneous Subsurface of the F. E. Warren Air Force Base</td>
<td>162</td>
<td>F-188</td>
</tr>
<tr>
<td>Dr. Herman Lemmens</td>
<td>FEI</td>
<td>Ultrafast Particle Characterization: Measuring the Previously Immeasurable in Environmental Samples Using New Automated Technologies</td>
<td>163</td>
<td>F-189</td>
</tr>
<tr>
<td>Tomasz Kalinowski</td>
<td>The Biodesign Institute at Arizona State University</td>
<td>In Situ Sediment Column Microcosms for Studying Bioremediation</td>
<td>164</td>
<td>F-190</td>
</tr>
<tr>
<td>Ms. Louise Parker</td>
<td>U.S. Army ERDC-CRREL</td>
<td>Final Conclusions from Demonstrations of the Snap Sampler Passive Ground Water Sampling Device</td>
<td>165</td>
<td>F-191</td>
</tr>
<tr>
<td>Mr. Alan D. Hewitt</td>
<td>U.S. Army ERDC-CRREL</td>
<td>Metallic Residues on Military Training Ranges: Method Development</td>
<td>166</td>
<td>F-192</td>
</tr>
<tr>
<td>Dr. Tiffany Downey</td>
<td>Tetra Tech, Inc.</td>
<td>Statistical Metrics for the Identification of Interdependent Analytes</td>
<td>178</td>
<td>F-193</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. William R. Major</td>
<td>Naval Facilities Engineering Command-Engineering Service Center</td>
<td>Optimized Enhanced Bioremediation Through 4D Geophysical Monitoring and Autonomous Data Collection, Processing, and Analysis</td>
<td>179</td>
<td>F-194</td>
</tr>
<tr>
<td>Linda Maring</td>
<td>Deltares</td>
<td>Location and Activity Specific Site-Management for Military Locations</td>
<td>180</td>
<td>F-195</td>
</tr>
<tr>
<td>June Wolfe</td>
<td>Texas AgriLife Research / Blackland Research and Extension Center</td>
<td>Using Bio-Mediated Sorption Processes to Improve Functionality of Recycled Concrete Materials Used for Pollutant Management in Brackish Coastal Areas</td>
<td>181</td>
<td>F-196</td>
</tr>
<tr>
<td>Dr. Charles J. Newell</td>
<td>GSI Environmental, Inc.</td>
<td>Determining Costs and Sustainability Metrics Using the AFCEE Sustainable Remediation Tool (SRT) and RACER</td>
<td>182</td>
<td>F-197</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ER: Vapor Intrusion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms. Emily H. Majcher</td>
<td>Geosyntec Consultants</td>
<td>CSM Development Through Field Investigation and Assessment: Implementation of a Strategic Approach for Complex VI Assessment at a Large Military Facility</td>
<td>161</td>
<td>F-198</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ER: Sediments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Charles Menzie</td>
<td>Exponent, Inc.</td>
<td>Results of a Treatability Study for Sediment™</td>
<td>160</td>
<td>F-199</td>
</tr>
<tr>
<td>Ms. Amy Hawkins</td>
<td>Naval Facilities Engineering Command-Engineering Service Center</td>
<td>In Situ Wetland Remediation Demonstration</td>
<td>184</td>
<td>F-201</td>
</tr>
<tr>
<td>Lt. Col. Robert G. Bozic</td>
<td>United States Military Academy</td>
<td>Peptide Separator Electrochemical Sensor (PSES) for the Long Term Monitoring of Munitions Constituents in Ground Water</td>
<td>185</td>
<td>F-202</td>
</tr>
<tr>
<td>Dr. Joseph Gailani</td>
<td>U.S. Army Corps of Engineers</td>
<td>Shear Stress Measurements and Erosion Implications for Wave and Combined Wave-Current Generated Flows</td>
<td>186</td>
<td>F-203</td>
</tr>
<tr>
<td>Dr. Bart Chadwick</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Demonstration of an In-Situ Friction-Sound Probe for Mapping Particle Size at Contaminated Sediment Sites</td>
<td>187</td>
<td>F-204</td>
</tr>
<tr>
<td>Philip Gschwend</td>
<td>Massachusetts Institute of Technology</td>
<td>Using a Few Performance Reference Compounds in Polyethylene Passive Samplers to Deduce Sediment Porewater Concentrations for Numerous Target Chemicals</td>
<td>188</td>
<td>F-205</td>
</tr>
<tr>
<td>Dr. James Leather</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Integrated Forensics Approach to Fingerprint Sediment PCB Sources</td>
<td>189</td>
<td>F-206</td>
</tr>
<tr>
<td>Dr. Cheng Gu</td>
<td>Michigan State University</td>
<td>Highly Reactive Subnano-Sized Zero-Valent Iron Synthesized on Smectite Clay Templates</td>
<td>201</td>
<td>F-207</td>
</tr>
<tr>
<td>Dr. Helen Hsu-Kim</td>
<td>Duke University</td>
<td>A New Look at the Bioavailability and Methylation Potential of Mercury Sulfides in Sediments</td>
<td>202</td>
<td>F-208</td>
</tr>
<tr>
<td>Dr. Bart Chadwick</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Demonstration and Validation of Enhanced Monitored Natural Recovery at DoD Sites</td>
<td>203</td>
<td>F-209</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. John Cargill</td>
<td>ITRC’S Technical and Regulatory Guidance for Incorporating Bioavailability Considerations in the Evaluation and Remediation of Contaminated Sediments</td>
<td>204</td>
<td>F-210</td>
</tr>
<tr>
<td>Richard Luthy</td>
<td>Measurement and Modeling of Ecosystem Risk and Recovery for In-Situ Treatment of Contaminated Sediments</td>
<td>205</td>
<td>F-211</td>
</tr>
<tr>
<td>Mr. Kenneth L. Dixon</td>
<td>Sequestration of Metals in Active Cap Materials: A Laboratory and Numerical Evaluation</td>
<td>206</td>
<td>F-212</td>
</tr>
<tr>
<td>Zofia Turek</td>
<td>Geochemical and Biological Factors Influencing Metal Accumulation in Benthic Animals</td>
<td>207</td>
<td>F-213</td>
</tr>
<tr>
<td>A. S. Hughes</td>
<td>Objective Identification of Structural Properties Associated with Polychlorinated Biphenyl Dechlorination Processes</td>
<td>208</td>
<td>F-214</td>
</tr>
<tr>
<td>Amanda Hughes</td>
<td>Continuous Time Hidden Markov Model to Determine Dechlorination Pathway Likelihoods of Polychlorinated Biphenyl Congeners</td>
<td>209</td>
<td>F-215</td>
</tr>
<tr>
<td>Dr. Katherine von Stackelberg</td>
<td>Preliminary Assessment of Risk Drivers at Sediment DoD Sites</td>
<td>210</td>
<td>F-216</td>
</tr>
<tr>
<td>Dr. Jeanne M. VanBriesen</td>
<td>PCB Analytical Method Uncertainty and Evaluation of PCB Transformations in Natural Systems</td>
<td>223</td>
<td>F-217</td>
</tr>
<tr>
<td>Dr. Jeanne M. VanBriesen</td>
<td>Evaluation of Reductive Dechlorination of Polychlorinated Biphenyls (PCBs) in Sediment Core Samples Using Tracker Pairs</td>
<td>224</td>
<td>F-218</td>
</tr>
<tr>
<td>Joseph R. Shaw</td>
<td>Combining Deep-Sequencing and Ultra-Dense Microarrays to Define Metal Exposure in the Killifish, Fundulus Heteroclitus</td>
<td>225</td>
<td>F-219</td>
</tr>
<tr>
<td>Piuly Paul</td>
<td>Application of Tools to Measure PCB Microbial Dechlorination and Flux into Water During In-Situ Treatment of Sediments: Microbial Degradation Results</td>
<td>226</td>
<td>F-220</td>
</tr>
<tr>
<td>Dr. Joel Baker</td>
<td>Application of Tools to Measure PCB Microbial Dechlorination and Flux into Water During In-Situ Treatment of Sediments: Resuspension and Desorption Results</td>
<td>241</td>
<td>F-221</td>
</tr>
<tr>
<td>Chris McGrath</td>
<td>Reactive Cap Design for Contaminated Sediment</td>
<td>242</td>
<td>F-222</td>
</tr>
<tr>
<td>Ms. Yan Xu</td>
<td>Bacterial Population Shifts Related to Anaerobic Reductive Dechlorination of Typical PCB Tracker Pairs in Hudson and Grasse Sediment Microcosms</td>
<td>243</td>
<td>F-223</td>
</tr>
<tr>
<td>Elisabeth L. Hawley</td>
<td>Assessing Alternative Endpoints for Groundwater Remediation at Contaminated Sites</td>
<td>244</td>
<td>F-224</td>
</tr>
<tr>
<td>Dr. Stacia L. Thompson</td>
<td>Reductive Dechlorination of Polychlorinated Biphenyl (PCBs) Tracker Pairs in Hudson and Grasse River Sediment Microcosms</td>
<td>245</td>
<td>F-225</td>
</tr>
</tbody>
</table>

Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.
<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>ORGANIZATION</th>
<th>POSTER TITLE</th>
<th>POSTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professor Donna</td>
<td>Rutgers University</td>
<td>Mesocosm-Scale Investigation of PCB Dechlorination in Sediments with Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fennell</td>
<td></td>
<td>Concentration Historical PCB Contamination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upal Ghosh</td>
<td>University of Maryland Baltimore County</td>
<td>Rational Selection of Tailored Amendment Mixtures and Composites for In In</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Situ Remediation of Contaminated Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Igor Linkov</td>
<td>U.S. Army Corps of Engineers-Engineer Research</td>
<td>Test and Validation of Multi-Criteria Decision Analysis Tools in Support of</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>and Development Center</td>
<td>Weight-of-Evidence Evaluation and Remedy Selection in Management of</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contaminated Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Danny Reible</td>
<td>University of Texas</td>
<td>Profiling SPME for Sediment and Remedial Assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Celia Chen</td>
<td>Dartmouth College</td>
<td>The Role of Organic Carbon in Controlling Metal Bioavailability and Trophic</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transfer in Intertidal Food Webs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professor Max</td>
<td>Rutgers University</td>
<td>Quantifying Enhanced Microbial Dehalogenation Impacting the Fate and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haggblom</td>
<td></td>
<td>Transport of Organohalide Mixtures in Contaminated Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professor Max</td>
<td>Rutgers University</td>
<td>Dechlorination of Polychlorinated Dibenzo-P-Dioxins in Soils and Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haggblom</td>
<td></td>
<td>from Areas Sprayed with Agent Orange</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mr. J. David</td>
<td>CH2M Hill</td>
<td>Shallow Application of ISCO Using Alkaline-Activated Persulfate for Treating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grose</td>
<td></td>
<td>Petroleum LNAPL in Heterogeneous Fill Aquifer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mr. Philip Gidley</td>
<td>University of Maryland Baltimore County</td>
<td>Modelling and SPME Measurement of Pore Water PAH Transport in Amended</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sediment Caps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. Allen Burton</td>
<td>University of Michigan</td>
<td>In Situ Based Monitoring Approaches for Improved Risk Assessment of</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contaminated Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Anna Knox</td>
<td>Savannah River National Laboratory</td>
<td>Field Deployment of Active Caps – Assessment of Metal Bioavailability,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erosion, and Toxicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dr. Y. Meriah</td>
<td>SPAWAR Systems Center Pacific</td>
<td>Bacteria, Polychaete, &amp; Geochemical Response to Apatite and Chitin in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arias-Thode</td>
<td></td>
<td>Metals Contaminated Sediments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Refer to the Exhibit Hall Floor Plan in the General Info/Maps section for poster locations.*
SOLIDS SEPARATION AND CONCENTRATION OF SHIPBOARD WASTEWATERS AND RESIDUALS BY A HIGH SHEAR ROTARY MEMBRANE SYSTEM

TRACY M. CAROLE
Naval Surface Warfare Center, Carderock Division
Environmental Quality, Code 634
9500 MacArthur Blvd., Building 60, Room 120
West Bethesda, MD 20817-5700
(301) 227-4893
t Tracy.carole@navy.mil

CO-PERFORMER: Dr. Brian Reed (University of Maryland Baltimore County)

Navy ships generate a variety of liquid wastes: bilge water, blackwater, graywater, shipboard “industrial” wastes and solid residuals from various systems. Many of the Navy’s current waste treatment systems would benefit from the efficient removal of solids. However, available solids removal technologies have not been particularly effective, necessitating the development of improved solids removal technologies. A High Shear Rotary Membrane System (HSR-MS) has shown superior abilities to separate and concentrate a variety of wastewater solids. However, HSR-MS has been confined to land-based applications where space is not a critical design consideration.

HSR-MS is a barrier technology using ultra or microfiltration membranes to separate practically all solids from liquid waste streams. During membrane separation, solids accumulate at the membrane surface decreasing throughput and is the major factor limiting membrane use. Conventional cross-flow systems pump the waste at high flow rates/cross flow velocities parallel to the membrane surface creating a scouring/cleaning action. However, at high feed concentrations/viscosities pumping becomes difficult and the high velocities needed to scour the surface are not possible. In contrast, HSR-MS consist of stacked rotating membrane disks that produce greater turbulence/shear at the membrane surface. By rotating the membrane, scouring energy is applied exactly where it is needed (i.e., membrane surface). The decoupling of the feed delivery/pressurization from turbulence/shear promotion allows the HSR-MS to produce highly concentrated wastes, operate at lower pressures, reduce fouling layer compaction/pore plugging, increase membrane life, and decrease cleaning frequency/residuals production.

Preliminary stirred-cell experiments on shipboard oily bilge wastewater, black-gray wastewater and plasma arc solids incineration wastewater will evaluate membrane-waste behavior in relationship to membrane material (e.g., stainless steel, teflon, polypropylene), membrane permeate flux rates, membrane permeate water quality and membrane restoration capabilities. These results along with preliminary conceptual design improvements and shipboard integration design aspects will be presented.

This work is funded under SERDP Project WP-1671.
ELIMINATION OF ACID CLEANING OF HIGH TEMPERATURE SALT WATER HEAT EXCHANGERS

DENIS COLAHAN
Naval Surface Warfare Center-Philadelphia
1000 Kitty Hawk Avenue
Philadelphia, PA 19112
(215) 897-7231
denis.colahan@navy.mil

CO-PERFORMER: Alfred Phillips (Thermacore)

High-temperature heat exchangers on ships that use sea water generate scaling, a physical phenomenon which results from the reduced solubility of salts at wall temperatures above 150°F—the temperature at which fouling occurs. This precipitation of dissolved solids in the seawater forms scaling, the calcareous deposits, on the tube walls which in turn causes the need for hazardous acid cleaning and excessive system maintenance and component failures. By using heat pipes to control the sea water side wall temperatures of the heat exchanger to below 150°F, scaling and cleaning with hazardous materials is avoided and system reliability improved.

The objective of this ESTCP-Weapons System Platform project (WP-0302) is to validate the elimination of acid cleaning of high temperature sea water heat exchangers, by applying heat pipe technologies to a masker cooler onboard a DDG-51 class ship. The problem of heavy scaling is more acute in bleed air and main condenser heat exchangers due to hot-side operating temperatures as high as 925°F and 525°F, respectively.

The goals for this demonstration are to meet or exceed the current shell and tube performance specifications, demonstrate the elimination of scaling in the heat exchanger thereby increasing the reliability of the cooler and reduce the hazardous material usage/waste generated in cooler cleaning.

During the past 7 years, NSWC has worked with a heat exchanger and heat pipe company to develop this technology for demonstration. A full-scale 425 KW heat exchanger, utilizing heat pipe technology, was delivered to the U.S. Navy in January 2005. In June 2005, the heat pipe cooler and instruments were installed onboard the DDG-61, U.S.S. RAMAGE. Installation of redesigned pre-production cooler is scheduled for ship install October 2009. Production transition pending with FY-10/11 ONR Technology Insertion Program for Savings (TIPS).
The objective of this project is to demonstrate and validate that the on-site biological treatment of expired shelf life paint is an economically and technically practical solution to the problem of waste paint disposal. To accomplish this, a full-scale biological treatment system will be assembled using commercially available components and operated at the demonstration site (PWC Pearl Harbor, HI). Over the course of the project design, cost, and performance data will be collected and used to validate treatment effectiveness and facilitate technology transfer.

Pilot studies used conventional biological batch reactors and biofilters populated by mixed bacterial cultures to demonstrate the biodegradation of non-volatile and volatile components in expired shelf life, solvent-based paints to innocuous and non-hazardous end products. Paint is diluted with water and a centrifugal pump is used to recirculate the reactor contents and emulsify water insoluble components. Rapid degradation of the insoluble components occurs when bacteria colonize the surface of the emulsified components. To promote bacterial growth and enhance biodegradation, the emulsified paint is amended with vitamins, amino acids, and nitrogen and phosphorous, a pH controller is used to maintain a neutral pH, and a high-pressure blower provides air and mixing. Exhaust air is vented through a biofilter charged with compost where volatilized compounds are captured and degraded. Process water from the reactor is passed through a filter press unit and discharged to the sewer. Solids in the ultrafilter concentrate are captured in a filter press and disposed of as non-hazardous solid waste.

Off-site disposal of expired shelf life paint costs $1.70 and $2.20 per pound for bulk waste and one gallon cans respectively, which results in a recurring charge to major facilities (Pearl Harbor, San Diego, and Newport) of more than $500K each per year. Based on the pilot studies and similar biological treatment systems that are used to treat industrial waste, the estimated cost (capital and operation and maintenance) to treat expired shelf life paint will be $0.30 to $0.60 per pound or ~ $230K/year, which represents a savings of $270K/year. Since the cost of a full-scale biological treatment system is ~ $600K, the return on investment for biological treatment is less than 3 years.

This work is funded under ESTCP Project WP-0520.
The need for shipboard wastewater (blackwater and graywater) treatment for military vessels is driven by existing and anticipated future regulations, and current and future military vessel operational requirements. Without treatment, military vessels required to operate in littoral waters for longer periods will be restricted by the limited holding capacity of the ships. The Clean Water Act of 1977 prohibits the discharge of untreated sewage (blackwater) in restricted waters from military or commercial vessels. Additionally, anticipated regulations will require the implementation of shipboard Marine Pollution Control Devices to control graywater discharges for all military vessels. Systems installed on current military vessels could not meet these added requirements, likely restricting operations in littoral waters, which are important to the U.S. Navy and U.S. Coast Guard. Treatment systems are challenged by the high strength wastewater generated shipboard, the need for fast startup to meet effluent quality standards quickly, the limited space for installation, and the lack of highly trained operators and reduced manning available on Department of Defense (DoD) vessels to operate and maintain a treatment system.

Advanced oxidation technology is used commercially and is being proposed for the treatment of shipboard-generated wastewater. However, the DoD has little, if any experience with this technology. A three-year demonstration project is sponsored by the Environmental Security Technology Certification Program (under Project WP-0802) and the Naval Sea Systems Command and managed by the Environmental Quality Division of the Naval Surface Warfare Center Carderock Division. The project will verify that advanced oxidation can be used to produce effluent quality meeting current and anticipated future United States and international standards while handling wastewater generated on military vessels.

The Navalis Orion™ advanced oxidation system was chosen as the test system based on successful land-based applications. The advanced oxidation step exposes ozone to ultraviolet light creating free radicals with high oxidation potential. The short-lived species then react with organic contaminants and impurities in the wastewater to reduce effluent levels of biochemical oxygen demand, total suspended solids and fecal coliform.

The multi-year project will demonstrate the use of advanced oxidation technology by testing the full-size Navalis Orion™ system in the laboratory with simulated shipboard wastewater and then progress to actual shipboard wastewater processing of the same system on a DoD vessel. The overall objectives are to demonstrate that this technology is capable of processing DoD vessel wastewater while meeting treatment requirements, and to evaluate the system installation and operation in a realistic shipboard environment.
Magneto-responsive Nanofiltration Membranes for Treatment of Naval Bilge Waters

HEATH HIMSTEDT
Colorado State University
1370 Campus Delivery
Fort Collins, CO 80523-1370
(501) 207-1539
soybean56@gmail.com

Bilge waters (BW) are naval wastewaters which are oil-water emulsions that often contain dissolved solids and other ship-bound wastes such as detergents, engine oil, etc. BW handling is a major consideration for any naval operation especially since it cannot simply be discarded into navigable waters. The U.S. Navy is seeking alternative methods for BW treatment which will produce clean water by concentrating BW, thereby reducing the volume of waste the ship must hold until a port is reached. If viable BW treatments can be achieved, the volume of wastewater produced by naval ships would be greatly reduced. The resulting treated water could be returned to the seas. Membrane technologies show promise for treating BW. However, fouling-resistant membranes must be developed to counter the highly fouling nature of BW.

Our group is creating magneto-responsive anti-fouling membranes to produce beneficial water from BW which are currently wastewaters. Successful production of anti-fouling membranes capable of treating BW would be beneficial to society by enabling cost-effective treatment options for beneficial outlets for BW and preventing environmental damage by BW disposal. Anti-fouling membranes could also see broader uses in any number of industries including food, pharmaceuticals, and beyond.

In order to accomplish this goal, polymer nanobrushes will be grafted onto the membrane surface and then iron oxide superparamagnetic nanoparticles will be attached onto the end of the nanobrushes. When these modified membranes are subjected to an alternating magnetic field, the nanoparticles align with the magnetic field. This alternating alignment creates mixing at the microscale directly above the membrane surface which will decrease fouling due to BW filtration and thus increase membrane lifetime.

Progress to date will be presented, as well as some of the technical challenges overcome thus far. Initially the superparamagnetic nanoparticles were attaching to multiple nanobrush ends and embedding themselves within the nanobrushes rather than attaching solely to the nanobrush ends. The chemical techniques to overcome these difficulties will be discussed, as well as the apparatus for delivering the alternating magnetic field and the current progress in treating BW.

This work is funded under SERDP Project WP-1670.
NOVEL MEMBRANE TREATMENT SYSTEMS FOR SHIPBOARD OILY WASTEWATER

DAVID MARIBO
Naval Surface Warfare Center, Carderock Division, Code 633
9500 MacArthur Blvd
West Bethesda, MD  20817-5700
(301) 227-5220
David.Maribo@Navy.mil

CO-PERFORMER: Alvin Ng (Membrane Technology, Inc.)

Oily wastewater (bilgewater), which collects in most shipboard machinery spaces must be processed prior to discharge overboard. Bilgewater is a highly variable mixture of water with contaminants which may include fuels, oils, hydraulic fluids, detergents, incidental leaks from blackwater/graywater systems, and a wide variety of other substances. DoD vessels target discharges containing less than 15 parts per million (ppm) of oil when within 12 nautical miles of land. To meet this threshold, Naval Sea Systems Command Carderock developed ceramic oily waste membrane systems as a secondary treatment for existing gravity separators.

Membrane systems life cycle costs are driven by membrane acquisition costs and membrane life. Membrane Technology and Research (MTR) Inc. has developed a nonporous coating for membranes under SERDP Project WP-1108. The polymer coating contains blocks of hydrophilic and hydrophobic polymers that lend it superior strength, water flux, and very high resistance to internal and external fouling, thereby extending membrane life.

Small-scale laboratory testing was completed to determine the best coating chemistry and the compatibility and short-term performance of polymer coated ceramic and polymeric membranes. A 100 ppm synthetic bilgewater mixture (average effluent concentration of primary treatment system) was processed for approximately 120 hours. Coated ceramic membranes produced equivalent hydraulic and separation performance as uncoated ceramic membranes at a significantly decreased fouling rate. Membrane life was potentially doubled. Permeate was below 15 ppm oil.

Full-scale laboratory testing further validated the effectiveness of the polymer coating of ceramic membranes by processing 100 ppm synthetic bilgewater mixture for 300 hours with periodic spikes of bilgewater contaminants such as bleach, acetone, paint thinner and seawater. Under this test, the membrane demonstrated no significant fouling rate, such that membrane life was more than doubled.

This project continues with full-scale shipboard testing. Coated membranes were installed on U.S.S. James E. Williams (DDG 95) in April 2009.

This work is funded under ESTCP Project WP-0215.
OILY SLUDGE BIODETOXIFICATION

MR. SONNY MAGA
Naval Facilities Engineering Command-Engineering Service Center
1100 23rd Avenue
Building 1100
Port Hueneme, CA  93043
(805) 982-1340
sonny.maga@navy.mil

CO-PERFORMER: Dr. Fred Goetz (WoodBank Environmental)

Each year mission essential activities (e.g., industrial wastewater treatment plants, washracks, fuel depots, forging and industrial operations, and maintenance facilities) at DoD facilities produce thousands of tons of oily waste. Since much of this waste cannot be recycled or burned, it is drummed and landfilled. The cost to the Navy alone to dispose of oily sludge recovered from fuel tank bottoms and the Bilge and Oily Wastewater Treatment System (BOWTS) is in excess of $6.5M per year. To reduce disposal costs and the liability associated with this waste stream, a simple and cost-effective treatment system that can be easily implemented throughout DoD is needed.

Previous pilot studies confirmed that biological treatment of oily wastewater and oily sludge is a technically sound approach to the treatment and disposal of these types of waste. To demonstrate/validate this approach, ESTCP funding was used to design and construct a full-scale on-site facility capable of treating oily sludge typically generated at a DoD industrial facility. The primary objective of this project is to demonstrate that a sequencing batch reactor populated with indigenous microorganism recruited from the oily waste rapidly and cost-effectively biodegrades oily waste while producing biomass, water, and CO₂ all of which can be recycled or safely discharged.

In collaboration with the U.S. Army, the Naval Facilities Engineer Service Center (NFESC) constructed a full-scale Oily Sludge Bioreactor treatment system at the Scranton Army Ammunition Plant (SCAAP), Scranton, PA. The system consists of two bioreactors that can be operated in series. The first reactor functions as a pretreatment tank and skims access oil that can be recycled. The second reactor has a capacity of 40,000 gallons and commercial pumps and blowers are used to recirculate and aerate the wastewater. Bacterial growth is enhanced by the addition of organic and inorganic nutrients and the system does require a pH controller. Treated wastewater is discharged through a tube filter and a filter press is used to consolidate the solids (primarily biomass and graphite) removed by the filter. The entire system is microprocessor-controlled and can be queried remotely. Full-scale operational testing of the treatment system shows that the hydrocarbons in the oily sludge are degraded to below the permitted discharge limit (100 ppm) in less than one week after the bulk of the oil from the pretreatment tank is removed. Exhaust air from the reactors is passed through activated carbon and the concentration of volatile organic compounds (VOCs) in the air vented to the atmosphere is below practical quantitation limits (PQL). Biological treatment costs (capital and O&M) were $0.08/lb vs. $0.76/lb for conventional disposal. Thus, biological treatment is both cost-effective (capital costs are recovered in less than 3 years) and it eliminates/minimizes the liability and recurring costs associated with conventional disposal. This work is funded under ESTCP Project WP-0307.
RESEARCH AND DEVELOPMENT EFFORTS TO REDUCE RISKS FROM EMERGING CONTAMINANTS

MR. ANDREW RAK
Noblis, Inc.
3150 Fairview Park Drive South
Falls Church, VA  22042
(703) 610-2166
andrew.rak@noblis.org

CO-PERFORMER: Kelly Scanlon (Concurrent Technologies Corporation)

Chemicals and materials that have pathways to enter the environment and present potential unacceptable human health or environmental risk and either (1) do not have regulatory peer-reviewed human health standards or (2) have regulatory standards that are evolving due to new science, detection capabilities, or pathways are called emerging contaminants. Emerging contaminants present risks to the many aspects of the Department of Defense’s (DoD) primary mission and its supporting activities. Early and proactive efforts must be taken to reduce risk to the Department before they become critical issues. Given the long lead time required to make significant changes in the operations of the Department, risks should be recognized early and appropriate risk management options (RMOs) adopted and acted upon in a timely manner. Implementation of the RMOs will result in reductions in the risks posed to DoD’s operations. Many of the RMOs developed to date focus on conducting research, development, testing, and evaluation (RDT&E) of materials or procedures that can replace emerging contaminants or otherwise mitigate their adverse mission effects. This project highlights the RDT&E-centered RMOs for all chemicals on the DoD’s Emerging Contaminants Action List with specific focus on sulfur hexafluoride, hexavalent chromium, naphthalene, and beryllium. Additionally, opportunities and responsibilities of researchers using nanomaterials will also be presented.
IMPROVED RESTRICTED MATERIALS TRACKING AND ALTERNATIVE IMPLEMENTATION THROUGH DEVELOPMENT OF A MATERIALS SELECTION AND ANALYSIS TOOL (MSAT)

MR. WAYNE ZIEGLER
U.S. Army Research Laboratory
Attn: AMSRD-ARL-WM-MC
Building 4600
Aberdeen Proving Ground MD 21005-5069
(410) 306-0746
wziegler@arl.army.mil

CO-PERFORMER: Ben Henrie (NASA Marshall Space Flight Center)

A gap analysis of the DoD’s current materials development and implementation process indicates that there is a lack of exchange of materials and process information early in the development cycle and throughout the lifecycle. This insufficient data coordination results in duplication of effort, failure to implement proven alternatives widely, and expensive design modifications later in the lifecycle. As part of the Army materials vision, technology options to address this gap were investigated. The development of a system for common materials and process data storage, retrieval and analysis from the ground up was cost and labor prohibitive, and the modification of existing commercial systems involved use of proprietary software code. NASA has developed a system to address similar materials design issues—Materials and Processes Technical Information System (MAPTIS). MAPTIS has many of the structural elements required for a DoD materials and selection analysis tool. However, it requires modification to conform to the unique data sets and analysis tools associated with restricted materials. NASA is currently working with partners to develop a restricted materials module which will assist in the screening of restricted materials in legacy and developmental weapon systems. This module will also provide a regularly updated screening tool tied to both domestic and international ESOH regulations and guidelines. There are related efforts at DLA that are working to track weapon system components back through the acquisition system to identify materials requirements and the coordination of these efforts will result in a powerful tool for identifying restricted material use and providing designers, weapon system managers and maintainers access to information on alternatives.

MSAT will be incorporated into the NASA MAPTIS system and is meant to serve as a pilot program to demonstrate the capability and usefulness of such a system to store, search, and retrieve non-classified material related data generated from DoD laboratories and their customers. The intent of this pilot is to demonstrate the effectiveness of utilizing core systems already developed by other government agencies to reduce duplication of effort and provide a quicker time to market. The success of this pilot will result in improved implementation of proven alternatives and serve as a model for future cross agency system utilization.
THE DEVELOPMENT OF AN INTERACTIVE GUIDE TO WORKING SAFELY WITH BERYLLIUM AND BERYLLIUM-CONTAINING MATERIALS

MR. THEODORE KNUDSON
Brush Wellman, Inc.
6070 Parkland Boulevard
Mayfield Heights, OH 44124
(216) 383-4040
theodore_knudson@brushwellman.com

CO-PERFORMER: Mr. Marc Kolanz (Brush Wellman, Inc.)

In December 2008, DoD’s Strategic Materials Protection Board concluded that beryllium is the only strategic and a critical material, possessing unique properties that make it indispensable in many of today’s U.S. defense systems, including sensors, missiles and satellites, avionics, and nuclear weapons. The safe use of beryllium will continue to be of interest to those in the DoD and industry involved with the production, fabrication and use of beryllium and beryllium containing materials. To assist those involved with this preventive effort, a unique and innovative program, the Interactive Guide to Working Safely with Beryllium and Beryllium-Containing Materials, has been created to provide individuals and organizations, including the various branches of the service, with tools and guidance to safely process and handle these important and beneficial materials. The Interactive Guide is a computer-based program that is simple to use and understand. Upon completion of the Interactive Guide, users are provided with an action plan and information to address most types of operations and tasks performed on beryllium-containing materials in an industrial environment.

The main tool introduced in the Interactive Guide is the Beryllium Worker Protection Model. The purpose of the Beryllium Worker Protection Model is to prevent Chronic Beryllium Disease and other potential adverse health effects in workers engaged in operations where there is potential airborne exposure to small beryllium-containing particles. The Beryllium Worker Protection Model is being successfully used at facilities manufacturing and processing beryllium and beryllium-containing materials. This model focuses on the control of multiple exposure pathways and monitors the effectiveness of these controls using leading measures. The Beryllium Worker Protection Model includes the following 8 elements:

- Keep beryllium out of the lungs.
- Keep beryllium work areas clean and shipshape.
- Keep beryllium off the skin.
- Keep beryllium off clothing.
- Keep beryllium at the source.
- Keep beryllium in the work area.
- Keep beryllium on the plant site.
- Keep beryllium workers prepared to work safely.

This poster will describe the development of the Interactive Guide and present the key elements of the Beryllium Worker Protection Model.
LOW TEMPERATURE POWDER COATINGS

MR. WAYNE PATTERSON
U.S. Air Force
AFMC 809 MSXX/CLA
7278 4th Street, Building 100
Hill Air Force Base, UT 84056
(801) 775-2992
Wayne.Patterson@hill.af.mil

CO-PERFORMERS: James Davila and Chris Geib (SAIC); Chris Mahendra (NAVAIR); Warren Assink (USAF HQ AFMC/A4DM)

The Department of Defense (DoD) currently spends millions of dollars each year to procure and use solvent-borne organic paint coatings and to dispose of toxic and hazardous materials associated with their use. Powder coatings have the potential to eliminate a significant amount of these toxic and hazardous materials as they are a VOC/HAP-free alternative to solvent-based paints and feature performance properties equal to or better than specification driven solvent-based coatings such as MIL-C-22750 (epoxy) and MIL-C-85285 (polyurethane). Powder coatings meeting DoD performance requirements have been commercially available for many years. Implementation of these powders has been limited to non temperature sensitive materials because of the high cure temperatures (300°F - 400°F). However, a lower temperature curing powder (250°F gloss white and 280°F semi-gloss gray) was developed under SERDP Project WP-1268 which can be utilized on temperature sensitive materials. This effort, the ESTCP Project WP-0614, seeks to build on that project with the demonstration, validation and implementation of low temperature cure powder coatings (LTCPC) on DoD hardware in a depot production environment. Currently, the demonstration is verifying the environmental and economic advantages of the proposed technology relative to the currently utilized technologies and is validating that the new technology is better in terms of cost, schedule, and performance when compared to the baseline solvent based coatings.

Laboratory testing of coating performance is complete and LTCPC coated hardware has been fielded. Air Force and Navy components coated with the LTCPC for the demonstration includes a C-130 aircraft nose landing gear door (interior surfaces), two Navy nitrogen servicing carts and a J-52 Aft Engine Yoke. The C-130 landing gear doors have been exposed to 6 months worth of firefighting duties, 6 months of training missions, and 6 months of desert operations. Inspection results as well as feedback from the aircraft maintainers indicates excellent coating performance. The N2 carts are on their second sea deployment and are displaying significant resistance to corrosion and wear. The Aft Engine Yoke was removed from service for mandatory nondestructive inspection following 12+ months of operational use. Inspection results and field observations were all positive. The expected DoD benefits of this project are: Greener – no VOC’s or HAP’s; Safer – minimized worker exposure to toxic and hazardous materials; Reduced cost – disposal of solvents and hazardous wastes eliminated.
A FUNDAMENTAL STUDY OF HOW METHYLENE CHLORIDE AND PHENOL INTERACT WITH EPOXY AND POLYURETHANE COATINGS

DR. JOHN L. GRAHAM
University of Dayton Research Institute
300 College Park
Dayton, OH  45469-0141
(937) 229-2807
john.graham@udri.udayton.edu

CO-PERFORMERS: Dr. Tak Yamada and Mr. J. Douglas Wolf (University of Dayton Research Institute); Mr. Victor Vuong (University of Dayton)

It is common practice throughout the aerospace industry to apply protective coatings to finished parts, components, and even entire aircraft. Throughout the useful life of a system many of these coatings must be periodically removed to conduct inspections, repairs, or the coating itself needs to be replaced. Unfortunately, the solvents used in these operations often include components that are considered hazardous air pollutants that pose serious threats to human health and the environment. Despite the problems associated with meeting air emission standards, chemical stripping remains one of the most favored options for removing coatings due in large part to its familiarity, effectiveness, and simplicity. Unfortunately, the development of alternative, environmentally acceptable chemical paint stripping solvents has met with mixed results. To assist in the development of alternative environmentally acceptable chemical paint strippers and solvent systems in an unambiguous manner, it is desirable to develop a sound, scientific understanding of how traditional chemical paint strippers work. Furthermore, since the most widely used chemical paint strippers are based on methylene chloride and phenol (MC/P), the specific objective of this study is to understand at a very fundamental level how these two solvent components interact with typical coating systems to effect their removal.

The overall experimental approach employed in this study is to examine the fundamental intermolecular bonding which gives typical aerospace coatings their requisite physical properties and to examine how MC/P solvents work to overcome their inherent environmental resistance. This is being accomplished through a combination of molecular modeling supported by laboratory analysis of the absorption of the solvent components, the resulting volume swell, and the debonding of example aerospace coatings using model solvent systems and molecular probes. Together, these tasks will provide a combined theoretical and physical understanding of the fundamental processes involved in chemical paint stripping from the source molecular interactions to how these interactions are expressed at the macroscopic level. This project will present an overview of the status of this study, including the latest results from the core tasks of molecular modeling, volume swell, solvent absorption, and infrared spectroscopy. A summary of the experimental tools that have been developed for this and similar studies will also be presented, including optical dilatometry to measure real-time volume swell and direct thermal desorption GC-MS for the quantitative analysis of solvent components absorbed by the coatings and coating components extracted by the solvents.

This work is funded under SERDP Project WP-1680.
COMPUTER-AIDED MOLECULAR DESIGN: A NOVEL APPROACH TO DESIGN ENVIRONMENTALLY FRIENDLY REPLACEMENT SOLVENTS

DR. ARUNPRAKASH KARUNANITHI
University of Colorado, Denver
1200 Larimer Street, Room 3019 C
P.O. Box 173364
Denver, CO 80014
(303) 556-2370
arunprakash.karunanithi@ucdenver.edu

P-D-680 and MIL-PRF-680 solvents are widely used by defense department for routine maintenance and cleaning applications. P-D-680 solvents contain hazardous air pollutants (HAPs) and volatile organic compounds (VOCs) while MIL-PRF-680 solvents do not contain HAPs, but have about the same VOC content as P-D-680 solvents. In view of recent environmental regulations, non-toxic, HAP-free and low VOC/VOC-free alternatives are being sought for these types of solvents. DoD applications also require alternative environmentally friendly solvent based coating systems and primers.

This project proposes a novel computer-aided molecular design (CAMD) approach to design alternative environmentally friendly solvents for cleaning applications and coating applications. Computer-aided molecular design is a state-of-the-art technique to computationally design chemical compounds that have specific desirable properties. The successful implementation of the CAMD method requires structure-property models to predict properties of interest from molecular structure. This project will demonstrate a CAMD model to generate feasible solvent structures that satisfy performance related properties as well as environmental properties. Case studies related to design of Type II and Type III MIL-PRF-680 replacement solvent structures will be demonstrated.
STRUCTURE AND COMPOSITION OF NON-CHROMATE INHIBITOR FILMS

PROFESSOR DALE W. SCHAEFER
University of Cincinnati
2600 Clifton Avenue
Mail Location 0012
Cincinnati, OH 45221-0012
(513) 556-5431
schaefdw@email.uc.edu

CO-PERFORMERS: Peng Wang and Xuecheng Dong (University of Cincinnati)

Vanadate and trivalent chromium conversion coatings and inhibitors are candidates to replace chromate in metal-protective applications. Currently, however, data on inhibitor film microstructure and speciation are minimal. This project will develop new nondestructive approaches to investigate the structure, density, speciation and growth of these non-chromate films by utilizing neutron reflectivity and x-ray reflectivity.

For the vanadate-based inhibitor system, uniform, crack-free films were grown on aluminum alloy AA-2024. The top part of the alloy participates in the formation of vanadate inhibitor film. The similarity of films formed in H₂O and D₂O implies that the film is not hydrated. The film has a layered structure with vanadium enriched at the film-alloy interface, which behaves as an effective water barrier if the film thickness is greater than 800 Å. This previously undetected hydrophobic interfacial layer is responsible for protective character of vanadium system. Efforts to develop more effective vanadium-based inhibitors should focus on this interface layer.

For the trivalent-chromium system, the inhibitor films were deposited on aluminum-alloy-coated silicon wafers via two methods: (1) by immersion in a diluted trivalent chromium solution and (2) by electrolytic deposition (anodic polarization to clean metal substrate followed by cathodic polarization to trigger the growth of the inhibitor film). Films prepared by immersion show a layered structure. After 30 seconds of immersion growth ceases. By contrast, electrolytically deposited films are single-layer with a thickness that increases linearly with deposition time. Comparison of the neutron scattering length density profiles before and after baking indicates trivalent chromium films are hydrated. Assuming the as-prepared film is Cr₂O₃•xH₂O, x is calculated to be 5.5 ± 0.5.

This work is funded under SERDP Project WP-1619.
NANOstructured Zn-BASED ELECTRODEPOSITS as ENVIRONMENTALLY BENIGN Cd-REPLACEMENT COATINGS for HIGH-STRENGTH FASTENERS

DR. JONATHAN McCREA
Integran Technologies, Inc.
1 Meridian Road
Toronto, ON M4E 3X8 CANADA
(416) 675-6266
mccrea@integran.com

CO-PERFORMERS: Dr. Paco Gonzalez and Gino Palumbo (Integran Technologies, Inc.)

This poster summarizes the results-to-date of the SERDP Project WP-1616, “Nanostructured Zn-Based Electrodeposits as Environmentally Benign Cd-Replacement Coatings for High-Strength Fasteners.”

Electrodeposited cadmium (Cd) is used extensively by the Department of Defense (DoD) to protect steel from corrosion. However, the Environmental Protection Agency lists Cd as a probable human carcinogen and strictly regulates its emissions to the atmosphere, and the disposal of Cd and Cd-containing wastes. Alternate coating technologies have found acceptance in various military and commercial Cd-replacement roles; however, there is still a technology gap for these alternatives, particularly when applied to high-strength fasteners, because of the susceptibility of the high-strength steels to hydrogen embrittlement.

The objective of the project is to develop and optimize a nanostructured zinc (Zn)-based coating by modifying conventional, environmentally benign, electroplating techniques to yield a coating process that meets or exceeds the overall performance (corrosion protection, torque-tension, etc.) and life-cycle cost of existing cadmium electroplating. The microstructure and properties of the electrodeposited nanostructured zinc-based alloys developed as part of this program will be presented and compared to that of conventional Cd plating.
HYDROGEN RE-EMBRITTLEMENT DOE

SCOTT GRENDAHL
U.S. Army Research Laboratory
RDRL-WMM-C B4600
Aberdeen Proving Ground, MD 21005
(410) 306-0819
sgrenda@arl.army.mil

CO-PERFORMERS: Ed Babcock and Steven Gaydos (The Boeing Company);
Craig Willan (Omega Research, Inc.)

Implementation of alternate maintenance chemicals and coatings can be a lengthy and involved process for the aerospace industry. Generating and collecting the data necessary to justify making the change is a daunting part of this undertaking. Standardized practices and specifications assist the researcher during this process. Especially for the aerospace industry, the standard practice or specification was consolidated from the historical actions of the many diverse aerospace companies. Specific to hydrogen re-embrittlement (HRE), ASTM-F-519 has many different geometries, loading levels and stress intensities from which to choose. Additionally, while the specification is meant to cover a worst-case scenario, it is likely excessive for materials of lower strength. While a chemical or coating may be proven harmful in a worst case scenario, there are likely hundreds of applications where they could be safely and successfully employed on less susceptible materials of lower strength.

This work utilized a design of experiments (DoE) approach to generate comparative data sets for the common test geometries across a range of load level, material strength, and hydrogen concentration. The DoE created a predictive mathematical model for failure based on the input conditions. Generically, the models proved very successful in qualitative and quantitative assessment of performance. For the first time, we now have a predictive tool that determines failure in terms of material strength and load level when exposed to a sodium chloride environment. Targeted models will be generated for prospective maintenance chemicals and coatings where implementation is currently being hindered based on hydrogen re-embrittlement concerns. These models will clearly show where the materials can be safely employed based on material strength and/or loading level in the application. Alleviation of the HRE concerns for the popular chemicals and coatings will lead directly to increased implementation at military depots and the commercial aerospace industry replacing the existing environmentally unfriendly solvents and coatings.

This work is funded under SERDP.
CHROMIUM REPLACEMENT AND EROSION MITIGATION TECHNOLOGY FOR MEDIUM CALIBER GUN BARRELS

MR. MARK MILLER
Benet Laboratories
U.S. Army RDECOM ARDEC WSEC, RDAR-WSB-L
1 Buffington Street
Watervliet, NY 12189
(518) 266-4177
mark.miller9@us.army.mil

CO-PERFORMER: Frank Campo (Benet Laboratories)

Medium Caliber Guns use electrodeposited chrome to protect the bore surface from the harsh environment of propellant gases. The electrodeposition process uses chrome VI, a known carcinogen. Various laws and statutes exist to eliminate chrome VI. In addition, advanced propellants used in higher lethality medium caliber ammunition increases cannon wear and erosion, and shortens barrel service life for current and future gun barrels. The solution is to develop environmentally-friendly, erosion resistant, gun bore coatings that meet or exceed current performance requirements. The technical objective of this program is to eliminate chromium plating in the production of medium caliber guns by developing an environmentally acceptable method for depositing wear and erosion resistant materials onto the gun bore surface through the exploitation of explosive cladding technology.

Benet Labs (part of the Weapons & Software Engineering Center-WSEC, Armament Research, Development, and Engineering Center-ARDEC) in conjunction with High Energy Metals, Inc. (HEMI) in Sequim, WA and Ares, Inc. in Port Clinton, OH has successfully cladded, rifled, and test-fired several full-length 25 mm medium caliber M242 Bushmaster Cannon Barrels using explosive bonding/cladding technology. The claddings were done with environmentally friendly chromium-free tantalum-tungsten alloys. The test firings were conducted using five rounds of M793 cartridges with no degradation in rifling. Several distinct milestones and breakthroughs were accomplished by ARDEC personnel that led to the successful test firing. For the first time:

- A full-length medium caliber canon has been lined via explosive bonding.
- A Ta-10W liner has been explosively bonded into a full-length medium caliber canon.
- A Ta-10W liner has been machined with a progressive twist in a full-length medium caliber canon.
- A full length medium caliber canon with an explosively-bonded liner has had ammunition fired through it.

This work is funded under SERDP Project WP-1426.
Scientific Understanding of the Mechanisms of Non-Chromate Corrosion Inhibitors

MARTA A. JAKAB
Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238
(210) 522-5240
marta.jakab@swri.org

CO-PERFORMER: John R. Scully (University of Virginia)

Environmental and health concerns associated with hexavalent chromium have catalyzed the development of a broad range of non-chromate treatments to inhibit corrosion of aluminum and iron-based alloys in DoD systems. The non-chromate inhibitors include various transition metal salts, rare earth salts and other anionic species. The mechanism of these corrosion inhibitors is still not understood in detail hindering their application in coatings systems.

The objective of this work is to gain understanding of the mechanisms of selected environmentally-friendly inhibitors under realistic metallurgical and environmental conditions in order to facilitate the development of non-chromate inhibitor systems that possess effectiveness comparable to that of chromates. This project focuses on aluminum alloys AA 7075 and AA 2024-T351, as well as AISI 1018 plain carbon steel substrates. High purity Al, Cu and synthesized S-Al2CuMg are also used as diagnostic materials to obtain mechanistic information. The ionic inhibitors of focus include cerium(III), molybdate, vanadate and permanganate added in the form of various salts to sodium chloride solution at various concentrations as well as selected combinations of the same inhibiting species.

Preliminary studies indicated that molybdate ions are effective anodic inhibitors of 1018 carbon steel, 2024 and 7075 aluminum alloys. Vanadate was also found to provide anodic inhibition of AA2024-T351 at selected concentrations. Cerium and vanadate ions were found to be good cathodic inhibitors of both 2024 and 7075 aluminum alloys when added in solution and as a pre-treatment. The effect of permanganate is complex. The oxidizing capability of this reducible ionic species actually raises open circuit potentials and cathodic reaction rates. However, pretreatment with permanganate species can suppress copper redeposition associated with corrosive processes during subsequent exposure in sodium chloride solutions. When applied in combination, cerium(III) and vanadate ions showed synergistic effects on both 1018 carbon steel and 7075 aluminum alloy.

This work is funded under SERDP Project WP-1621.
ENVIRONMENTALLY BENIGN REPAIR OF COMPOSITES USING HIGH TEMPERATURE CYANATE ESTER NANOCOMPOSITES: REPAIR SYSTEM EVALUATION

PROFESSOR MICHAEL R. KESSLER
Ames Laboratory and Iowa State University
2220 Hoover Hall
Ames, IA 50011
(515) 294-3101
mkessler@iastate.edu

CO-PERFORMERS: Dr. Mufit Akinc, Dr. Xia Sheng, Wilber Lio, Katherine Lawler, Dr. Mahendra Thunga, and Jonathan Henson (Iowa State University)

The present work deals with the development of an efficient repair process for rehabilitating polymer matrix composites (PMCs) in complex structures. This method can be widely applicable in repairing the internal delaminations and microcracks in PMCs that are generated under extreme thermomechanical loading conditions. This technique is observed to be quite simple and environmentally friendly when compared to other conventional repair methods like scarf-type or resin infusion processes.

The novelty of this method lies in adopting bisphenol E cyanate ester (BECy)/alumina nanocomposites as a crack filling adhesive whose primary phase (BECy) combines a high glass transition temperature of the cured network (Tg), easy processability, and excellent adhesive and mechanical properties. The interaction between heterogeneous phases that can strongly influence the adhesive strength and processability in BECy/alumina nanocomposites was eminently tuned by varying the filler content and surface grafted functional groups of the filler.

The dispersion of alumina particles in BECy resin was qualitatively studied by TEM and the structural attributes from local morphologies were correlated to the bulk material behavior and shear rheological properties. The experimental flow curves at different vol.-% of filler content were fitted with theoretical models of colloidal solutions. The fit parameters reveal the presence of physical interactions between the heterogeneous phases. The adhesive strength of the nanocomposite resins at different filler contents was systematically investigated with conventional lap-shear tests on composite and aluminum substrates. The optimum filler concentration was determined from a transition in the maximum adhesive strength at 5 vol.-% filler content. The transition point was reaffirmed consistently at the targeted operating temperature of 200°C.

In order to evaluate these efficient repair resins for practical applications, bismaleimide/carbon fiber (BMI) panels were delaminated using a holed plate shear (HPS) method. The delaminated BMI panels were repaired by infusing the resin using an injection process. From advanced ultrasonic non-destructive tests, it was observed that the inherent delaminations and micro cracks in the BMI panels were successfully filled and repaired with the injected resin.

This work is funded under SERDP Project WP-1580.
VALIDATION OF NOVEL ELECTROACTIVE POLYMERS AS ENVIRONMENTALLY COMPLIANT COATINGS FOR REPLACEMENT OF HEXAVALENT CHROMIUM PRETREATMENTS

DR. PETER ZARRAS
Naval Air Warfare Center Weapons Division
1900 N. Knox Road
China Lake, CA 93555-6106
(760) 939-1396
peter.zarras@navy.mil

CO-PERFORMERS: Nicole Anderson, Cindy Webber, Dr. John D. Stenger-Smith, Amy L. Fowler, Andy Schwartz, and Christopher S. Mahendra (NAWCWD); Diane Buhrmaster and Michael Spicer (WPAFB/University of Dayton Research Institute); Dr. Mark R. Kolody (Kennedy Space Center); Christopher E. Miller (U.S. Army Research Laboratory); Dr. Dan Cerven (MB Research Laboratory)

ESTCP Project WP-0527 is currently demonstrating an effective, environmentally benign, repairable coating system using electroactive polymers (EAPs) as the replacements for chromate conversion coating (CCC) pretreatments on aluminum and steel alloys. The NAWCWD, China Lake, California is leading this effort in collaboration with Wright Patterson Air Force Base (WPAFB); Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, Maryland and Lakehurst, New Jersey; Kennedy Space Center (KSC) and the Army Research Laboratory (ARL), Aberdeen Proving Grounds, Maryland. The EAP polymer that is being field tested for this program is poly (2, 5-bis (N-methyl-N-hexylamino) phenylene vinylene), (BAM-PPV). BAM-PPV is processed using a VOC-exempt solvent 4-chlorobenzotrifluoride, Oxsol-100. BAM-PPV as the pretreatment coating on both aluminum and steel alloys along with both hexavalent chromium and non-chromium primers followed by topcoats is being tested for marine outdoor exposure at the KSC. The testing at 6 months of exposure has shown that the chromium based primers with BAM-PPV have survived while BAM-PPV with the non chromium primers has corrosion along the scribe with blistering. The Air Force is testing BAM-PPV on the rear hatch door of the C-5 cargo plane at WPAFB. There have been no visible signs of corrosion, loss of adhesion or color changes at 8 months of field testing BAM-PPV pretreatment with hexavalent chromium and non chromium primers and topcoats. The aircraft has flown almost 300 hours with the coating systems on the door without any issues reported. BAM-PPV has been coated onto the headlight cover for the Bradley vehicle. After 6 months of field testing, no issues with the coatings have been reported. Recently BAM-PPV has also been coated onto ground support equipment for the Navy with field testing starting June 2009. Finally, BAM-PPV has been sent out for toxicology testing with preliminary results showing no signs of dermal irritation. BAM-PPV is a non-sensitizer and has an LD50 for acute oral and dermal toxicity of greater than 2000 mg/kg.
DEMONSTRATION/VALIDATION OF HIGH PERFORMANCE CORROSION PREVENTIVE COMPOUND (CPC) FOR INTERIOR AIRCRAFT APPLICATIONS

DR. EL SAYED ARAFAT
Naval Air Systems Command (NAVAIR)
48066 Shaw Road, Building 2188
Patuxent River, MD 20670
(301) 342-8054
elsayed.arafat@navy.mil

As a part of the corrosion control program for maintaining aircraft and weapon systems, the application of corrosion inhibiting compounds on most in-service airplanes has expanded in recent years. In recent years, regulations that restrict allowable emissions of volatile organic compounds (VOC) from coating processes and maintenance chemicals have affected many areas of the coating industries. The main goal of this project is to demonstrate/validation a newly developed high-performance corrosion preventive compound (Navguard) into an airframe for long-term protection to minimize environmental effects on aging aircraft. This project seeks to reduce hazardous waste, VOCs, and HAPs, while improving the performance of this type of internally applied corrosion preventive compounds. The key benefits of using Navguard are reducing VOC emission from CPC application by 50% or more, eliminating HAPs, and reducing the maintenance intervals for re-application of CPCs. Navguard was tested through a Lead-The-Fleet demonstration on F-18 at Naval Air Station Oceana, VA, and Expeditionary Fighting Vehicle (EFV) at U.S. Marine Corps Camp Pendleton, CA, and showed no sign of corrosion after twenty-four months of exposure. Currently, Navguard has been applied on multiple platforms such as H-46 (4), EA-6B (5), EFV (8), H-60 (1), and F-18 (17) at several DoD testing sites (Army, Navy, and Marine Corps). Two-year maintenance inspections for platforms used in the field test have shown no sign of corrosion in the area it was applied. The goal is a two-year maintenance interval—four times the current one. Successful completion of this project will result in the implementation of high-performance, long-lasting CPCs specifically suited for Navy, Air Force, and Army Aviations requirements and operating environments. Two vendors have licensed the Navguard CPC formulation to manufacture the product for use by DoD and commercial applications.

This work is funded under ESTCP Project WP-0615.
NANOCRYSSTALLINE COBALT-ALLOY COATINGS FOR CHROME REPLACEMENT APPLICATIONS

D. FACCHINI
Integran Technologies, Inc.
1 Meridian Road
Toronto, ON M9W 4Z6 CANADA
(416) 675-6266
facchini@integran.com


The replacement of hard chromium (Cr) plating in aircraft manufacturing activities and maintenance depots is a high priority for the U.S. Department of Defense. Hard Cr plating is a critical process that is used both for applying hard coatings to a variety of aircraft components in manufacturing operations and for general re-build of worn or corroded components that have been removed from aircraft during overhaul. Chromium plating baths contain chromium in the hexavalent state, a known carcinogen. Wastes generated from plating operations must be disposed of as hazardous waste and plating operations must abide by EPA emissions standards and OSHA permissible exposure limits (PEL). OSHA recently reduced the PEL for Cr\textsuperscript{6+} and all Cr\textsuperscript{6+} compounds from 52 µg/m\textsuperscript{3} to 5 µg/m\textsuperscript{3}. Due to the expected increase in operational costs associated with compliance to the revised rules and the expected increased turnaround times for processing of components, there is tremendous pressure to find an environmentally benign alternative to hard Cr.

Electrodeposited nanocrystalline cobalt-phosphorus (nCoP) coatings have been developed as an environmentally benign alternative to hard Cr coatings for non-line-of-sight (NLOS) applications under the SERDP Project WP-1152. Demonstration and validation testing was initiated in a project under the Environmental Security Technology Certification Program (ESTCP) (WP-0411). The current program under the ESTCP (WP-0936) aims at fully qualifying this technology through performance testing and demonstration/validation on a number of components from NAVAIR (air vehicle and ground support equipment) and NAVSEA (shipboard machinery components and ground support equipment) with leveraged funding from the Navy Environmental Sustainability Development to Integration Program. Nanocrystalline CoP coatings show great potential as an alternative to hard chrome for NLOS and LOS applications due to: higher cathodic efficiency, higher deposition rates, high hardness, good sliding wear, and superior corrosion resistance. Furthermore, recent tests have demonstrated nCoP coatings to be non-embrittling and non-fatiguing. Originally developed on the laboratory scale, the nCoP deposition process has been scaled up to the industrial/production scale and a pilot tank is operational at Fleet Readiness Center Southeast (FRC-SE).

This poster will outline the process and properties of the nCoP coating in comparison to hard Cr, as well as the broad areas of application for the coating. A general overview of the process and properties of nCoP coatings will be presented as they pertain to a hard Cr alternative with recent supporting data. A review of the ongoing and future demonstration and validation programs for nCoP will also be presented.
CORROSION PROTECTION MECHANISMS OF RARE EARTH-BASED COATINGS

DR. BECKY L. TREU
Missouri University of Science and Technology
101 Straumanis Hall
401 W. 16th Street
Rolla, MO  65409
(573) 341-4358
treubl@mst.edu

CO-PERFORMERS: William R. Pinc, Simon Joshi, William G. Fahrenholtz, and Matthew J. O’Keefe (Missouri University of Science and Technology); Eric Morris (Deft, Inc.)

The mechanisms by which rare-earth compounds inhibit corrosion of aluminum alloys are being investigated along with the phase stability of rare-earth species. Initial work has focused on characterizing cerium-based conversion coatings (CeCCs). Coatings were examined using analytical and electrochemical methods to characterize CeCCs in the as-deposited state as well as after corrosion testing in salt spray (ASTM-B117) for times up to two weeks. Process parameters were chosen in order to deposit CeCCs that could provide either good or poor corrosion protection to compare the response to salt spray for protective and non-protective coatings. To complement information provided by conventional techniques, a micro-scale electrochemical test cell with capabilities of probing areas with diameters of less than 100 μm has been employed. Using this method, polarization and electrochemical impedance spectroscopy experiments were performed on specific areas of substrates and coated test panels. Because corrosion protection requires that the appropriate phase of a rare-earth compound be incorporated into the proper type of coating, the phase stability of rare-earth oxides was investigated. The thermal decomposition of rare-earth oxides, carbonates, and hydroxycarbonates was characterized. Precipitation studies were also conducted to study phase stability in the tertiary rare earth-H₂O-CO₂ system. The long-term project goal is to combine information from analytical characterization, electrochemical testing, and phase stability studies to develop mechanistic models for corrosion protection. The models will identify phases present in as-deposited coatings, transport processes that occur during corrosive attack, and species that form to passivate the substrates. Understanding the mechanisms by which rare-earth compounds inhibit corrosion will reduce the risk of implementing environmentally benign coating systems as chromate replacements.

This work is funded under SERDP Project WP-1618.
MULTIFUNCTIONAL UV (MUV) AND CERIUM-BASED CORROSION COATINGS

PROFESSOR MATT O’KEEFE
Missouri University of Science and Technology
101 Straumanis Hall
401 W. 16th Street
Rolla, MO  65409-1170
(573) 341-6764
mjokeefe@mst.edu

CO-PERFORMERS: Professor Bill Fahrenholtz (Missouri University of Science and Technology); Mr. John DeAntoni (Boeing); Dr. Ben Curatolo (Light Curable Coatings)

Corrosion coatings comprising cerium-based conversion coatings (CeCC) and multifunctional ultraviolet (MUV) curable polymers are being developed and evaluated to replace existing corrosion coatings used on military weapon systems that contain hexavalent chromium as the corrosion inhibitor. The CeCC/MUV coating system is free of volatile organic compounds (VOCs) and chemicals on the toxic release inventory (TRI) list. Five rounds of testing have demonstrated that MUV coatings with different amounts of corrosion inhibitor can pass at least 2,000 hours of ASTM B117 neutral salt spray testing on high strength aluminum alloy substrates with chromate conversion coatings (CrCC). MUV coatings on trivalent chromium passivation (TCP) and CeCCs are not as effective at preventing corrosion during salt spray testing as the MUV/CrCC coating system or existing chromate and non-chromate epoxy primer/topcoat systems used as test controls. Evaluation of the MUV and CeCC processing parameters indicated that adjustments to coatings that improve adhesion result in better corrosion protection during salt spray testing. Other MUV properties, such as low temperature flexibility, wet tape adhesion, room temperature flexibility, color change, filiform corrosion and fluid resistance, are being optimized to meet military aerospace requirements via formulation changes in the amount and/or type of oligomer, monomer, corrosion inhibitor, and additives in the MUV.

This work is funded under SERDP Project WP-1519.
ENVIROMENTALLY BENIGN MULTILAYER POLYMER COATINGS WITH CONTROLLED SURFACE PROPERTIES FOR MARINE ANTIFOULING APPLICATIONS

PROFESSOR CHRISTOPHER K. OBER
Cornell University
Materials Science and Engineering
Ithaca, NY 14853
(607) 255-8417
cko3@cornell.edu

CO-PERFORMERS: Harihara S. Sundaram, Youngjin Cho, and Marvin Y. Paik (Cornell University); Craig Weinman (Intel); Michael Dimitriou and Edward J. Kramer (University of California at Santa Barbara); John A. Finlay, Maureen E. Callow, and James A. Callow (University of Birmingham)

Marine biofouling is the unwanted accumulation of microorganisms, plants and animals on artificial surfaces submerged in seawater. Biofouling causes undesirable drag, which in turn leads to significantly higher fuel consumption. This work seeks to develop new coatings that help resolve both the energy consumption issues caused by biofouling and the environmental concerns of the previous generation of marine antifouling coatings. Our approach is to use bilayer coatings based on commercially available polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene (SEBS) thermoplastic elastomers which provide necessary mechanical properties with respect to both durability and bulk modulus. Meanwhile, a relatively thin layer of the specially designed surface-active block copolymer (SABC) coated on top of the elastomeric layer modifies the surface properties. This project has made significant achievement towards anti-fouling coatings that use the concept of the ambiguous surface to produce fouling release. A series of amphiphilic polymers have been synthesized with different compositions of fluoro and poly(ethylene glycol) (PEG) chains. Amphiphilic functions with mixed fluorinated and PEG coatings have been shown to exhibit good fouling release behavior for both Ulva Zoospores and Navicula Diatoms. This concept has been extended to synthesize new amphiphilic polymers using a series of Brij samples (containing PEG and hydrophobic chain) and pluronic samples (contains polypropylene oxide and polyethylene oxide). These polymers have been characterized using depth resolved near-edge x-ray adsorption fine structure (NEXAFS), X-ray photoelectron spectroscopy (XPS) and single molecule force spectroscopy. Biofouling tests are being performed in several marine labs, and samples have exhibited encouraging antifouling performance with regards to both soft and hard marine fouling. Ulva zoospore settlement and release showed that the spore settlement densities were lower on all the K3-Brij samples than on the glass and PDMSe standards or SEBS control. The settlement and release studies of Navicula Diatoms are underway. Promising coating compositions have been identified and further development is on-going.

This work is funded under SERDP Project WP-1454, with additional support for analytical research provided by the Office of Naval Research.
FINAL REPORT: QUALIFICATION, DEMONSTRATION, & VALIDATION OF COMPLIANT REMOVERS FOR AIRCRAFT SEALANTS AND SPECIALTY COATINGS

MR. JIM TANKERSLEY
Battelle
5100 Springfield Pike, Suite 110
Dayton, OH 45431-1261
(937) 258-6724
tankersleyj@battelle.org

CO-PERFORMERS: Jeff Kingsley (U.S. Air Force Research Laboratory); Diane Kleinschmidt (Naval Air Systems Command); Susan Saliba (University of Dayton Research Institute)

The Air Force, Navy, and commercial airline industry have funded numerous studies to identify and evaluate non-chemical, environmentally friendly technologies or processes for safely and efficiently removing degraded sealants and specialty coatings from the internal and external surfaces of aircraft structures. Technologies have included mechanical (pressurized water, bio-based and nano-engineered dry media blends, ultrasonic scrapers, and bristle brushes), light energy (handheld lasers, and Flashjet), as well as various combinations of these processes. The conclusion from these studies is that there is no one technology, method, or procedure that efficiently removes the various types of sealant or specialty coating materials without the risk of damaging the underlying substrates or surface coatings.

This project has focused on identifying, qualifying, demonstrating, and validating an environmentally friendly (contains no TRI chemicals, no HAP, or chlorinated compounds) substitute material or product for removing sealants and specialty coatings from aircraft structures. Candidate materials examined are commercial off-the-shelf (COTS), and are assessed on how effectively each material removes different sealants used by Air Force, Navy, and commercial aircraft MRO facilities. Structural aerospace materials included 2024-T3 aluminum alloy and two types of composites (graphite/bismaleimide and graphite epoxy).

The project will have been successfully completed for this presentation. Accomplishments have included a controlled set of laboratory testing of COTS materials for polysulfide, polythioether, and polyurethane sealant removal on various substrates, followed with successful process demonstration/validation testing performed at OO-ALC, FRC-SE and NAVAIR Cherry Point (polythioether). The final report, expected to be submitted in November 2009, will detail and analyze the results of this activity. Test and dem/val results, cost/benefit analyses, and a detailed assessment of the technical transition and implementation phase will be presented.

AFRL is the lead for the project, and NAVAIR is a partnering agency. Battelle and UDRI are responsible for identifying vendors of compliant removers, down-selecting candidate materials, and coordinating laboratory and field demonstrations. Project-related technical information exchanges include stakeholders from specific Air Force Air Logistic Centers, Navy Fleet Readiness Centers, the Army, and commercial MRO organizations.

This work is funded under ESTCP Project WP-0621.
ULTRAVIOLET CURE POWDER COATINGS FOR MILITARY SYSTEMS

MR. COREY BLISS
U.S. Air Force Research Laboratory
2700 D Street, Building 1661
Wright-Patterson AFB, OH 45433
(937) 255-0943
Corey.Bliss@wpafb.af.mil

CO-PERFORMER: Christopher Geib (SAIC, Inc.)

Powder Coatings produce a superior durable coating, while reducing/eliminating hazardous waste and hazardous air pollutants (HAPs), and do so at a lower cost than conventional solvent-borne coatings. Powder coatings are generally classified as non-hazardous waste, and have little if any disposal or compliance costs. Powder coatings also eliminate the costly environmental recordkeeping burden associated with solvent-borne paint hazardous waste. As a bonus, powder coatings eliminate volatile organic compound (VOC) paint emissions. VOCs are precursors to ground level ozone, a major EPA criteria pollutant that is problematic for many regions.

Temperature-sensitive substrates such as aluminum and magnesium are used in the manufacture and sustainment of weapon systems and ground support equipment. This project will demonstrate, validate and successfully implement a VOC/HAP-free, ultraviolet-cure powder coating (UVCPC) on DoD depot production hardware to replace solvent-borne organic coatings. UVCPC significantly reduces energy use by not requiring curing ovens, and it also cuts turnaround times from days to hours. Because no oven is required, large, bulky and oversized objects can be powder coated and cured. Only the powder needs to be heated to melting, therefore the substrate is exposed to less heat for shorter periods of time. Lower temperature, shorter heating/curing times reduce both the energy costs and return to service times associated with this process. Combining reduced process times with the improved transfer efficiency of powder coatings (up to 95% vs. 60% for wet coatings) results in less expense, on a square foot basis, to apply powder coatings. This project will utilize both existing and new UV-curable powders in a side-by-side demonstration with the current existing wet paint system (MIL-PRF-23377J & MIL-PRF-85285D). The use of state-of-the-art-robotics will also be demonstrated.

Robot integration with both Infrared and UV light sources has been completed. A demonstration of the robotic curing system was accomplished with government stakeholders in July 2009. This project has demonstrated the application and curing of the UVCPC on a fiberglass radome. The beginning of coating validation testing has also begun and will continue through the summer of 2009. A report of some of the initial testing results and the current state of the robotic integration is in production.

This work is funded under ESTCP Project WP-0801.
DYNAMIC MULTIVARIATE ACCELERATED CORROSION TEST PROTOCOL

MR. COREY BLISS
AFRL/RXSSO Coatings Technology Integration Office
2179 12th Street
Room 122, Building 652
Wright-Patterson AFB, OH 45433
(937) 255-0945
Corey.Bliss@wpafb.af.mil

CO-PERFORMERS: Dr. Doug Hansen, Mr. Chris Joseph, and Mr. Bill Culhane (University of Dayton Research Institute); Dr. Bill Abbott (Battelle); Major John Crane (Det 3 2 WXG)

Current laboratory accelerated corrosion test methods do not adequately rank performance nor accurately replicate the failure modes of coating systems used in DoD applications in the field. The reason for this may be the limited parameters under which the accelerated exposure tests are performed, resulting in corrosion behavior that is different from that observed on coating systems exposed in the field. The influence of certain critical environmental factors may play a greater role in the corrosion behavior of the coating systems than those currently utilized in laboratory environments. The current research effort will attempt to identify the most critical environmental factors which lead to the corrosion of various metallic substrates, which can then be replicated in the laboratory exposure test method. It is anticipated that this new method will form the basis of a new laboratory accelerated corrosion test that will more accurately predict field-level performance of current and future alloys and coating systems. Bare and coated metallic test specimens are currently being exposed outdoors at eight DoD-relevant test sites over a two-year period. Corrosion rate and corrosion product data will be correlated to several environmental factors believed to be the main drivers for the corrosion process. These factors will then be incorporated into a laboratory exposure test that will mimic the corrosion behavior of alloys and coating systems observed at the field exposure sites.

This work is funded under SERDP Project WP-1674.
INNOVATIVE WELDING TECHNOLOGIES TO CONTROL HAP EMISSIONS USING SILICON ADDITIVES

DR. CHANG-YU WU
University of Florida
Department of Environmental Engineering Sciences
406 AP Black Hall
Gainesville, FL 32611-6450
(352) 392-0845
cywu@ufl.edu

CO-PERFORMERS: Nate Topham, Mark Kalivoda, and Joyce Huang (University of Florida); Dr. Sewon Oh (Sangmyung University); Dr. Yu-Mei Hsu (Wood Buffalo Environmental Association); Dr. Kuk Cho (Korea Institute of Geoscience and Mineral Resources); Kathleen Paulson (Naval Facilities Engineering Service Center)

The objective of this project is to demonstrate a novel technology that uses tetramethyilsilane (TMS) or tetraethylxilane (TEOS) additives to welding shield gas to control hazardous air pollutants (HAPs), particularly hexavalent chromium (Cr\(^{6+}\)), generated during certain welding operations. During these operations, DoD releases HAPs into the atmosphere. Facilities estimate the residual risk to public health and in certain states must report the findings to the public when cancer risk exceeds a threshold of one in a million. When the threshold is exceeded, the facility is also expected to initiate measures to reduce the fugitive emissions.

Current welding technology uses inert shield gas, such as argon, to prevent oxidation of trivalent chromium to the hexavalent species. The TMS/TEOS added to the shield gas pyrolyzes to form amorphous silica (SiO\(_2\)) while oxygen species are scavenged during the TMS/TEOS oxidation. The resultant silica product condenses and forms a coating on Cr\(^{6+}\) particles. This technology not only addresses chromium but also other metals (e.g., Manganese (Mn), Nickel (Ni) and Copper (Cu)) that exist in welding fumes.

Various flow rates of TEOS and TMS will be added to welding shield gases in order to determine the optimum amount of silica precursor that can maximize Cr\(^{6+}\) reduction while minimizing silica precursor waste. Preliminary experimental results show 45% Cr\(^{6+}\) reduction when 3.0% TEOS was added to the shield gas. Additionally, the same silica precursor flow rate reduced nitrate concentrations in the welding fume by 53%, indicating a reduction in oxidative potential within the welding fume. The results demonstrate that silica precursors are capable of preventing oxidation of gaseous and particulate species in welding fumes. TEM imagery showed a film of SiO\(_2\) surrounding metallic aerosols collected from the welding fume. The SiO\(_2\) film minimizes toxicity of the metals by decreasing their solubility and preventing contact with tissue in the respiratory system. Particle size can also be increased through the use of SiO\(_2\) films to enhance the collection efficiency of traditional particle collection devices.

This work is funded under ESTCP Project WP-0903 and the Korea Institute of Geoscience and Mineral Resources (KIGAM).
EVALUATION OF IMPROVED METAL-RICH PRIMERS FOR CHROMATE-FREE CORROSION PROTECTION

DR. CRAIG PRICE
Naval Air Systems Command (NAVAIR)
48066 Shaw Road, Unit 5
Building 2188
Patuxent River, MD 20653
(301) 342-8050
craig.price@navy.mil

CO-PERFORMERS: Mr. Craig Matzdorf, Mr. Bill Nickerson, and Mrs. Rachel Naumann (NAVAIR)

Hexavalent chromium has long been an indispensable component of corrosion-preventing coating systems. Although, hexavalent chromium compounds (chromates) offer outstanding corrosion protection, they are known carcinogens and an EPA priority pollutant. OSHA recently lowered the acceptable exposure limits for chromates, and as a result, chromates are a major source of exposure to hazardous waste and their use is become increasingly discouraged.

Over the past several years, much effort has been focused on finding viable alternatives to chromates for the coatings industry. One approach is to employ a metal-rich primer in the overall protection scheme, such as the use of zinc-rich coatings for steel substrates. These metal-rich primers offer galvanic corrosion protection whereby the metal particles are oxidized preferentially to the substrate. In particular, one new application of metal-rich primers is the use of magnesium-rich primers for the protection of aluminum substrates. While the overall performance of the Mg-rich primer is good compared to other non-chromate systems, recent modifications by NAVAIR and AkzoNobel Aerospace Coatings have improved the corrosion protection offered to aluminum. This project will focus on the performance of improved metal-rich primers in accelerated corrosion testing, with comparisons to chromate and other non-chromate coating systems.

This work is funded under ESTCP Project WP-0731.
ULTRAVIOLET (UV)-CURABLE COATINGS FOR AEROSPACE APPLICATIONS

MATTHEW CAMPBELL
Concurrent Technologies Corporation
425 Sixth Avenue, 28th Floor, Regional Enterprise Tower
Pittsburgh, PA  15219
(412) 992-5382
campbell@ctc.com

CO-PERFORMERS: Mr. Glen H. Baker (Hill AFB); Mr. Corey Bliss (Air Force Coatings Technology Integration Office); Mr. Randall Straw (Concurrent Technologies Corporation)

Ogden Air Logistics Center (OO-ALC), the United States Coast Guard (USCG) Aviation Logistics Center (ALC) in Elizabeth City, North Carolina, NAVAIR in support of the Fleet Readiness Center Southeast (FRCSE), and the Air Force Research Laboratory (AFRL) are currently leading the Ultraviolet (UV)-Curable Coatings for Aerospace Applications project to demonstrate, validate, and implement commercial off-the-shelf (COTS) UV-curable coatings as an alternative to currently used hazardous and long cure time coatings used on aerospace equipment. This project will demonstrate the ability of this technology to replace current solvent-borne coatings in a production environment for topcoat applications such as simple geometry off-aircraft components, exterior/interior panels, markings, and touch-up and repair. If successful, UV-curable coatings will exhibit the same or better performance, reduce the overall environmental burden, and reduce the overall process flow-time compared to currently used and approved coatings. Upon successful completion of the efforts under this project, UV-curable coatings will be validated, implemented at the OO-ALC, USCG ALC, FRCSE, and be ready for implementation at other maintenance and repair facilities throughout the Department of Defense (DoD).

UV-curable coatings are volatile organic compound (VOC)-, hazardous air pollutant (HAP)-, and isocyanate-free single component high-solids (nearly 100%) cross-linked coatings cured by brief exposure to intense UV light. The chemical reaction, or polymerization, that occurs in UV-curable coatings involves two major constituents—oligomers and monomers—and is set in motion by the photoinitiators blended into the coating. UV-curable coatings can be applied through traditional coating techniques (i.e., brush, roll or spray) and are rapidly cured with exposure to an UV light source of the proper intensity and frequency. Implementing UV-curable coatings at DoD facilities will lead to significant environmental, occupational, safety, and health benefits, and productivity increases throughout the DoD.

Currently selected COTS topcoats that have gone through minor reformulation are undergoing final laboratory testing at the United States Air Force’s Coatings Technology Integration Office (CTIO) as per the Joint Test Plan. After successful completion of testing, they will be demonstrated as stencil and small area coatings at the OO-ALC, USCG ALC, and FRCSE. Demonstration targets will include stencils and small surface areas on aircraft such as the C-130, F-16, HH-60, P-3, as well as small off-aircraft parts. Demonstrated coatings will be evaluated over a year to monitor coating performance under field conditions.

This work is funded under ESTCP Project WP-0804.
UV CURABLE NON-CHROME PRIMER AND ADVANCED TOPCOAT SYSTEM

DR. THOMAS PHELY-BOBIN
QinetiQ North America, Foster-Miller Inc.
360 A Second Avenue
Waltham, MA 02451
(781) 684-4022
tphely-bobin@foster-miller.com

CO-PERFORMERS: Mr. Stan Bean (Northrop-Grumman Corporation); Dr. Eric Morris (DEFT, Inc.); Mr. Corey Bliss and Mr. Gary Wright (U.S. Air Force Research Laboratory); Dr. Edward Lipnikas (U.S. Naval Air Warfare Center Aircraft Division)

QinetiQ North America (QNA), Foster-Miller (FMI), Deft, Inc. and Northrop Grumman (NGC) are developing an environmentally benign surface pretreatment, primer and topcoat system for aircraft applications. QNA/FMI is using its patented chemistry for single-component coating formulations that contain no volatile organic compounds (VOC), hazardous air pollutants (HAP) or toxics release inventory (TRI) constituents and cures rapidly by chemical reaction on exposure to ultraviolet (UV) irradiation. QNA/FMI coating chemistry is implemented by Deft’s proprietary corrosion inhibiting pigments. The team is developing a high-performance coating that will ultimately comprise a corrosion inhibiting coating system that doesn’t contain VOCs, HAP, or SARA 313-reportable chemicals. The coatings will be sprayable, comprising of a UV-curable corrosion-inhibiting primers and high-performance topcoats. They will provide superior protection to aluminum substrates even when non-chromated surface pretreatments are employed. Work done to date and results obtained will be presented.

This work is funded under ESTCP Project WP-1520.
DEMONSTRATION OF COMPOSITES WITH LOW HAZARDOUS AIR POLLUTANT CONTENTS FOR MILITARY APPLICATIONS

DR. JOHN LA SCALA
U.S. Army Research Laboratory
RDRL-WMM-C
Aberdeen Proving Ground, MD 21005
(410) 306-0687
jlascala@arl.army.mil

CO-PERFORMERS: Dr. Xing Geng, Mr. Alexander Grous, and Dr. Giuseppe R. Palmese (Drexel University); Dr. Steven Boyd, Dr. James M. Sands, and Mr. Ian McAninch (U.S. Army Research Laboratory); Mr. David Fudge, Dr. Nicholas Shevchenko, Mr. Stephen Andersen, and Dr. John Gillespie, Jr. (University of Delaware); Mr. Frank Bruce, Lt. Dane Morgan, Mr. Ken Patterson, and Mr. Lawrence Coulter (U.S. Air Force Research Laboratory); Dr. Maureen Foley and Dr. Roger Crane (Naval Surface Warfare Center, Carderock); Mr. Michael Starks and Mr. Jorge Gomez (U.S. Army TACOM)

Liquid resins used for molding composite structures are a significant source of hazardous air pollutant (HAP) emissions. One method of reducing styrene emissions from vinyl ester (VE) resins is to replace some or all of the styrene with fatty acid-based monomers. Fatty acid monomers are ideal candidates because they are inexpensive, have low volatilities, and promote global sustainability because they are derived from renewable resources. This patented technology allows for the formulation of high performance composite resins with no more than 25 wt% styrene, which is a 25-50% reduction in HAP emissions vs. commercial VE resins. This work has validated the commercially produced low HAP vinyl ester resins from Applied Poleramics, Inc. for use in DoD composite structures. Tests have shown that the established resin formulations meet the property requirements, including viscosity, glass transition temperature, modulus, strength, short beam shear strength, and fracture toughness. Furthermore the low HAP fatty acid composites have improved weatherability relative to the baseline vinyl ester composites. The Army has demonstrated and validated the use of these HMMWV transmission container, M35A3 hood, and M939 hood under laboratory testing and field conditions. The Air Force has demonstrated the production of an F-22 canopy cover, T-38 dorsal cover, and rapid prototyping splash molds. The F-22 canopy cover and splash molds were completely validated, but the T-38 dorsal cover was only validated at the laboratory level. MCM rudders were successfully demonstrated and were validated at the laboratory level. An economic analysis has shown that these resins will cost an additional $0.1-1.20/lb (depending on manufacturing scale) more than baseline resins. However, these resins reduce life cycle cost by more than $1.20/lb, making them economically feasible.

This work is funded under ESTCP Project WP-0617.
DEMONSTRATION OF NANOSCALE TUNGSTEN ALTERNATIVES TO DEPLETED URANIUM IN ANTI-ARMOR PENETRATORS

DR. LEE MAGNESS
U.S. Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5066
(410) 278-6022
magness@arl.army.mil


The objectives of this project are to demonstrate the materials and processing technologies needed to produce tungsten nanocomposite anti-armor penetrators that display superior penetration performance relative to conventional tungsten heavy alloy penetrators, while at the same time eliminating matrix alloying elements that are known or suspected to be toxic. Prior work at the Army Research Laboratory has shown that nanograin tungsten exhibits the type of adiabatic shearing behavior desired in heavy armor piercing ammunition. We are currently developing a low-cost, high-volume approach to synthesizing and safely consolidating tungsten nanocomposite powders to maximum overall density and plan to demonstrate the efficacy of these materials as potential replacements for depleted uranium (DU) in anti-armor penetrators through ballistic testing. The project is being coordinated with OSRAM Sylvania, a leading producer of tungsten-based projectiles, to assure rapid deployment of the technology into the existing production base.

To date, we have demonstrated two methods of synthesizing nanocrystalline tungsten-based powder for use in developing a high-performance tungsten-based anti-armor penetrator, the flash freeze-drying process and the glycine nitrate process (GNP). We recently down-selected the GNP approach based on the superior material attributes of lab-scale powder batches synthesized by this process. GNP consists of two basic steps: (1) the formation of an aqueous metal nitrate-glycine solution that (2) is heated to dryness and eventual autoignition, at which point a self-sustaining combustion reaction takes place to produce the final powder product in a matter of a few seconds. In this process, the glycine serves two purposes: it prevents precipitation of the metal salts as the water is evaporated, thereby ensuring that the metal ions remain molecularly mixed in solution up to the point of combustion or chemical conversion, and it acts as the fuel for the combustion reaction by undergoing oxidation with the nitrate ions during heating. The resulting precursor material is calcined and subsequently reduced in hydrogen to form the final nanograin powder.

This work is funded under ESTCP Project WP-0805.
Here exists a need for environmentally benign coatings to eliminate cadmium or chromate coatings on high-strength fasteners. These coatings would provide high-strength, corrosion resistant fasteners for use weapon systems. Traditionally, high-strength steels have been used with cadmium (Cd) electroplated coatings, followed by a hexavalent chromium (Cr$_{6+}$) rinse. The environmental hazards associated with both cadmium and chromates are well established.

Alternatives to both processes have been pursued within the coatings industry with very promising results. Developments with combinations of coatings may meet future DOD requirements. These systems are free of hazardous post-treatments (Cr$_{6+}$ rinse) and avoid embrittlement phenomena.

The elimination of hazardous materials will improve the life cycle costs and environmental and occupational health issues associated with the manufacture and maintenance of DoD weapon systems. Cd and Cr present personnel hazards, and environmental hazards. These approaches would impart high end sacrificial corrosion resistance properties without use of hazardous Cr or Cd and without hydrogen embrittlement of fasteners.

This project will demonstrate a multi-layer approach to provide a protective coating system. These systems will include a sacrificial metal base coat and may also include an organic topcoat technology that will provide the best combination of corrosion resistance and torque tension control.

The sacrificial zinc based primer system is key to high-end corrosion performance. This requires the development inorganic and hybrid binder systems as well as new types of zinc flake technology. Thin film cathodic protection and excellent adhesion characteristics are demonstrated. Corrosion performance has been achieved on high-strength steel fasteners at greater than 2000 hours of ASTM B117 Salt Spray.

With all high strength fastener coatings, hydrogen embrittlement and in-service embrittlement are always of concern. This poster will also show the results of ASTM F519-06e2 testing.

This work is funded under SERDP Project WP-1617.
SCIENTIFIC UNDERSTANDING OF NON-CHROMATED CORROSION INHIBITORS FUNCTION

DR. GERALD FRANKEL
The Ohio State University
2041 College Road, 477 Watts Hall
Columbus, OH 43210
(314) 688-4128
frankel.10@osu.edu

CO-PERFORMERS: Dr. Rudy Buchheit (Ohio State University); Dr. Mark Jaworowski (United Technologies); Dr. Greg Swain (Michigan State University)

This project addresses the mechanisms of leading chromate-free candidates and the cross-cutting, underlying fundamental issues. Advances in the scientific understanding of these issues are relevant to many if not all of the non-chromate technologies.

Progress was made in the following individual topics: (1) Fundamental Studies of the Trivalent Chrome Process (TCP). During this year, TCP layers were characterized by a number of analytical techniques to reveal the surface morphology, thickness, structure and composition of the film; (2) Mechanisms of selected inhibitors. Preliminary experiments on aluminum alloys in molybdate-containing solutions found molybdenum to be an anodic inhibitor only within a certain pH range, and can actually increase the cathodic current at low pH values. Studies on rare-earth metal salts in solution found them to be cathodic inhibitors with decreasing order of corrosion inhibition being Ce$^{3+}$, Pr$^{3+}$, La$^{3+}$ and Zn$^{2+}$. Ion-exchanged bentonite pigments containing these ions in a non-protective polymer matrix did not provide scribe protection, despite their cathodic inhibiting ability; (3) Paint adhesion strength and mechanism. The apparatus and sample preparation protocol for the blister test was developed. The surface characteristics, as revealed through the effects of surface roughness directionality from the final polishing step, were found to influence paint delamination; (4) Inhibitor activation and transport in the primer layer. A protocol for identifying, characterizing, and evaluating commercial paint pigments was developed. The active pigments in a number of commercial primers were identified. Solubility testing of inhibitors commenced, with most progress made toward evaluating solubility of strontium chromate. Interesting observations include a strong supersaturation effect during evaporation as well as a strong influence of NaCl in solution on solubility; and (5) Interactions between polymer matrix, pigment, surface treatment, and alloy. The interactions between polymer matrix, pigment, surface treatment and alloy were studied on chromated systems while samples with combinations of treatments were prepared for future analysis. The chromated systems were sectioned and analyzed, and water uptake experiments indicated rapid saturation.

This work is funded under SERDP Project WP-1620.
ArmorGalv® Thermal Diffusion – Environment-Friendly, Cost Effective

MOSHE MOLED
Distek North America, LLC
1800 Touhy Avenue
Elk Grove Village, IL 60007
(617) 566-0058
moshe@distekna.com

The ArmorGalv® technology is an environment-friendly process that offers superior corrosion protection and wear resistance as well as anti-galling properties. Following are some highlights of the ArmorGalv® technology, which is a modern, greatly improved, version of the well established Sherardizing zinc/iron vapor diffusion process:

ArmorGalv® is not merely a sacrificial coating. It coats and penetrates the surface of any steel part, including wrought and/or forged steel, castings, powdered metal (with no impregnation required), and all grades of stainless steel, to become integrated with the part. Furthermore, ArmorGalv® is/has:

- Highly corrosion and abrasion resistant.
- Excellent anti-galling properties – a replacement for Cadmium.
- Controllable and precise - thicknesses from 0.0003” to 6 mils
- Hard, non-magnetic, weldable and spark-free.
- Chip-proof and amenable to crimping and bending.
- Highly heat-resistant 12,000°F (650°C) continuous service.
- Excellent base for paint, powder coating and rubber bonding.
- Particularly interesting for powder metal parts, requiring no impregnation and providing not only extremely good corrosion protection, but also improved mechanical properties.
- Totally heavy metal-free and non-toxic.
- Hydrogen embrittlement-free. Heat treated parts can safely be coated and protected.
- Works extremely well in harsh marine environment.

The unique combination of properties offered by the ArmorGalv® coating make it an excellent replacement for cadmium and hex chromium. It is also beneficial to a multitude of military applications, including construction in corrosive environments, components on Navy ships, land vehicles, small arms, artillery, ordnance and others.

ArmorGalv® Thermal Diffusion Coating is covered by ASTM # A-1059.

The Thermal-Diffusion technology is the recipient of the EPA’s prestigious MVP² award (Most Valuable Pollution Prevention).
ROBOTIC LASER COATING REMOVAL SYSTEM

TIMOTHY HOEHMAN
76 AMXG/QPP
Tinker Air Force Base, Oklahoma
(405) 736-7757
timothy.hoehman@tinker.af.mil

CO-PERFORMERS: Jim Arthur and Tim Hoehman (Concurrent Technologies Corporation);
Randel Bowman (Tinker Air Force Base)

Oklahoma City Air Logistics Center (OC-ALC), Headquarters Air Force Material Command (HQ AFMC/LGPE), and the Air Force Research Laboratory (AFRL) are currently leading the Robotic Laser Coating Removal System (RLCRS) program to demonstrate and validate a RLCRS as an alternative technology to the current chemical and mechanical methods that are used to remove coatings from large off-equipment aircraft components at Tinker Air Force Base, OK. This project will demonstrate the ability of this technology to meet the requirements for coatings removal in a production environment as well as the pollution reduction that can be achieved through its use across the Department of Defense (DoD). The RLCRS system will be designed to accommodate processing of large parts that are currently subjected to coatings removal operations once they are removed from the airframe.

This technology has the potential to reduce the environmental burden associated with coatings removal operations while reducing the labor and chemical costs and positively impacting the production schedule. The implementation of the RLCRS will also provide the maintenance facility with the flexibility to remove coatings from components of various sizes and geometries using a single system.

The ultimate goal of the project was to design a system of commercially available off the shelf (COTS) components that can be easily integrated onto different robotic platforms. This will allow individual depots to adapt the technology to meet their specific configuration and space needs.

The RLCRS system has been completed and implemented at OC-ALC. Demonstration of this system in accordance with the ESTCP Demonstration Plan has been completed and OC-ALC is currently moving forward with obtaining approvals to use the system on production KC-135 parts.

This work is funded under ESTCP Project WP-0526 and by HQ AFMC.
FORMULATION AND PERFORMANCE TESTING OF NOVEL PYROTECHNIC INCENDIARY COMPOSITIONS

DR. TREVOR GRIFFITHS
QinetiQ
Fort Halstead
X59
Sevenoaks, Kent TN146PE UNITED KINGDOM
44-1959-515347
ttgriffiths@qinetiq.com

CO-PERFORMERS: Professor E. L. Charsley, J. J. Rooney, and H. M. Markham (Huddersfield University)

Perchlorates are used as high energy oxidizers in a wide range of military applications including rocket propellants and pyrotechnics. When used in ammunition incendiary systems, pyrotechnic compositions containing potassium perchlorate are formulated to mark an impact point or act as ignition sources for flammable liquids.

Potassium perchlorate has a high solubility in water which results in very low retardation in aquifers, as a result, any groundwater plumes can be extensive and poses severe remediation problems. It can be released into the environment as a result of spillages during manufacture, demilitarization, or when ammunition fails to function correctly. The presence of potassium perchlorate in drinking water is a cause for concern, as all perchlorates are recognized as a potential hazard to human health. In particular, their ingestion is known to inhibit iodide uptake by the thyroid gland.

Formulation studies on a wide range of new incendiary pyrotechnics have been completed. The performance of selected compositions containing a range of binders will be reported along with the results of thermal studies and aging trials under conditions of high humidity and temperature. The performance testing includes burning rate studies, thermal analysis and gun firing trials. The results of the work demonstrated that potassium perchlorate could be eliminated from incendiary compositions without degrading the performance or aging characteristics.

The work formed part of an investigation for the Strategic Environmental Research and Development Program (SERDP) into the development of environmentally benign, perchlorate-free incendiary and pyrotechnic mix technologies for projectiles (WP-1424).
**EVALUATING DECISION SUPPORT PLANNING METHODS FOR INCORPORATING CLIMATE CHANGE UNCERTAINTIES**

MR. DOUGLAS OWEN  
Malcolm Pirnie, Inc.  
104 Corporate Park Drive, Box 751  
White Plains, NY 10602  
(914) 641-2700  
dowen@pirnie.com  

CO-PERFORMERS: Edward Means, Maryline Laugier, and Jennifer Daw  
(Malcolm Pirnie, Inc.)

Agencies with water supply needs that perform assessments of their vulnerabilities to climate change are faced with a large range of projections of future climate and the dilemma of how to develop short and long-range plans that incorporate this uncertainty about future weather conditions. As such, climate change is challenging agencies to consider broader integration of planning assumptions. There is little guidance available for agencies attempting to address these uncertainties in water planning practices.

Water supply planning has traditionally used historical supply patterns and projections of operational need. These planning techniques incorporated past variability using recorded weather and hydrology time series. The core assumption has been that these climate patterns exhibit stationarity, that is, they will be largely repeated into the future. Agencies are rethinking planning methods as evidence builds that historical weather patterns may be giving way to greater climate variability and (depending on geography) water supply reductions. To this end, agencies are seeking better tools to guide the incorporation of climate change information into water planning.

Several approaches are emerging for incorporating climatic uncertainty into short- and long-term water planning. Decision support planning methods (DSPMs) are needed that integrate broader planning assumptions such as watershed development and land use changes, water quality and quantity changes, and demand changes in planning for future water supplies. DSPMs are valuable approaches, which can aid in the transition from stationary planning to uncertainty-based methods. These methods are beneficial in their ability to characterize and manage uncertainties and to assist utilities in making defensible water resources decisions for short- and long-term planning while minimizing the risks associated with these decisions.

This project will present six promising DSPMs, such as, decision analysis (probability-based method); traditional scenario planning and robust-decision making (scenario-based methods), portfolio planning and real options (financial-based methods); and catastrophe models (insurance-based methods), that agencies can consider to manage climate change uncertainties in their planning. These six DSPMs have been researched, reviewed, documented, and evaluated according to twenty-one relevant evaluation criteria organized in four main groups, including general characteristics, resource requirements, input data and models, and outputs and results. The findings of this evaluation will provide fundamental guidance to agencies in choosing which DSPM is the best fit for different situations and agency capabilities.
GREENHOUSE GAS (GHG) EMISSIONS FROM A TRANSPORTATION – FOCUSED ARMY INSTALLATION

DR. ANIKET SAWANT
O'Brien & Gere
512 E. Township Line Road
Suite 120, Two Valley Square
Blue Bell, PA 19422
(215) 628-9100
sawanta@obg.com

CO-PERFORMERS: Susan Miller and Arba Williamson (Fort Eustis); Dr. Parikhit “Ricky” Sinha (O'Brien & Gere)

Coupled with future resource scarcity and resultant potential adverse human impacts, global climate change has the potential to pose a long-term threat to the national security of the United States. Conversely, the intelligent formulation and application of climate change adaptation and mitigation approaches can lead to strategic and tactical advantages during times of war and peace.

According to the international scientific consensus, greenhouse gases (GHGs) released through combustion of fossil fuels are a major contributor to climate change. As the world’s largest consumer of energy and until recently the largest emitter of GHGs, the United States has a responsibility towards understanding and mitigating its GHG emissions. Further, as one of the largest holders of land (1% of total area), and the single largest consumer of energy (1% of total consumption) in the United States, GHG emissions are especially relevant to the U.S. Department of Defense (DoD).

The development of GHG inventories for military installations serves as an important first step both in understanding total GHG emissions as well as in setting appropriate GHG reduction targets for the DoD. Towards this end, this project presents the development of a GHG inventory for the U.S. Army installation of Fort Eustis, VA. The inventory includes direct GHG emissions from stationary and mobile combustion sources. The latter source is of special relevance, since Fort Eustis serves as headquarters for the U.S. Army Transportation Center and School, the 8th Transportation Brigade, and the Army Aviation Logistics School, among others. Other sources in this inventory include use of refrigerants and process gases; third-party utility (electricity, heat, steam and chilled water) usage; and tons of solid waste sent to landfills. Also discussed are initiatives related to energy efficiency, waste minimization, and renewable energy, all of which can have a material impact on the resource use and associated emissions at this installation.

It is anticipated that this GHG inventory will be useful in both quantifying current energy- and environment-related resource emissions at Fort Eustis, and in setting future GHG reduction targets for this installation. Further, it is hoped that the lessons learned from this GHG inventory, especially those related to transportation emissions, can serve to assist other U.S. military installations in their own GHG inventory management and future mitigation planning.
NASA GSFC: A CASE OF STATE DRIVEN GHG INVENTORY DEVELOPMENT & SERENDIPITY

MS. KATHLEEN MOXLEY
NASA Goddard Space Flight Center (GSFC)
Code 250
Greenbelt, MD 20771
(301) 286-0717
Kathleen.M.Moxley@nasa.gov

CO-PERFORMER: Jeremey Alcorn (Concurrent Technologies Corporation)

Following the release of Executive Order (EO) 13423, NASA Headquarters (HQ) redoubled its efforts to understand the internal and external landscape of greenhouse gas (GHG) inventory programs and the accepted methodologies for development of a GHG inventory. Aside from EO 13423’s emphasis on GHGs, this initial research revealed a growing number of federal programs and mandates that required a better understanding of the Agency’s GHG emissions. These findings led NASA to develop a new GHG related goal in the EO 13423 Toxic and Hazardous Chemical Plan. In the late-fall of 2007, NASA had developed a draft baseline GHG inventory approach and tools that concurrently utilize the widely accepted WRI/WBCSD GHG Protocol and the Federal Energy Management Program to calculate the initial facility-level GHG emissions baseline.

In January of 2008, NASA GSFC received notice from the Maryland Department of Environment (MDE) that it had been requested to provide information on the GHG emissions of its permitted air sources as part of the mandatory CY 2007 Air Emissions Certification report. Leveraging NASA HQ’s earlier efforts and the existing NASA GHG tool, the NASA GSFC team was not only able to comply with MDE’s request but to also start a constructive dialog with their state regulators about future regulatory action on GHGs. While successful in meeting their CY 2007 requirement, GSFC’s environmental management system (EMS) team identified and elevated GHG as a high priority aspect. As a result, GSFC and HQ support resources started a collaborative effort to understand the Center’s Scope 1 and 2 GHG sources and develop a hybrid GHG Inventory tool, which was a developed to help anticipate and prepare for emerging GHG regulations and reduction mandates.

Drawing on this experience, this project will elaborate on GSFC’s GHG inventory efforts, calculation tool, and findings to date. It will also provide lessons learned and useful resources identified while developing GSFC GHG inventory approach and tool. Finally, it will provide an update on current and future approach development efforts.
FROM THE TRENCHES: TOP-DOWN AND BOTTOM-UP GHG INVENTORY APPROACHES

MR. JEREMEY ALCORN
Concurrent Technologies Corporation
1225 South Clark Street, Suite 500
Arlington, VA  22202-4376
(703) 310-5662
alcornj@ctc.com

CO-PERFORMER:  Shannon Lloyd, Ph.D. (Concurrent Technologies Corporation)

The Department of Defense (DoD) and civilian federal agencies have accelerated efforts to better understand greenhouse gas (GHG) emission inventory frameworks, calculation methods, and voluntary and regulatory programs. There is growing activity to develop authoritative and practical GHG inventory approaches for the federal sector. “Top-down” approaches leverage existing institutional data systems while others are installation-focused, “bottom-up” efforts that utilize detailed site-specific data.

Several top-down GHG inventory approaches have been developed within the defense community and federal family. These pragmatic efforts leverage existing institutional data systems (i.e., energy, transportation, munitions) to rapidly develop useful installation-level Scope 1 & 2 GHG inventories. They are advantageous because they can utilize consistent template-based approaches, enable rapid installation results, and allow easy agency-wide rollup totals. However, the inherent scope uncertainties (e.g., tenants) and omitted emission source data do limit their ability to meet emerging state regulatory requirements for GHGs and identify specific energy and emission reduction opportunities. Despite such limitations, top-down GHG inventory approaches offer significant utility for agency-level GHG inventory results, their analysis, and strategic decision-making on mitigations.

Likewise, bottom-up GHG inventory efforts are also emerging at both defense and civilian installations and are being developed to proactively anticipate or respond to federal and state regulations. These installation-centric GHG inventory approaches have advantages because of better defined scope boundaries, higher resolution data, and detailed emission source inventories. However, they are time consuming, have complex scope boundary issues, and are difficult to roll-up to the agency level. Conversely, these efforts can effectively reveal data and emission factor gaps, identify complementary energy program opportunities, and directly meet state regulatory requirements.

Current defense and federal agency experiences provide the basis for a timely discussion of the advantages, limitations, and unique utility inherent to top-down, bottom-up, and hybrid approaches and technologies. By doing so, it is possible to understand how the different approaches meet distinct needs and are complementary. This project will present the pros and cons of these complementary approaches and suggest how they can ultimately produce more robust and comprehensive institutional GHG management for the DoD and its Service Branches.
RENEWABLE DOESN’T MEAN CARBON NEUTRAL: EMERGING GREENHOUSE GAS INVENTORY CHALLENGE

MR. JEREMEY ALCORN
Concurrent Technologies Corporation
1225 South Clark Street, Suite 500
Arlington, VA  22202-4376
(703) 310-5662
alcornj@ctc.com

CO-PERFORMER: Shannon Lloyd, Ph.D. (Concurrent Technologies Corporation)

Executive Order (EO) 13423, the EPA “Greenhouse Gas (GHG) Rule,” the American Clean Energy and Security Act, and emerging state regulations have been spurring federal agencies to better understand GHG inventory frameworks, regulatory programs, and calculation methodologies. A growing number of projects have emerged to understand and account for federal installations’ GHG emissions. After participating in some of these efforts, one increasing area of concern with current GHG inventory calculation approaches and tools is the calculation of biogenic (or biologically sequestered) CO₂ emission sources. The WRI/WBCSD GHG Protocol and programs based upon it (e.g., EPA Climate Leaders, CCAR) exclude biogenic CO₂ emissions from Scope 1 & 2 GHG emission inventories. Conversely, the N₂O or CH₄ emissions from those same sources are considered anthropogenic (or human generated) and included in inventories.

On DoD and other federal installations, biogenic CO₂ emissions are generated from the combustion of renewable fuels (e.g., biomass, landfill gas), including the bio-based portion of mixed biofuels (B20, E85). While guidance states the need for biogenic emission calculation, it is considered optional in some GHG reporting programs and not included in Scope 1 & 2 emissions. As federal GHG inventory efforts move forward, it has been recognized that inventory approaches and emission factors account for biogenic emissions in divergent ways. One approach is to “zero out” the biogenic emissions. However, some question whether this is appropriate as these emissions contribute to climate change, if on a shorter timescale. The second approach is to fully but separately account for biogenic emissions. This approach enables installations to account for their GHG emissions and conform to various regulatory programs’ biogenic emissions requirements.

With dynamic regulations, it seems prudent to develop defense specific GHG inventory approaches that utilize this second approach as it is requires minimal resource now and avoids costly rework in the future. However, several defense and federal GHG inventory efforts currently utilize this first approach and, as a result, do not account for their biogenic emissions despite including provisions to calculate the CO₂ sequestration potential in hope to document off-set credits. Given the methodological risks associated with this latter approach, examples of biogenic CO₂ calculation approaches will be presented along with their strengths and weaknesses.
ADAPTING TO CLIMATE CHANGE: USE OF MULTI-SCALE MODELS, DATA AND SCENARIO PROJECTIONS TO REDUCE RISK TO BIRDS ON FLORIDA MILITARY INSTALLATIONS

DR. IGOR LINKOV
U.S. Army Engineer Research and Development Center
696 Virginia Road
Concord, MA 01742
(617) 233-9869
Igor.linkov@usace.army.mil

CO-PERFORMERS: Dr. Richard Fischer and Dr. Christy Foran (U.S. Army Engineer Research and Development Center); Dr. Gregory A. Kiker, Dr. Rafael Muñoz-Carpena, Dr. Christopher Martinez, Dr. Keith T. Ingram, and Axel Emanuelsson (University of Florida); Dr. Resit Akcakaya (The State University of New York); Dr. Nicholas A. Friedenberg (Applied Biomathematics)

Climate change (via sea-level rise and altered weather patterns) is expected to significantly alter low-lying coastal and intertidal areas, which provide significant seasonal habitats for a variety of shoreline-dependent organisms. Many coastal military installations in Florida have significant coastal habitats and shoreline-dependent bird data that strongly illustrate their seasonal importance for birds. This project is developing a meta-population model of the Snowy Plover in Florida models to assess the risk of climate change effects and human disturbances on this species. The approach integrates three types of models: a habitat model of the species, results of climate models and a demographic model. The integrated model incorporates effects of climate change, land-use change, and other threats on both the habitat and the population dynamics of the species. To date, preliminary habitat modeling efforts have been conducted with the Sea Level Affecting Marsh Model (SLAMM). The model was executed with topological data at landscape-scale (30m) resolution and with LiDAR-based (1-2m) data. These early results have pointed out challenges in integrating different scales of ecosystem information for near-shore habitats and set the stage for subsequent global sensitivity and uncertainty analysis efforts. The projections from these models will produce site-specific information that will be useful to military natural resource managers for identifying the significance of military lands in contributing to the long-term sustainability of threatened and endangered species under various climate change scenarios. The projections will then be used in multiple-criteria decision analysis theoretical models, built on the Risk-Informed Decision Framework (RIDF) developed by the U.S. Army Engineer Research and Development Center (ERDC), to integrate uncertain regional and species information with the values and intuition of decision makers.

This work is funded under SERDP Project SI-1699.
A METHOD FOR ASSESSING THE IMPACT OF SEA LEVEL RISE ON REPRESENTATIVE MILITARY INSTALLATIONS IN THE SOUTHWESTERN UNITED STATES

DR. BART CHADWICK
SPAWAR Systems Center Pacific (Code 17150)
53475 Strothe Road
San Diego, CA 92152
(619) 553-5333
bart.chadwick@navy.mil

CO-PERFORMERS: Dr. Reinhard Flick (Terra Costa, Consulting Group); Dr. Walt Oechel (San Diego State University); Dr. John Helly (San Diego Super Computer Center); Dr. Tracy Nishikawa (U.S. Geological Survey); Dr. Kevin Knutti (U.S. Army Corps of Engineers); Mr. Matt Martinez (Moffitt and Nichol); Dr. PF Wang, Ms. Marissa Brand, and Mr. Bill Wild (SPAWAR Systems Center Pacific)

Climate change has potential ramifications for national security as recognized in recent legislation that directs the Department of Defense (DoD) to provide guidance to military planners to assess the risks of potential climate change. Accelerated rates of sea level rise (SLR) and associated phenomena contributing to potential impacts in the 21st century could lead to installation vulnerabilities, including loss/damage to mission essential infrastructure; loss/degradation of mission capabilities; loss of training and testing lands; loss of transportation means, facilities, and/or corridors; and increased potential for loss of life.

The general objective of this project is to develop analysis methods to assess the impacts of local mean sea level rise and associated phenomena on Southwestern U.S. DoD installations. The methodologies will be tested through application to Naval Base Coronado and Marine Corps Base Camp Pendleton. The specific objectives of this project are to develop an analysis framework for determining Southwestern U.S. military installation vulnerabilities under joint scenarios for the four specified increases in local mean sea level of 0.5 meters, 1.0 meters, 1.5 meters and 2.0 meters and associated regional-specific climatic responses, as projected over the next century. This effort will provide a military-relevant framework for assessing accelerated SLR vulnerability, including a cutting edge visualization and analysis tool and expert input for developing the best scientifically-based scenarios of waves, tides, and storms and associated implications on selected coastal military installations in the southwestern United States.

First year efforts are directed toward development of the framework and vulnerability assessment which will consist of five primary components: (1) a generalized vulnerability framework for application to coastal military installations; (2) characterization and prediction of the strength, frequency, and probability of underlying forcing factors that control regional sea level to develop realistic assessment scenarios for a range of regional sea level conditions; (3) a compilation of critical biogeophysical and infrastructure data for each installation within a three-dimensional GIS modeling environment; (4) characterization of the expected physical effects of SLR within the Southwest region; and (5) initialization of development of a GIS modeling system combined with infrastructure analysis. This work is funded under SERDP Project SI-1703.
ASSESSMENT FRAMEWORK FOR ADDRESSING CLIMATE CHANGE IMPACTS AND ADAPTATION

I. SAM HIGUCHI
NASA, Environmental Management Division
300 E Street, SW
Washington, DC 20546
(202) 358-0149
shiguchi@nasa.gov

CO-PERFORMERS: Kim Toufектis (NASA-Facilities Engineering and Real Property Division); Christina Hudson (SAIC); Dr. Cynthia Rosenzweig (NASA’s Goddard Institute for Space Studies); Dr. Radley Horton (Columbia University’s Center for Climate Systems Research)

Climate change will impact NASA’s institutional capabilities in a variety of ways, including: cost, availability, and reliability of water and energy; sea level rise; and changing weather patterns and increasing extreme events which may affect safety and operations (e.g., more hot days, floods, and fire).

NASA leads in many aspects of the science of climate change and held a workshop in July 2009 between the NASA climate science community and the NASA operational community to begin addressing questions such as: What is the state of the science and how can it be used to address NASA’s needs? What are potential risks to NASA institutional capabilities and how does NASA incorporate these risks into its risk management system? How can NASA use climate science data to determine its operational vulnerabilities and single point failures? How can the climate science and operational communities work together so NASA can make sustainable infrastructure and asset investment decisions?

The workshop serves as a pilot for how a federal agency can start to: (a) understand current and future climate change risks, (b) develop a list of vulnerable institutional capabilities and assets, and (c) develop next steps so flexible adaptation strategies can be developed and implemented. Eight Adaptation Assessment Steps, utilized and proven by other organizations and cities, provided a workshop framework and participants interfaced through groups organized by geographic similarities (coastal, arid, or temperate) and functional (facilities and master planning, environmental management and natural resources, and science).
EFFECTS OF NEAR-TERM SEA-LEVEL RISE ON COASTAL INFRASTRUCTURE

DR. JOSEPH F. DONOGHUE
Florida State University
Department of Geological Sciences
Tallahassee, FL 32306
(850) 644-2703
jfdonoghue@fsu.edu

CO-PERFORMERS: Dr. James B. Elsner, Dr. Bill X. Hu, Dr. Stephen A. Kish, Dr. Yang Wang, Dr. Ming Ye, Jennifer Coor, Oindrila Das, Shawn Lewers, and Kelsey Scheitlin (Florida State University); Dr. Alan W. Niedoroda (URS Corporation)

This project will investigate the potential risks to coastal military infrastructure due to predicted changes in climate and sea level over the next century. The study focuses on the Florida panhandle coast and specifically Eglin Air Force Base (AFB). It incorporates existing and new data into models for evaluating the effects of accelerated sea-level rise, increased rates of coastal retreat, increased wetland loss, higher storm surge, enhanced storm effects, and saltwater intrusion. The results will be used to evaluate how to make reliable predictions of the effects of future climate change on natural coastal systems and on coastal infrastructure, and to enable cost-effective mitigation and adaptation strategies.

This project has analyzed remote-sensing data and historic charts to establish rates of change in natural coastal systems. In addition, coastal lake sediments have been collected and are being analyzed to establish a long-term storm history for the region. The results are being employed in refining the historic storm climatology and morphodynamic and storm models.

A large-scale numerical morphodynamic model of complex coastal systems is being developed based on the CST Model (Niedoroda et al. 2001). This new model, the Sea Level – Process Response model, will be a substantial advance from the CST model. The model can now represent the shelf, shoreface, surf zone and beach system processes that are representative of the entire length of Santa Rosa Island, a long barrier which houses significant military infrastructure. The model has been used to simulate 137 years of measured shoreline change and to extend these to predictions of future rates of shoreline migration.

For the storm modeling, hourly-interpolated hurricane track data are being used to identify historical storms that directly affected Eglin AFB. Twelve major hurricanes came within 75 nm of Santa Rosa Island over the period 1851-2008. The 12 tracks are merged to create a “climatological” pathway that defines a corridor bounding an ensemble of realistic tracks based on the past climate.

This project will provide a set of unique tools for predicting, mitigating, and adapting to the effects of sea-level rise and associated phenomena on coastal infrastructure. These predictive tools will be in a format that is readily available to use and apply to management decisions related to any coastal installation at risk from future sea-level change.

This work is funded under SERDP Project SI-1700.
**DECISION SUPPORT METHODOLOGY FOR THE INTEGRATION OF ADAPTATION PLANNING OF INFRASTRUCTURE AND ECOSYSTEMS IN THE COASTAL ZONE**

**DR. PAUL KIRSHEN**  
Battelle  
One Cranberry Hill  
Lexington, MA 02421  
(781) 869-1402  
kirshenP@battelle.org

**CO-PERFORMER:** Norman Richardson (Battelle)

Being at the nexus of the terrestrial and marine environments, the coastal zone faces a variety of natural and anthropogenic stressors. Examples of these stressors include present climate variability, population growth, urbanization, and land use change. Climate change trends are exacerbating these impacts. The built and natural environments in the coastal zone are highly intertwined and infrastructure and ecosystems services are both essential for the functioning of modern society. Unfortunately, infrastructure services often stress ecosystems due to mismanagement of water, wastes, habitat, and land use. Those responsible for coastal planning, prioritizing actions, and monitoring in this region face many challenges due to the conflicting uses of resources, myriad of uncertainties, complexities of interactions, limited funding, and the overlapping, often competing interests of the multiple stakeholders in the region.

This project provides an overview of the decision support methodology that is being developed to integrate ecosystem and infrastructure climate change adaptation planning efforts in the coastal zone. Utilizing ecosystem and infrastructure models, the methodology uses scenario-based risk assessment to find robust adaptation solutions that work well over future uncertainties including climate change and socio-economic conditions. It is designed for use by federal, state, and local decision makers in a participatory framework.

This project is currently in the process of working with local stakeholders at several case study sites to develop and field test the approach. Preliminary results from the case studies will be presented.
ULTRASONIC GUIDED WAVE TECHNOLOGY FOR NON-INVASIVE ASSESSMENT OF CORROSION-INDUCED DAMAGE IN PIPING FOR POLLUTION PREVENTION IN DOD FUEL STORAGE FACILITIES

DR. JOHN M. LIU
Naval Surface Warfare Center Carderock Division
9500 MacArthur Boulevard
W. Bethesda, MD 20817-5700
(301) 227-5024
john.liu@navy.mil

CO-PERFORMER: Ms. Terri Regin, P.E. (Naval Facilities Engineering Command)

The Oil Pollution Act (OPA) of 1990 specifies operational and maintenance requirements for DoD and civilian fuel/oil storage and transport facilities in the U.S. Fuel/oil spills are unacceptable because they harm the environment, generate bad publicity for DoD, and require costly remedial clean-up efforts. In addition to visual inspection, spill prevention practices for pipelines in use today include the passage of a “pig” (pipe inspection gauge) along the inside of a pipe and “pressure” testing by inducing a visible leak in a pipeline followed by immediate repair or replacement of the weaker sections. These techniques interrupt the normal operation of a pipeline, are costly to set up, and do not provide sufficient information to predict the future health of a pipeline.

This project intends to demonstrate the use of ultrasonic guided wave technology for a non-invasive assessment of the conditions of above ground and buried pipelines. In addition, it attempts to validate the capability of this technology to track the growth of corrosion-induced defects in such pipelines remotely by monitoring and analyzing the changes in ultrasonic signals propagating along a pipeline over time. If successful, this technology should provide a cost-effective means to monitor the health of a pipeline.

This project presents results obtained in the laboratories at the Naval Surface Warfare Center Carderock Division on the successful tracking for the growth of defects in a steel pipeline over one hundred feet long, and the baseline measurements of a live JP-5 fuel pipeline in a Naval fuel facility where a field demonstration of this technology is being carried out. In the laboratory tests, electrochemical means were used to generate controlled, hidden, and localized corrosion at predetermined areas which were detected and monitored by ultrasound using two different types of commercial equipment. The conditions in the field tests should provide significant challenges to allow a thorough evaluation of the current state of this technology for monitoring the health of a buried fuel line.

This work is funded under ESTCP Project SI-0819.
DESIGN, MONITORING, AND VALIDATION OF A HIGH PERFORMANCE BUILDING

MS. MANETTE MESSENGER
U.S. Army Installation Management Command-Southeast
1593 Hardee Avenue SW
Fort McPherson, GA 30329
(404) 464-0786
manette.messenger@us.army.mil

CO-PERFORMERS: Ms Kim Fowler (Pacific Northwest National Laboratory); Mr. Ray Barbeau (Fort Bragg); Ms. Catherine Bingham (Savannah District); Annette Stumpf and Rich Schneider (U.S. Army ERDC-CERL); Ms. Anne Rogers (Southface); Ms. Christy Etter (CH2MHiIl)

The objective of this project is to document that off-the-shelf building materials and components used in a whole buildings design will achieve higher facility performance. Whole building design uses an integrated design approach that optimizes the interdependencies of building systems using a diverse team of stakeholders. High performance buildings are the result of whole building design. This project will test the process of whole, building integrated design to document how a well-designed building performs in comparison to one designed using traditional design practices.

Whole buildings design principles were used to design a Fort Bragg emergency services building which is currently under construction. This building and a similar building built in 2003 will be monitored for a period of one year and the difference in life-cycle cost, energy and water use, occupant comfort, and solid waste and wastewater generation will be measured and documented. The building will be certified under the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED) standard. The project is targeting the highest rating of platinum.

This work is funded under ESTCP Project SI-0724.
MODELING AND SIMULATION OF A DG-INTEGRATED INTELLIGENT MICROGRID

SAIFUR RAHMAN
Virginia Tech - Advanced Research Institute
4300 Wilson Boulevard, Suite 750
Arlington, VA 22203
(703) 387-6027
srahman@vt.edu

CO-PERFORMER: Manisa Pipattanasomporn (Virginia Tech - Advanced Research Institute)

The objective of this project is to model and simulate a specialized microgrid called an Intelligent Distributed Autonomous Power System (IDAPS), which will play a crucial role in building a scalable power grid that facilitates the use of renewable energy technologies. The technical approach for modeling and simulation of an IDAPS microgrid consists of several steps including the development of IDAPS physical components, the development of local control algorithms, the development of an IDAPS energy management system, the demonstration of how a connection between the IDAPS physical components and the IDAPS decision support system can be established, and the simulation and evaluation of the IDAPS microgrid in both parallel and islanded operations. The implementation of an IDAPS microgrid in a mission-critical facility optimizes the operation of internal generation and loads during normal conditions and increases the security of energy supply to critical loads by shedding non-critical loads during emergencies. The IDAPS control agents have an embedded intelligence that works in collaboration with local controllers to coordinate both distributed energy resources (DERs) and loads to achieve any mission-based environmental, operational, and economic performance criteria.

This work is funded under SERDP Project SI-1650.
MULTI-AGENT SYSTEMS IN A DISTRIBUTED SMART GRID:
DESIGN AND IMPLEMENTATION

MANISA PIPATTANASOMPORN
Virginia Tech - Advanced Research Institute
4300 Wilson Boulevard, Suite 750
Arlington, VA 22203
(703) 387-6031
mpipatta@vt.edu

CO-PERFORMER: Saifur Rahman (Virginia Tech - Advanced Research Institute)

The objective of this project is to explore the design and implementation of a multi-agent system that provides intelligence to a distributed smart grid – a smart grid located at a distribution level. A multi-agent application development will be discussed that involves agent specification, application analysis, and application design and application realization. The message exchange in the proposed multi-agent system is designed to be compatible with an IP-based network (IP = Internet Protocol) which is based on the IEEE standard on Foundation for Intelligent Physical Agent (FIPA). The work demonstrates the use of multi-agent systems to control a distributed smart grid in a simulated environment. The simulation results indicate that the proposed multi-agent system can facilitate the seamless transition from grid-connected to an island mode when upstream outages are detected. This denotes the capability of a multi-agent system as a technology for managing the microgrid operation.

This work is funded under SERDP Project SI-1650.
IMPACT OF PLUG-IN HYBRID VEHICLES ON A DISTRIBUTION NETWORK

SHENGNAN SHAO
Virginia Tech - Advanced Research Institute
4300 Wilson Boulevard, Suite 750
Arlington, VA 22203
(703) 387-6021
sshao@vt.edu

As Plug-in Hybrid Vehicles (PHEVs) take a greater share in the personal automobile market, their penetration levels may bring potential challenges to the electric utility especially at the distribution level. This work examines the impact of PHEV penetration on the distribution transformer under different charging scenarios, including both normal and quick charges. The modeling indicates that the penetration of PHEVs will create new peak loads, some of which may exceed the distribution transformer capacity. The new peaks caused by charging PHEVs may also result in the distribution transformer operating efficiency loss. In order to keep the PHEVs from causing harmful new peaks while increasing the overall energy flow, several PHEV charging profiles are analyzed and some possible demand management solutions, including PHEV stagger charge and household load control, are recommended.
PERFORMANCE-BASED NON-DESTRUCTIVE LOAD ASSESSMENT TOOLS FOR HISTORIC BUILDINGS AND STRUCTURES

MR. CHRIS INABA
Naval Facilities Engineering Service Center
1100 23rd Avenue, Code CI62
Port Hueneme, CA 93043-4370
(805) 982-1261
chris.inaba@navy.mil

CO-PERFORMERS: Cecilia Booker and Dr. Robert Zueck (Naval Facilities Engineering Service Center)

Performance-based non-destructive (ND) load assessment determines actual capacity, which optimizes rehabilitation strategies and avoids environmental impacts that are inherent in facility demolition. By knowing the actual load capacity, owners can accurately formulate strengthening or repair estimates for MILCON (Military Construction) funding. Distress-based ND evaluation technologies are commonly available that identify distresses, such as, cracks, voids, etc. Performance-based methods identify actual load response of structure regardless of observable distress. The Naval Facilities Engineering Service Center (NFESC) developed and uses performance-based ND methods to assess the load capacity of the U.S. Navy’s reinforced concrete piers. These methods have demonstrated that +60 year-old structures have adequate capacity despite indications of distress. Fleet readiness was sustained or improved by allowing continued or increased operational use without substantial rehabilitation or demolition. NFESC is determining the feasibility of a similar performance-based ND load assessment system for reinforced concrete floor slabs in historical DoD buildings. The prototype system will include an impact load device sensors, and a signal processor used in conjunction with finite element analysis (FEA). The ND system will measure the structural response of the floor slab, establishing actual performance-based stiffness. A baseline FEA model is refined to reflect the test response. The refined FEA model will be used to evaluate load cases, capacity, and rehabilitation alternatives. Low-frequency accelerometers or velocity transducers will be placed on the floor slab along 90 degree axes about the loading point measuring two-way floor slab load distribution. Sensor signals will be processed in the time domain and integrated to get deflection time histories using a PC-based spectrum analyzer.

The critical issue in supporting further development is the feasibility of developing a portable impact load device that can impart a measurable but non-destructive response. The device must be deployable in confined spaces of historical DoD buildings. The proof of concept will be demonstrated on a reinforced concrete floor slab, which paves the way for full development into a complete assessment tool for all types of structural components and historical buildings.

Full implementation includes a complete set of facility assessment tools that are applicable to most historical and non-historical DoD buildings. Peer review includes development of testing standards, such as ASTM (American Society for Testing and Materials). Recipients of fully implemented assessment tools will be government contracted architect-engineering (AE) firms, where Naval Facilities Engineering Command (NAVFAC) will be the DoD center of expertise. This work is funded under SERDP Project SI-1654.
STREAMLINED ARCHAEOGEOPHYSICAL DATA PROCESSING AND INTEGRATION FOR DoD FIELD USE: RESULTS OF LARGE-AREA GEOPHYSICAL SURVEY AT PRESIDIO LOS ADAES, LOUISIANA

DR. EILEEN ERNENWEIN
Center for Advanced Spatial Technologies
University of Arkansas
Fayetteville, AR  72701
(479) 575-6159
eernenw@cast.uark.edu

CO-PERFORMERS:  Dr. Michael Hargrave (U.S. Army ERDC-CERL); Dr. Jackson Cothren, Dr. William Johnston, and Dr. W. Fredrick Limp (University of Arkansas)

A major expense for military installations with active training programs is the evaluation of archaeological sites for the National Register of Historic Places (NRHP). Traditional archaeological methods for site assessment, which rely primarily on excavation of shovel tests and small test units, are invasive, time consuming, costly, and often unreliable. The use and integration of geophysical methods (magnetics, electrical resistivity and conductivity, and ground-penetrating radar) were recently shown to reduce invasiveness and improve reliability of archaeological site evaluations, as well as dramatically reduce site mitigation costs (SERDP Project SI-1263). Unfortunately, the benefits of this multi-sensor approach are not currently accessible to DoD Cultural Resource Management (CRM) personnel because geophysical data processing and integration is labor intensive and requires a high level of technical expertise.

This project will address this problem by (1) creating a new user-friendly software program called ArchaeoMapper, which will allow installation CRM personnel with relatively modest levels of expertise and experience to accomplish the data processing required by the integrated, multi-sensor approach; and (2) demonstrate and validate the cost and performance benefits of the approach and technology infusion tool (ArchaeoMapper) to DoD geophysical users, representatives of federal, state, and tribal Historic Preservation offices, federal and state resource managers, and other CRM practitioners. The project’s demonstration and validation component includes a multi-sensor survey of a complex archaeological site, processing and integration of the data using ArchaeoMapper, predictions about the nature of subsurface features, and an independent evaluation of those predictions by means of small-scale, carefully targeted excavations.

The project team has completed the large-area multisensor (magnetometry, electrical resistance, conductivity, magnetic susceptibility, and ground-penetrating radar) geophysical survey of the chosen archaeological site: Presidio Los Adaes, a Spanish military post (1721-1773) located near Natchitoches, Louisiana. The overall results were excellent and provide the opportunity to compare the fort’s actual layout with a 1729 architectural plan and a scaled map drawn in 1767. Small scale carefully targeted excavations to test selected anomalies, are planned for the winter of 2009-2010. This project will show results of the geophysical surveys, with multi-sensor data processed using ArchaeoMapper.

This work is funded under ESTCP Project SI-0611.
FORMAL PREDICTIVE MODELS OF ARCHAEOLOGICAL SITE LOCATION

JEFFREY H. ALTSCHUL
SRI Foundation
33 Rio Rancho Drive, Suite 103
Rio Rancho, NM  87124
(505) 892-5587
jhaltschul@sricrm.com

CO-PERFORMER:  Paul R. Green (U.S. Air Force ACC/CEVP)

Many DoD installations have predictive models of archaeological site locations. The utility of these models varies directly with their degree of formality. Formal models are those in which the elements of the model and the relationship between the elements are precisely defined and measurable. Informal or subjective models tend to be anecdotal, based on the experience of one or more archaeologists who have worked in a region for some time. Variables in these models are subject to varying degrees of formal description and are rarely defined according to rigorous statistical, quantitative approaches.

Although informal models have been used as planning tools, they have not been accepted as a primary tool for archaeological compliance. Stakeholder confidence demands that models have a clear, understandable logic in addition to predictive power, especially when these models are used for making decisions about level of effort, scopes of work, schedules, and budgets for archaeological compliance. Formal models provide a more solid grounding in decision-making, especially if a compliance effort is challenged.

This project found that many installations have models that are a mixture of informal and formal elements. Some installations have taken formal models and added informal elements to them. In other cases, installations have defined model elements in a rigorous manner, but measured them in informal and non-replicable ways. In many cases, the models have not been documented, adding complexity and difficulty to formalizing the logic used in model construction and making it difficult to convey in understandable and transparent terms to stakeholders.

As part of the predictive modeling project, models have been taken from four installations: Fort Drum (New York), Eglin Air Force Base (Florida), Utah Test and Training Range (Utah), and the Saylor Creek Range (Idaho); and, as necessary, ensured that all elements and relationships in the model are formally defined. For each installation, this project created or recreated two models: a surface and subsurface model. This work will present the results to date, identifying common problems with DoD models and offering pragmatic solutions.

This work is funded under ESTCP Project SI-0720.
A COMBINED DYNAMIC METHOD FOR NON-DESTRUCTIVE EVALUATION OF CONCRETE BEAMS

THOMAS BOOTHBY
The Pennsylvania State University
Department of Architectural Engineering
104 Engineering Unit A
University Park, PA 16802
(814) 863-2082
tebarc@engr.psu.edu

CO-PERFORMERS: Paul Kremer, Elisabetta Pistone, and Sezer Atamturktur (The Pennsylvania State University)

The DoD owns and manages thousands of National Register-eligible or listed properties. Federal mandates require a conservative, preservation-oriented approach to the management of these properties. As a result, the structure of historic buildings under DoD control needs to be carefully assessed by the least invasive methods possible.

Non-destructive tests are obviously preferred for historic, and often for non-historic, properties. Among the non-destructive assessment methods recently implemented, interest has grown in the Impact-Echo (IE) method and in the Experimental Modal Analysis (EMA) method. IE is used to determine the integrity of concrete and masonry, while EMA is used to assess the global structural characteristics of strength, stiffness, and frequency response. Traditionally, these assessments are used separately, both because the frequency content differs and because the information captured is of different nature. The IE method usually works with frequencies up to 80 kHz while the EMA method works in the low frequency domain.

This project combines the two methods into a single device. The capability of unifying the EMA and the IE method is explored in order to capture both the modal and the IE parameters using the same data acquisition system. This has the potential to save money and testing time and can lead to additional benefits in the collection of fundamental information for the assessment and evaluation of structures.

The paper concentrates on two concrete beams. The first set of tests is run under controlled conditions in a laboratory at Penn State University while the other focuses on a field case located in a classroom at Penn State University. Both beams present defects, in particular an area of concrete segregation, known as rock pocket. In the beam in the laboratory, the location of the defect is carefully designed and so it is perfectly known, while in the real case, the defect is located approximately. The signals are registered with two accelerometers and they are processed in LabView. The structures are excited with a set of hardened steel balls for the IE and with an instrumented hammer for the EMA.

This work is funded under SERDP Project SI-1653.
Conservation and protection of the marine environment in accordance with U.S. laws has been the goal of an ongoing ocean sonic boom (OSB) study by the Space and Missile Systems Center’s (SMC’s) Acquisition Environmental Office and its technical support contractor The Aerospace Corporation, a federally funded research and development center. Aircraft, rocket launch, and space reentry vehicle sonic boom models have been studied theoretically and have been shown experimentally correct in many cases. However, in collaboration with the University of Southern California, SMC has been seeking to better understand and develop ocean wavy surface models that predict the biological effects of the sonic boom disturbances that occur over a wavy ocean surface. These efforts have shown that the interaction of sonic booms with surface waves can strongly alter the sound level, frequency range, and signal waveform reaching the deeper part of the ocean. Unlike conclusions from studies based on flat-ocean models, which indicate little effects at depth beyond one footprint signature length, the interaction of sonic-boom waves with a surface-wave train can generate non-evanescent, downward propagating waves which, owing to their lower spatial-attenuation rate, overwhelm the otherwise primary (flat-ocean) wave field. Theoretical results substantiate and elucidate the significant differences between flat and wavy surfaces in waveform characteristics and their audibility in deep and moderately deep water. Laboratory experiments have been performed specifically to validate this theoretical model and to ascertain the distinct differences in wave-field characteristics under a wavy and flat interface. The experimental measurements confirm the theoretical findings, showing the predicted differences between the sound fields measured under wavy and flat air-water interfaces stimulated by a passing sonic boom.

Failure to address OSB impacts on marine mammals is one of the primary risks to armed forces launch operations as well as space debris supersonic and hypersonic reentry operations. The current OSB models have theoretical and experimental implications that are unknown and controversial. Like the Navy’s use of sonar, military weapon systems operations may be at risk unless technical uncertainties and controversies are minimized by ensuring OSB model accuracy.
REAL-TIME MILITARY IMPULSE NOISE CLASSIFIER

MATTHEW RHUDY
University of Pittsburgh
560 Benedum Hall
Pittsburgh, PA 15261
(610) 509-6108
mbr5002@gmail.com

CO-PERFORMERS: Dr. Jeffrey Vipperman and Brian Bucci (University of Pittsburgh); Jeffrey Allanach and Justin Borodinsky (Applied Physical Sciences)

In an effort to create an accurate record of military impulse events around military installations, a classifier was developed to distinguish between impulse noise and non-impulse noise. The classifier utilizes an artificial neural network (ANN) with four scalar metric inputs, and one scalar output between zero and one, where zero indicates non-impulse noise, and one indicates impulse noise. To implement this classifier, a real-time system was developed on a low power embedded computer. A microphone array is used to continuously monitor four channels of sound levels. When a specified peak value (Lpk) is exceeded, the classifier is activated. First, the four channels are analyzed to determine if an acoustic event is possible, given the array geometry and the speed of sound in air. If so, the four channels are combined using a conventional beamformer that reduces the effect of undesired noise. Otherwise, the event is considered a false event, most likely due to wind. If an acoustic event is possible, the array response to this event is used to calculate four scalar metric inputs to an ANN, which is then used to calculate the output, which determines the classification of the event. In addition to the classification, using the geometry of the array, the direction of arrival (DOA) of the acoustic event can be determined. This entire process is done in real-time, on-site, using a custom developed low power embedded platform based on PC/104 components. This platform runs a custom Linux OS and uses the Intel Performance Primitives (IPP) to perform the computations required for the detection and classification processing. Outputs from the signal processor can be sent wirelessly to a central station where the results of multiple monitoring stations can be combined and logged to disk. If multiple monitoring systems record the same event, the position of the event can be found using triangulation. These waypoints are then plotted on a Google Earth map to be used by noise monitoring personnel. By combining spatial and temporal signal processing, a robust method of detection and classification was developed.

This work is funded under SERDP Project SI-1585.
COMMUNITY ATTITUDES TOWARD MILITARY BLAST NOISE

MR. EDWARD T. NYKAZA
U.S. Army ERDC-CERL
2902 Newmark Drive
Champaign, IL 61822
(217) 373-4561
edward.t.nykaza@usace.army.mil

CO-PERFORMERS: Kathleen Hodgdon (Applied Research Laboratory at Penn State University); Dr. Peg Krecker (PA Consulting Group)

Existing impact assessment procedures for large weapons noise or blast noise do not fully meet the military’s noise management needs. Military noise impacts currently are assessed in terms of the response metric “annoyance” as predicted by a long-term average noise level metric. This method has proven to be unsatisfactory for extremely variable impulsive military noise. As a result, a series of field studies is underway to enhance the understanding of human response to military blast noise, and to develop a methodology to accurately predict human response to blast noise. An overview of the four research protocols employed in this project will be presented and the most recent findings from the personal interview protocol and complaint survey will be given. The preliminary results from the personal interview protocol indicate that residents adapt to the basic noise environment over time and often do not notice smaller noise events, but do notice unusually large noise events or noise in conjunction with house vibrations. The preliminary results of the complaint survey indicate that those who file complaints are significantly more annoyed on average than their neighbors who were exposed to a similar noise environment. All findings in this project thus far indicate that the number, timing, and level of discrete blast events are important for predicting the human response to blast noise.

This work is funded under SERDP Project SI-1546.
THE USE OF POPULATION VIABILITY ANALYSIS IN THE RECOVERY OF PLANT SPECIES LISTED UNDER THE U.S. ENDANGERED SPECIES ACT

MS. SARA ZEIGLER  
University of Maryland  
2116 Plant Sciences Building  
College Park, MD  20742  
(301) 405-9780  
szeigler@umd.edu

CO-PERFORMER: Maile Neel (University of Maryland)

Studies have shown that populations of endangered species listed under the U.S. Endangered Species Act of 1979 were more likely to be characterized as “improving” if the species had clear, quantitative, biologically-based recovery criteria. However, most species either do not have clear criteria or have criteria that have been criticized for not being biologically-based. Population viability analysis (PVA) has been recommended as a tool for using species-specific demographic data to inform recovery criteria and management goals. The objectives of this study are (1) to examine PVA studies for both endangered and non-endangered plant species across the world to determine trends in how such models have been used and constructed in the past, and (2) to determine if such studies could be used to inform models for endangered plant species in the U.S. for which information gaps in demographic data exist. Using ISI’s Web of Science database and Google Scholar we found 223 PVA studies discussing 246 plant species. Many of the PVAs were constructed from age- or stage based models and contained components for simulating the impact of threats and/or management options on species’ persistence. It also was found that the results of PVAs and their sensitivity analyses were highly species and context dependent. PVA results changed dramatically depending on the underlying time and location demographic data were collected. Results also depended on the components used within the PVA models such as stochasticity and density dependence. Finally, sensitivity analyses, which highlighted the most important life-history stages for the persistence of a population or species, were dependent on the type of sensitivity methodology used, growth rate of the population, and components included in the model. This work concludes that, although PVA may be an important tool for informing biologically-based recovery criteria for endangered species, conservationists will likely need to continue to base such models on demographic studies specific to individual species and even populations.

This work is funded under SERDP Project SI-1475.
AN ECOINFORMATIC APPROACH TO DEVELOPING RECOVERY GOALS AND OBJECTIVES

DR. MAILE NEEL
University of Maryland
2116 Plant Sciences Building
College Park, MD 20742
(301) 405-9780
mneel@umd.edu

CO-PERFORMERS: Allison Leidner, Sara Zeigler, David Luther, and William Fagan
(University of Maryland)

A profound lack of data hinders managers’ abilities to set scientifically defensible recovery goals and criteria for all but a few threatened and endangered species. Because the biology of most listed species is poorly known, recovery plans commonly recommend a laundry list of research needs and recovery actions that differ little among species. Such blanket recommendations hinder prioritizing efforts for individual species and make prioritizing among species nearly impossible. The ecoinformatic recovery-planning framework proposed in this project—which takes advantage of the fact that a lot more is known about at-risk species as a group—is a significant departure from one-size-fits-all approaches. The objective of this work is to develop and implement methods that will quantify scientifically defensible recovery goals for federally listed species on DoD-managed lands via a sophisticated comparison with a diverse set of well-studied species.

Two web-based conservation databases have been built, one for well-studied species and one for federally listed species. Second, tree-based statistical modeling has been used to identify sets of well-studied species that would constitute reasonable, individualized comparison sets for each listed species. Because the preliminary results from the comparison set analysis did not yield strong evidence for robust sets of similar species, the inverse function models that were intended to provide predictive models of the relationships among biological traits, extrinsic threats, and recovery goals for each comparison set of well-studied species have not been employed yet. Recovery goals for listed species on DoD-managed lands have not been calculated either, which would require substituting the traits and threats of each listed species into the inverse functions arising from its respective comparison set.

The comparative, ecoinformatic approaches that are being developed can eventually be implemented at multiple DoD sites. These methods constitute an analytical framework intermediate between disappointingly generic conservation rules of thumb and expensive, time-consuming, and often unattainable, single-species approaches like population viability analyses. These approaches will provide (1) a characterization of the units of measure that constitute the most relevant recovery criteria (e.g., population size, number of populations, or total area occupied); (2) quantitative, scientifically defensible recovery objectives based on those criteria; (3) analysis of the scientific information available for informing key management decisions or refining recovery criteria, goals, and actions; and (4) clarification of what classes of monitoring actions are needed to assess how well recovery goals are being met. This work is funded under SERDP Project SI-1475.
INTRINSIC AND EXTRINSIC CAUSES OF LOW HATCHING SUCCESS OF GOPHER TORTOISE EGGS

CARL QUALLS
University of Southern Mississippi
Biological Sciences
118 College Drive #5018
Hattiesburg, MS 39406-0001
(601) 266-6906
Carl.Qualls@usm.edu

CO-PERFORMER: Thomas Smith (U.S. Army ERDC Construction Engineering Research Laboratory)

Despite ongoing conservation efforts, western populations of threatened gopher tortoises, Gopherus polyphemus, including those at Camp Shelby in Mississippi, are declining and their age-class distributions are heavily skewed toward adults, suggesting unsustainably low recruitment. This lack of recruitment is largely due to unexpectedly low hatching success of the tortoises’ eggs, resulting from a combination of intrinsic (egg quality) and extrinsic (nest environment) problems. This project presents a combination of field and laboratory-based studies to determine the causes of observed low hatching success of gopher tortoise eggs at Camp Shelby. This research includes population genetic studies using DNA microsatellites to assess genetic variation within and among populations (intrinsic factor), as well as artificial nest experiments to identify specific environmental (extrinsic) factors that lead to egg mortality. Genetic analysis has shown that western populations exhibit significantly lower allelic variation (number of alleles per locus, proportion of polymorphic loci, heterozygosity) than do studied eastern populations, which also reportedly experience higher egg hatching success. Thus, low genetic variability may contribute to low egg fertility and/or high embryo mortality, explaining a portion of the eggs’ failure to hatch. Further, many eggs that are intrinsically capable of hatching fail to do so in natural nests, presumably because some aspect of their nest environment is insufficient to support their full development. It was hypothesized that the particulate composition of nest soils, specifically their clay content, may play a role by influencing gas exchange. Clutches (N = 34) of eggs were split into paired man-made nests, identically constructed but in high and low clay substrates, to experimentally evaluate the effects of clay content on hatching success. In a paired sample design, we monitored hatching success in these experimental nest pairs, along with nest temperature, soil composition, understory vegetation, tree canopy cover, and the respiratory microenvironment (weekly oxygen and carbon dioxide concentrations). Pair-wise comparisons of hatching success and nest environmental conditions between high and low clay nests show that experimental pairs clearly differed in environmental parameters other than soil composition. Thus, pair-wise differences in hatching success and environmental conditions are being calculated for each experimental nest pair, to search for correlations between environmental variables and hatching success. Analysis based on pair-wise differences should allow a more powerful search for environmental factors correlated with hatching success, by removing error variance resulting from intrinsic differences in egg quality among clutches (hatching success is bimodally distributed, with peaks at zero and 100%).
HABITAT DEGRADATION AND IMPACTS ON POPULATION GENETICS IN TWO ENDANGERED SONGBIRDS

DR. RICHARD LANCE
U.S. Army ERDC Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS  39180
(601) 634-3971
richard.f.lance@us.army.mil

CO-PERFORMERS:  Paul L. Leberg, Kelly R. Barr, and Giridhar N. R Athrey (University of Louisiana at Lafayette); Denise L. Lindsay, Timothy J. Hayden, and Scott A. Tweddale (U.S. Army ERDC Construction Engineering Research Laboratory)

The golden-cheeked warbler (Dendroica chrysoparia, GCWA) and black-capped vireo (Vireo atricapilla, BCVI) are habitat-specialist songbirds, utilizing, respectively, late-successional woodland and early-successional scrub habitat. Breeding ranges of both species occur throughout central Texas and, in BCVI, northern Mexico and southern Oklahoma, as well. The largest extant populations of both species are on U.S. Army Reservations, Fort Hood, TX and Fort Sill, OK. Habitat fragmentation and conversion over the last century, in combination with increasing rates of brood parasitism by brown-headed cowbirds (Molothrus ater), are believed to have resulted in large population declines in both species, and both species are listed as endangered under the Endangered Species Act. As part of a large-scale, multi-year study, the regional genetic structure and population-level attributes in both species were determined and associations of population genetic attributes to landscape and habitat features were explored. In GCWA, the level of interpopulation genetic structure was positively associated with geographic distance and the amount of agricultural land between sites, and was negatively associated with two measures of intervening forest habitat between sites (connectivity and % forested habitat). Genetic structure of the BCVI was correlated with geographic distance (log transformed) on more local scales, but not at regional scales. One BCVI population appears to have experienced a recent bottleneck associated with a founder event. Our recent work on fine-scale genetic patterns in BCVI indicate strong male philopatry, a behavioral factor affecting dispersal patterns that may, in part, explain the relatively strong genetic structuring in this species, as well as the lack of associations between genetic structure and habitat and landscape features. Finally, additional recent studies of BCVI and GCWA samples taken from museum archives indicate that a significant loss of genetic diversity has occurred over the past 100 years in both species, corresponding to a period of significant habitat alteration within the species’ breeding ranges. Losses in genetic diversity and effective population size were particularly strong in GCWA. Ratios of effective population sizes to current census population sizes in GCWA populations are very low and argue for further scrutiny of variance in breeding success and survival among and within populations of this species.
GENETIC STRUCURING AMONG HIBERNACULA POPULATIONS OF THE ENDANGERED GRAY BAT (MYOTIS GRISESCENS)

DR. RICHARD LANCE
U.S. Army ERDC Environmental Laboratory
CEERD-EP-P
3909 Halls Ferry Road
Vicksburg, MS 39180
(601) 634-3971
richard.f.lance@us.army.mil

CO-PERFORMERS: Denise L. Lindsay, Natalie D. Barker, Laura C. Ruff, and Myra D. Blake
(U.S. Army ERDC Environmental Laboratory)

Past population declines in the endangered gray bat (Myotis grisescens) have been attributed to disturbance and loss of hibernacula. Due to stringent hibernation requirements, gray bats from throughout a region will often share one or a very few hibernacula. Mating generally occurs at these sites prior to hibernation. In the spring, hibernacula populations scatter across the landscape to form maternity colonies, sometimes joining bats from other hibernacula. As hibernacula have become increasingly well protected, gray bat numbers have increased, with large gains and losses at some hibernacula. Linkages between hibernacula, and between summer roosts and hibernacula, were studied extensively using wing bands in the 1970s and earlier. However, banding is unlikely to be used to study recent changes in population sizes and, potentially, linkages due to concerns about associated bat mortality. Genetic approaches provide an alternative means for studying these population dynamics, and can be conducted using nonlethal (wing tissue) or noninvasive (guano) sampling methods. This study used a combination of wing tissue and guano samples, six microsatellite loci previously identified in M. myotis, and a range-wide sampling scheme to determine population genetic structure in gray bats. 330 individuals from 10 major hibernacula across five states were genotyped, as were 43 individuals from a maternity colony on Fort Leonard Wood, MO. Genetic diversity in gray bats was low relative to other Myotis species and significant pairwise interpopulation differentiation was common. Isolation-by-distance was not detected among hibernacula, though proximal sites tended to be more genetically similar. Bayesian maximum likelihood approaches identified several different putative genetic clusters, some of which included hibernacula that were relatively distant. AMOVA also indicated significant interpopulation genetic differentiation, as well as differentiation among identified clusters, with a population graph indicating that most hibernacula were genetically linked to several other hibernacula. Finally, mixed-stock analysis of the Fort Leonard Wood maternity colony did not identify any particular hibernacula as likely origins for bats using that site; a larger, species-specific suite of microsatellites could provide more effective assortment at the observed levels of genetic differentiation. This work’s analyses largely support past banding results and indicate that linkages among populations are not entirely structured around simple dispersal patterns or geographic proximity. In addition to an interesting and complex population history, the threat of White-Nose Syndrome spreading among caves in the eastern U.S. argues for increased focus on population genetic studies of bats in this region, particularly for threatened or endangered species.
OPERATIONAL STANDARDS FOR DEPLOYMENT OF DESERT TORTOISE DETECTION DOG TEAMS

DR. MARY CABLK
Desert Research Institute
2215 Raggio Parkway
Reno, NV  89512
(775) 673-7371
mary.cablk@dri.edu

CO-PERFORMERS: Dr. Todd Esque and Dr. Ken Nussear (U.S. Geological Survey); Dr. Susan Clark (Education Design Group); Cindee Valentin (Applegate School for Dogs); Dr. Russell Harmon (U.S. Army Research Office)

Detection of federally listed “threatened” Mojave Desert tortoises (Gopherus agassizii) is done by humans using primarily visual cues. Despite the fact that adult tortoises can be large (> 280 mm MCL) they can be difficult to locate. Relatively smaller tortoises less than 180 mm are even more challenging to find and the smallest tortoises, between ~55 and 110 mm are extremely difficult for people to locate. The detection problem becomes more acute when tortoises are concealed in vegetation or subsurface in burrows, and for these reasons the use of dogs trained to find Mojave Desert tortoises using olfactory cues was developed. In Spring 2008, the final capability demonstration of tortoise detection dogs to find all size classes of tortoises was completed, which included testing of a certification protocol that yields tortoise detection dog teams that are both safe and effective. In order for this technology to transition from a research program to a widely-used search technology, project results need to be brought to Department of Defense (DoD) installations directly and certification protocols need to be accepted by the permitting agencies. To accomplish the transition will involve disseminating information about tortoise dog capabilities to the military and other land managers, finalizing the acceptance of the certification protocols by permitting agencies, and providing contractors with the minimum qualifications requirements to survey with tortoise dogs. A DTK9 Technology Transfer workshop was conducted in order to accomplish this. The workshop was held over multiple days and targeted two different groups: the military and federal/state land management partners, including permitting agencies; and private contractors, who will provide the tool for conducting surveys. The focus of the workshop for the military and partners on the first day was to disseminate research findings of the DTK9 Program, including capability, cost, and deployment guidance for fielding tortoise detection dog teams. For the contractors, the focus was to emphasize technical information needed to provide tortoise detection dogs for contracted surveys. The workshop was held at the U.S. Geological Survey in Henderson, Nevada and the Desert Tortoise Conservation Center (DTCC), where tortoises were available for demonstration. Key outcomes of the workshop will be documented in a report to ESTCP, the U.S. Army Research Office, and distributed to the workshop participants.

This work is funded under ESTCP Project SI-0609.
DEVELOPING MANAGEMENT STRATEGIES FOR MULTIPLE SPECIES USING POPULATION VIABILITY MODELS IN A HIGHLY FRAGMENTED LANDSCAPE IN THE CONTEXT OF CLIMATE CHANGE

DAWN M. LAWSON
Naval Facilities Southwest
1220 Pacific Highway
San Diego, CA 92132
(619) 726-5684
dawn.lawson@navy.mil

CO-PERFORMERS: Dr. Helen M. Regan (University of California, Riverside); Dr. Janet Franklin (California State University, San Diego)

The key to cost-effective management of at-risk species is to maintain sufficient sub-population size and number that the risk of species extinction is reduced. However, over the last century habitat loss and fragmentation have made this much more difficult because they reduce population size and decrease the chance that extirpated sub-populations will be recolonized. Around many Department of Defense installations, anthropogenic habitat loss and fragmentation has resulted in the decline of many species and left landscapes where habitat linkages are scarce. In these situations there is often a need to manage multiple at-risk species with small and overlapping distributions but with differing population dynamics and habitat requirements. In order to evaluate risks to persistence and management strategies to mitigate threats, this project constructed Population Viability Analyses (PVA) for several at-risk species of the coastal chaparral and coastal sage scrub of coastal southern California. The species were selected to span a range of persistence probabilities in fragmented landscapes and responses to fire. The results for two of the species will be presented: Wart-stemmed ceanothus (Ceanothus verrucosus), and Big-eared woodrat (Neotoma macrotis). Simultaneous evaluations of multi-species risks and benefits were conducted in order to determine appropriate management strategies to maximize persistence of these species within the study area. The primary management options evaluated were various fire management scenarios, translocation, seed introduction, and restoration of unoccupied habitat. In addition to shifts to the species’ distribution, climate change poses risks to these species due to both potential effects on vital rates and increases in fire frequency. Two scenarios evaluated under the U.S. Climate Sciences Program were considered. One predicts a warmer and wetter climate while the other a warmer and drier climate for southern California. Under both scenarios, the probability of extreme wet and dry events increase in the future and the probability of fire could increase as well. PVAs were used to evaluate the direct effects of changes in temperature and precipitation on population dynamics by considering likely changes in the means and variances of vital rates and fire frequencies. There is often a lack of data for rare species. It is important to establish methods to develop conservation priorities in spite of this uncertainty. The sensitivity analyses and model results shows that informative models can be constructed for poorly studied species using the data available augmented with strategic data collection and data from conspecifics.

This work is funded under SERDP Project SI-1473.
USING MOVEMENT BEHAVIOR TO DETERMINE CONNECTIVITY IN COMPLEX LANDSCAPES

DR. BRIAN HUDGENS
Institute for Wildlife Studies
55 Ericson Court, Suite #1
Arcata, CA  95521
(707) 822-4258
hudgens@iws.org

CO-PERFORMERS: Nick Haddad, Will Fields, Nicole Thurgate, Catherine Frock, and Daniel Kuefler (North Carolina State University); Todd Jobe (University of North Carolina)

Wetland species are particularly sensitive to connectivity between habitat patches. Managing these species on military lands can have minimal impact on military goals if it is understood where dispersal corridors and barriers exist on and around bases and how changing the landscape changes connectivity. There are two significant challenges to achieving such an understanding. First, because dispersal is a rare event, it is difficult to measure directly. Second, different species perceive the landscape in different ways, so that landscape features that may promote or inhibit dispersal of one species may have little or opposing effects on dispersal of another. This project demonstrates a simplified approach to quantifying dispersal across a landscape based on short-term observations of individual movements in different habitats and at habitat edges. Unlike long distance dispersal, short-term movement data are easily collected through observational and experimental studies. Movement simulations calibrated from observed movement of wetland butterflies and amphibians were used to identify isolated and connected breeding habitats and landscape features that promote or inhibit dispersal on Ft. Bragg, NC. Dispersal maps generated from the movement simulations for both butterflies and amphibians were overlaid to take an integrated look at how different habitats impact dispersal of rare wetland species within the base. In a separate poster, the dispersal of these species and the red cockaded woodpecker between Fort Bragg and nearby protected areas is studied.

This work is funded under SERDP Project SI-1471.
A DECISION SUPPORT SYSTEM FOR IDENTIFYING AND RANKING CRITICAL HABITAT PARCELS FOR RED-COCKADED WOODPECKERS ON AND AROUND DEPARTMENT OF DEFENSE INSTALLATIONS

DR. JEFF WALTERS
Virginia Tech
Derring Hall
Blacksburg, VA 24061
(540) 231-3847
jrwalt@vt.edu

CO-PERFORMERS: Paige Baldassaro, Ken Convery, and Dr. Ross McGregor (Virginia Tech)

This project developed a decision support system (DSS) software application to address the management issue of how best to evaluate the relative value of land as potential red-cockaded woodpecker (RCW) habitat on, and in the vicinity of, DoD installations. An existing spatially explicit individual based population model was modified to operate in a GIS environment to create an accessible user friendly interface. While an earlier version of the population model validated successfully from system data from two locations (including the locality used to create the population parameters of the model) it was necessary to repeat this exercise with the modified model used in the DSS. The DSS also completed the validation exercise well. Model predictions of population size, structure, and behavior were compared with real data from two localities in North Carolina: Fort Bragg and Camp Lejeune. In addition to typical population parameters, such as group size and social structure, the development of the model also allowed spatial comparisons to be made such as the locations of territory budding and the successful occupation of recruitment clusters. Subsequently the DSS was used to assess the effects of proposed changes to Fort Benning, Georgia, needed to accommodate new training needs under the BRAC process. In this case the DSS was used to predict the effects of the base realignment on the overall population of RCW’s at Fort Benning. However, it was also possible to determine the spatial locations of particularly vulnerable groups of active RCW clusters and to adjust the proposed base developments not only to minimize losses of woodpecker clusters, but also to reduce secondary impacts caused by fragmentation. Finally, the DSS was used to evaluate land parcels for possible acquisition to augment the RCW population in and around Marine Corps Base Camp Lejeune. Working at a larger landscape scale the DSS was used to predict the potential movement of RCWs between different groups of active clusters, including potential future groups on various land parcels, and to determine which groups were predicted to remain stable over a period of 50 years. The Fort Benning and Camp Lejeune results illustrate the utility of the DSS.

This work is funded under SERDP Project SI-1472.
A TEST OF UMBRELLA SPECIES FOR HABITAT CONNECTIVITY

DR. R. TODD JOBE
The University of North Carolina
Geography Department
CB#3220
Chapel Hill, NC 27599-3220
(919) 933-8906
toddjobe@unc.edu

CO-PERFORMERS: Aaron Moody, Will Fields, Dr. Nick Haddad, Dr. Nicole Thurgate, and Anne Trainor (University of North Carolina); Dr. Brian Hudgens (Institute for Wildlife Studies); Dr. Bill Morris (Duke University); Dr. Jeff Walters (Virginia Technical University)

Most treatments of umbrella species consider only core habitat of both the umbrella species and the other species that the umbrella species might cover. Yet, connectivity between core habitats may be equally important for species conservation, and traits that make species umbrellas for core areas may differ from those that make species umbrellas for connectivity. This project will develop and test an umbrella species framework that includes habitat connectivity not just habitat core area. The red-cockaded woodpecker (RCW) was tested as an umbrella species for two other target species found on Fort Bragg, North Carolina, the Saint-Francis satyr and tiger salamander. Habitat resistance surfaces were developed based on empirical movement data from each species for the areas including and surrounding Fort Bragg. Specifically, this study will assess the conservation value of RCW habitat in the non-conserved habitat between Fort Bragg and the Sandhills Game Land. Results will include the summation of habitat resistance values for each model. Three different conservation scenarios will be compared based on different resistance weighting of each species.

This work is funded under SERDP Project SI-1471.
Estimating the Connectivity of Red-Cockaded Woodpecker (Picoides borealis) by Incorporating Prospecting Behavior and Landscape Features at North Carolina’s Fort Bragg Military Installation

Anne Trainor
University of North Carolina - Chapel Hill
Geography Department
CB 3220
Chapel Hill, NC 27599
(919) 619-4678
atrainor@email.unc.edu

Co-performers: Dr. William Morris (Duke University); Dr. Jeffrey Walters (Virginia Polytechnic Institute and State University); Dr. Aaron Moody (University of North Carolina)

Habitat loss and fragmentation due to human land uses have drastically altered the size and configuration of ecosystems and severely reduced many wildlife populations. The persistence of these reduced populations depends upon the degree to which landscape features facilitate or impede movement between the remaining habitat patches. This ‘habitat connectivity’ usually represents dispersal behavior as a single abrupt movement in a featureless landscape. However, many species perform complex prospecting movements, leaving and returning to their home area many times to assess the relative quality of breeding sites based on environmental structure or social cues before their final dispersal event. One example in which habitat connectivity plays an important role in the persistence of wildlife populations is the federally endangered red-cockaded woodpecker (RCW; Picoides borealis), which is endemic to mature longleaf pine woodland. These woodlands once covered over 360,000 km² in the southeastern United States but now exist only as small scattered patches covering only 3% of its former area. Currently, Fort Bragg contains some of the largest intact remnants of longleaf pine ecosystems and the largest RCW population in North Carolina. To quantify RCW habitat connectivity, we evaluated the likelihood of individuals visiting a territory during prospecting movements of 36 radio-tagged individuals in 2006 and 2007 on Fort Bragg. The distance traveled and landscape composition within a 100 m path was compared between territories visited and not visited within the maximum distance traversed from their natal territory while returning home each night, prospecting range. Radio-tagged RCW visited territories significantly closer to their natal territory within their prospecting range (p < 0.001). A greater proportion of longleaf pine forest was identified between territories visited (mean = 83.2%, SE = 0.98) compared to territories not visited (mean = 77.6%, SE = 0.52) within RCW’s prospecting range. The proportion of all other land cover features (hardwood forest, evergreen forest that is not longleaf pine, developed areas, and open area or water) was greater between territories not visited compared to territories visited within RCW prospecting range. Increased knowledge of RCW detailed dispersal behavior will help identify areas necessary to maintain habitat connectivity and should be useful in establishing and implementing effective RCW management strategies.

This work is funded under SERDP Project SI-1471.
LANDSCAPE MOSAICS OF CORAL REEFS: POWERFUL TOOLS FOR COMMUNITY ASSESSMENT AND MONITORING

DR. PAMELA REID
University of Miami-RSMAS
4600 Rickenbacker Crossway
Miami, FL 33149
(305) 421-4606
preid@rsmas.miami.edu

CO-PERFORMERS: Dr. Nuno Gracias (University of Girona); Dr. Diego Lirman, Dr. Arthur Gleason, Brooke Gintert, and Meghan Dick (University of Miami); Dr. Philip Kramer (The Nature Conservancy)

Efficient survey methodologies that provide comprehensive assessment of reef condition are fundamental to coral reef monitoring. Current state-of-the-art techniques in coral reef assessment typically rely on highly trained scientific divers to measure indices of reef health (e.g., substrate cover, species richness, coral size, coral mortality). Underwater landscape mosaics developed under SERDP Project SI-1333 are an innovative survey technology that provide large-scale (up to 400m²), spatially accurate, high-resolution images of the reef benthos without extensive survey times or a need for scientific divers. The first-generation mosaic products, produced from video imagery, were insufficient for species-level identification of many benthic taxa, thereby limiting the monitoring potential of the technique. Therefore, a second-generation mosaic methodology was developed, which integrates high-resolution still-image acquisition with high-definition video surveys of the reef benthos. The second-generation products have sub-millimeter benthic resolution, allowing for species identification of coral colonies (as small as 3cm), identification of macroalgal genera, and information on coral colony health and small scale competitive interactions. The second generation survey technology allows users to collect imagery on both a landscape and colony level over 100’s of square meters in under an hour of in-water dive time. The resulting mosaic products have excellent archive potential and are a superior tools for tracking changes over time.
Dynamic References in Ecological Restoration: Accounting for Temporal

ROBERT MITCHELL
Joseph W. Jones Ecological Research Center
Route 2, Box 2324
Newton, GA 39870
(229) 734-4706
robert.mitchell@jonesctr.org

CO-PERFORMERS: Kevin Hiers (Eglin Air Force Base); Michelle Mack (University of Florida); Jeff Walters (Virginia Polytechnic and State University); Lora Smith, Mike Conner, and L. Kay Kirkman (Joseph W. Jones Ecological Research Center); Rob Sutter (Enduring Conservation Outcomes, LLC); Doria Gordon (The Nature Conservancy)

Recovery within ecological systems implies that an ecosystem degraded (by past management) will be moved toward a targeted state, and that the targeted state is one that more fully sustains native diversity and the ecological services provided by natural systems. The dominant paradigms guiding this approach have been desired future condition and historic range of variability. Both of the concepts look back in time to evaluate success in restoration. This “past as prologue” definition for a targeted condition is based upon a general consensus that natural ecosystems were the only ones that could be trusted to be sustainable, a state where rarity, diversity, and resilience are maximized. These ideas are founded on the belief that ecosystems are rich co-evolved assemblages interacting with each other, the climate, and natural disturbances. However, invasive species, novel climates, and altered disturbance regimes are increasingly common and are likely to modify the direction of future recovery and rates of change. This work will address the conceptual basis for the dynamics reference concept for measuring recovery success by an approach that more fundamentally incorporates both temporal and spatial variation of benchmark ecosystems. Moreover, an experimental approach is proposed that may provide a means of measuring dynamic reference conditions, determine trajectory of managed ecosystems, and assess the success of ecosystem recovery goals.

This work is funded under SERDP Project SI-1696.
USE OF SATELLITE TELEMETRY TO INFORM MANAGEMENT OF BALD EAGLES AT ABERDEEN PROVING GROUND, MARYLAND

ELIZABETH K. MOJICA
Center for Conservation Biology
College of William and Mary
P.O. Box 8795
Williamsburg, VA  23187-8795
(757) 221-1680
ekmojica@wm.edu

CO-PERFORMERS:  Dr. Bryan D. Watts (Center for Conservation Biology);
John T. Paul (U.S. Army Aberdeen Proving Ground);
Samuel T. Voss (EA Engineering, Science, and Technology)

The Chesapeake Bay is a convergence area for migrant and resident populations of Bald Eagles on the Atlantic Coast. The U.S. Army’s Aberdeen Proving Ground (APG) is located along the northwest shoreline of the Bay in an area where thousands of eagles seasonally congregate. APG hosts 46 breeding territories and over 30 communal roosts of non-breeding eagles. In response to a series of eagle deaths from electrocutions and mid-line strikes, a biological opinion mandated initiation of a satellite telemetry study to investigate eagle movements on the installation.

From 2007-2009, 63 Bald Eagles were fitted with hybrid GPS-satellite transmitters powered by solar cells. Transmitters provided a GPS location on each eagle every hour during daylight and one additional fix at midnight. Over 400,000 GPS locations were analyzed to examine movement patterns of eagles on APG including eagle use of power lines, identification of communal roosting areas, and use of shoreline habitat. This data was used to minimize conflicts between eagles and Army testing, training, and research programs. Satellite telemetry facilitated Army wildlife managers making informed management decisions about the eagle population on APG while supporting Army testing and training missions.
MODEL EXPERIMENTS TO EVALUATE FACTORS LIMITING SHORTNOSE STURGEON IN THE Ogeechee RIVER

DR. HENRIETTE JAGER
Oak Ridge National Laboratory
Environmental Sciences Division
Oak Ridge, TN 37922-6036
(865) 574-8143
jagerhi@ornl.gov

CO-PERFORMERS: Mark S. Bevelhimer (Oak Ridge National Laboratory); Douglas Peterson and Daniel Farrae (University of Georgia); Roy King (ORISE/Fort Stewart)

The Ogeechee River in Georgia is one of the smaller coastal rivers believed to support subpopulations of shortnose and Atlantic sturgeon. This project developed a spatially explicit and individual-based population viability (PVA) model for shortnose sturgeon (Acipenser brevirostrum) with mechanistic linkages to river habitat conditions and other potential limiting factors in this blackwater river. A variety of hypotheses about the small size of this subpopulation have been proposed. For example, the spawning population in this relatively small river may not be sufficiently large to be self-supporting without immigration from nearby rivers. The availability of freshwater spawning habitat far enough inland may expose early life stages to lethal salinities as they drift downstream. Deterioration in water quality during summer, including high temperatures and low dissolved oxygen, may limit southern populations such as this one. With regard to dissolved oxygen, this study also will conduct a field study to describe watershed influences on nearby Fort Stewart on water quality. Two additional factors that will be evaluated are mercury bioaccumulation and harvest as by-catch in the shad fishery. The PVA model was designed to quantify each of these influences on the persistence of this sub-population with uncertainty bounds. Preliminary results involving a subset of these factors suggest that habitat for freshwater rearing and indirect effects of temperature on bioenergetics during summer likely keep this population small.

This work is funded under SERDP Project SI-1543.
UNDERSTANDING AND MANAGING MULTIPLE STRESSORS THAT IMPACT THREATENED AND ENDANGERED PLANT SPECIES

BERND BLOSSEY
Cornell University
Department of Natural Resources
Fernow Hall
Ithaca, NY 14853
(607) 255-5314
bb22@cornell.edu

CO-PERFORMERS: Dr. Amy Blair and Dr. Evan Cooch (Cornell University);
Victoria Nuzzo (Natural Area Consultants)

Declines in many plant species in eastern deciduous forests have been attributed to a number of factors (e.g., deer overabundance, invasive earthworms, slugs, nutrient deposition, invasive plants). This project elucidates the relative importance of these stressors through demographic modeling of four threatened or endangered plant species (TES) (*Aristolochia serpentaria*, *Agrimonia rostellata*, *Carex retroflexa*, and *Trillium erectum*). Through a combination of field and lab experiments, this study examines how discreet age classes (seeds, seedlings, juveniles, adult plants) are affected by the selected stressors. One year after establishing deer exclosures at West Point Military Academy in New York, the start of recovery of native plant communities (height increase and ability to reproduce) was observed. Earthworm species composition varied widely among the 12 sites and between years with *Lumbricus terrestris* and *Amynthas sp.* the dominant taxa. In a mesocosm experiment designed to examine the impact of earthworms on native seed germination, *Amynthas* worms negatively impacted the germination of *Aquilegia canadensis*, but appear to have less influence on the other species that were seeded. The dominant introduced slug species at West Point is *Arion subfuscus* and as with the earthworms, large abundance differences among sites and fluctuations between years were observed. In feeding trials, native (*Phylomyces sp.*) and additional non-native slugs (*Limax maximus*) were incorporated to test feeding on 55 different species of seedlings or fruits of native and introduced plant species. Slug consumption varies widely within and among species, but overall, non-native slugs consume more tissue from a wider variety of plant species. This project assessed abundance of the root weevil *Barypeithes pellucidus* at the 12 West Point sites at 3-week intervals throughout summer 2009. Peak abundance occurred in early summer, and by late July, the weevil was largely undetectable. In no-choice feeding trials adult weevils readily consumed oak and cherry leaves but avoided the majority of other species offered. The impact of this species with larvae feeding below ground on roots is largely unknown and more experiments are being established to further assess the impact of this cryptic introduced species.

This work is funded under SERDP Project SI-1542.
MODELING POPULATION VIABILITY OF SPECIES OF CONCERN USING COUNT DATA

DR. KATHERINE STRICKLER
University of Idaho
Department of Fish and Wildlife Resources
College of Natural Resources
Moscow, ID 83844-1136
(208) 885-4343
kstrickler@uidaho.edu

CO-PERFORMERS: Dr. J. Michael Scott (U.S. Geological Survey); Dr. Jon Horne, Dr. Oz Garton, and Dr. Brian Dennis (University of Idaho); Dr. L. Scott Mills and Dr. Cynthia Hartway (University of Montana)

Natural resource managers are often asked to predict the effects of different management or training activities on populations of threatened or endangered species. Estimation of a population’s viability is thus an important component of endangered species management. With SERDP funding, this project has developed an approach for modeling population and metapopulation viability by estimating relevant parameters of stochastic population growth models based on a time-series of abundance data. The approach includes most of the models that have been developed for this type of data including those based on exponential growth, density dependent growth, and population growth influenced by environmental covariates. After estimating model parameters, these estimates are then used to infer population viability under different management scenarios. In addition, the approach includes techniques for quantifying uncertainty in viability estimates that arises from model selection and parameter estimation. This approach is demonstrated using management questions involving greater sage-grouse (Centrocercus urophasianus) populations on and around Department of Defense (DoD) installations in the western United States.

Greater sage-grouse have declined in both numbers and distribution throughout most of the western United States and now occur on less than 60% of their presettlement range. With 47 DoD installations falling within the current sage-grouse range, DoD recognizes the need to actively manage the species and its sagebrush habitat to stabilize or increase sage-grouse populations across its range. Through seasonal restrictions on training near sage-grouse leks, intensive monitoring programs, and habitat restoration, sage-grouse management plans seek to reverse the species’ decline on DoD lands. Managers are interested in determining the efficacy of various protection and restoration measures in increasing sage-grouse persistence. Specific management questions include: Under different management scenarios, what is the probability of persistence of individual sage-grouse populations over 30 and 100 years? How do installation-specific populations contribute to overall persistence of sage-grouse? This work provided information to answer these questions by first fitting population growth models and obtaining model parameter estimates. Parameter estimates for the best growth model were then used to simulate future population growth and predicted the probability of reaching an extinction threshold of fewer than 50 males at 30 and 100 years in the future. A sample of viability estimates under a range of management scenarios, population characteristics, and population growth models will be presented. This work is funded under SERDP Project SI-1477.
DEVELOPMENT OF HABITAT TRADING PROGRAMS FOR MILITARY INSTALLATIONS AND THEIR NEIGHBORS THROUGH ADAPTIVE MANAGEMENT

DR. DOUG BRUGGEMAN
Michigan State University
Department of Fisheries & Wildlife
13 Natural Resources
East Lansing, MI 48824
(828) 505-3578
bruggem3@msu.edu

CO-PERFORMERS: Mike Jones (Michigan State University); Thorsten Wiegand (Helmholtz Centre for Environmental Research); Ken Convery (CMI/Virginia Tech); Aaron Moody (University of North Carolina-Chapel Hill); Carl Qualls (University of Southern Mississippi)

The objective of this research project is to provide science-based tools to support habitat trading for at-risk species at broad geographic scales. Uncertainty regarding critical biological processes required to maintain persistent subdivided populations should be the focus of any scientifically defensible habitat trading program. Previously, a Decision Analysis was devised to determine the most cost-effective habitat trade that minimized the effects of habitat fragmentation given uncertainty in dispersal behaviors of the Red-cockaded Woodpecker (RCW; SERDP Project SI-1469). This study is extending the approach to work at broader scales, with new species, and new collaborators. The technology in development for RCWs will predict the presence of habitat from remotely sensed data, determine the most informative monitoring data to be collected to reduce uncertainty, and estimate the influence of climate change on habitat trades. This work also is developing habitat trading models for the Gopher Tortoise, which is less well studied than RCWs. A landscape genetic study will be conducted to support construction of a spatially-explicit population model and provide information on effective population size and rates of inbreeding and migration. Preliminary results describing the advancement in these technologies will be provided.

This work is funded under SERDP Project SI-1656.
DEVELOPMENT AND USE OF GENETIC METHODS FOR ASSESSING AQUATIC ENVIRONMENTAL CONDITION ON PACIFIC ISLANDS

DR. MICHAEL J. BLUM
Tulane University
Department of Ecology and Evolutionary Biology
6823 St. Charles Avenue
New Orleans, LA 70118
(504) 862-8295
mjblum@tulane.edu

CO-PERFORMERS: Dr. James F. Gilliam (North Carolina State University); Dr. Peter B. McIntyre (University of Michigan)

Department of Defense (DoD) activities give rise to military and anthropogenic stressors that can threaten freshwater stream ecosystems on Pacific islands, and DoD personnel need improved stream assessment protocols for watershed management and restoration. The objective of this project is to develop and demonstrate genetic approaches for assessing the condition of Pacific island streams. Genetic assessment protocols are promising alternatives to current approaches because analysis of genetic variation can reveal how environmental stressors affect individuals and populations within spatially explicit frameworks. However, use of genetic assessment protocols for Pacific islands requires identifying the factors responsible for variation in recruitment and dispersal of native amphidromous fishes. To do so, this project will first examine ocean-stream connectivity across the Hawaiian archipelago by comparing genetic profiles of immigrating juveniles to resident adult populations of native amphidromous fishes, and by characterizing ontogenetic patterns of otolith microchemistry. Secondly, patterns of covariance between environmental stressors, estimates of census and effective population size, and immigration will be examined to assess how local recruitment varies according to in-stream conditions and watershed land use. The results of this work will elevate general understanding of oceanic island stream ecosystems and help DoD identify watershed management strategies to effectively sustain military activity in Hawaii and elsewhere in the Pacific.

This work is funded under SERDP Project SI-1646.
Using Edge Response Information to Choose the Best Sites for Management Action

DR. LESLIE RIES
University of Maryland
Department of Biology
College Park, MD 20742
(301) 273-3344
lries@umd.edu

CO-PERFORMER: Thomas D. Sisk (Northern Arizona University)

Over the past several decades, a significant body of theory has been developed to help managers and researchers understand how the structure of the landscape may ameliorate or exacerbate management actions. Yet most of this work has focused on exploring the landscape-scale effects of patch size and isolation, but much less has been done using edge effects. This despite decades of research showing edges impact habitat quality for numerous species at a local scale. Indeed, a recent review showed that most area effects are likely scaled-up edge effects. Despite their obvious utility in understanding large-scale distribution patterns, the extrapolation of edge responses to entire landscapes has been rare and is complicated by a theoretical and empirical body of work that is focused on highly simplified edges. The vast majority of edge studies are designed to understand responses along straight edges with only two distinct habitat types on either side of the edge. In reality, edges have complex shapes and any patch can be surrounded by multiple habitat types. Adding to this complexity, recent research has shown that species should show different edge responses at different edge types and a large review of the empirical literature confirmed that species’ edge responses do vary depending on the type of edge studied. This project used the Effective Area Model, an ArcGIS plug-in developed with SERDP funding, to extrapolate edge responses over complex landscape mosaics. It was found that the influence of edge has profound effects on the predictions of landscape-scale distributions. Further, patch context (the mosaic of habitats that each patch occurs in) was more important than patch size and even could erode differences in patch type. This information can be used to select sites to minimize the influence of management actions on the ecological community. This project presents the Effective Area Model as a tool that allows managers to consider landscape context when targeting areas for management action.

This work is funded under SERDP Project SI-1597.
INTEGRATION AND VALIDATION OF AVIAN RADARS

MS. MARISSA BRAND
SPAWAR Systems Center Pacific
53475 Strothe Road
San Diego, CA 92152-6301
(619) 553-5334
marissa.brand@navy.mil

The crash of US Airways Flight #1549 into the Hudson River on January 15, 2009 following an apparent collision with a flock of Canada Geese has focused worldwide attention on a technology that was developed under the sponsorship of the U.S. Defense Department. The Integration and Validation of Avian Radar (IVAR) project is demonstrating and validating avian radar technology for both natural resources management (NRM) and bird-aircraft strike hazard (BASH) applications. Scientists and engineers from the federal government, industry, and academia are evaluating data from digital radar systems to identify and track biological targets and then validating these systems under realistic operational conditions. The Accipiter® radar system utilizes off the shelf X-band marine radar coupled with advanced digital signal processing and tracking algorithms to process target information. Overall project objectives include: (1) the use of independent visual, thermal, and other observations to validate automatic detection, tracking, and display of targets in real-time; (2) demonstrate the statistical validity of sampling protocols for bird activity; (3) validate protocols and algorithms for streaming real-time bird track data from multiple sites for immediate display and subsequent analyses; (4) demonstrate algorithms for fusing data from multiple radars; (5) capture baseline data on bird activity at the demonstration sites; (6) develop objective criteria for functional, performance, and interoperability requirements of these radars, and to guide research to extend avian radar technology. The dissemination of information through the peer review process is essential before the natural resources management community can effectively use radar to assist in the decision making process. This project will demonstrate that avian radar systems can provide natural resource management and air safety personnel with improved tools for automatically monitoring the abundance and behavior of resident and migratory birds. The data gathered from these systems over time can be used by environmental planners to locate structures to minimize disrupting bird movement corridors and by air operations personnel to schedule aircraft training operations to avoid periods of peak bird activity. Wildlife managers at several of the IVAR study locations now carry notebook computers that are connected wirelessly to the avian radar so they can monitor bird activity and quickly investigate patterns of interest or concern.

This work is funded under SERDP Project SI-0723.
EXPLORING THE EFFECTS OF CLIMATE CHANGE AND DISEASE ON DESERT TORTOISES

DR. BETSY A. BANCROFT
University of Washington
School of Forest Resources
Box 352100
Seattle, WA 98195-2100
(206) 543-5772
betsyba@u.washington.edu

CO-PERFORMER: Joshua J. Lawler, Ph.D. (University of Washington)

Global climate change has been identified as an important driver of changing stress regimes. Expected changes due to global climate change include altered thermal regimes and increased variability in precipitation. These changes can interact with existing stressors to have large effects on at-risk species. A new spatially-explicit individual-based model, HexSim, was used to explore the relative and cumulative effects of multiple stressors on desert tortoises (Gopherus agassizii), an at-risk species at Fort Irwin, CA. The tortoises are susceptible to upper respiratory tract disease (URTD), which exhibits varying morbidity in different populations and at different times. In extreme cases, URTD can cause widespread mortality. Rainfall between September and March drives the production of winter annuals, a major food source for desert tortoises in the Western Mojave. Thus, rainfall can be a determinant of body condition for these tortoises and may be related to the observed variation in virulence of URTD. Future rainfall projections were downscaled from three general circulation models (GCM) run for three emissions scenarios. The effects of projected rainfall and URTD on the desert tortoise population around Fort Irwin were then modeled, and the potential interactions between precipitation and URTD were determined by exploring multiplicative and additive effects of the two stressors. The results provide managers with a range of potential population-level effects of these two important stressors.

This work is funded under SERDP Project SI-1541.
THE POTENTIAL EFFECTS OF MILITARY TRAINING ACTIVITIES, HABITAT MANAGEMENT, AND CLIMATE-INDUCED VEGETATION CHANGE ON BLACK-CAPPED VIREO POPULATIONS AT FORT HOOD, TX

MR. CHAD WILSEY
University of Washington
Box 352100
Seattle, WA 98195-2100
(206) 543-5772
cbwilsey@u.washington.edu

CO-PERFORMERS: Betsy Bancroft and Joshua Lawler (University of Washington); Nathan Schumaker (Environmental Protection Agency)

Black-capped vireos (BCVIs) occupy early seral shrubland habitats historically maintained by fire. Changes to the natural disturbance regimes associated with military training, habitat management actions, and a shifting climate may affect the formation and maintenance of BCVI habitats. Successful management of the species requires an assessment of the individual and cumulative effects of these drivers of change. As part of SERDP Project SI-1541, scenarios representing projected changes in military training, habitat management, and climate-induced vegetation change for Fort Hood were generated. The effects of these scenarios were reflected in projections of future BCVI habitat. HexSim, an individual-based spatially explicit population model, was then used to project the effects of training, management, and climate change on BCVI populations inhabiting these future landscapes. The population model was parameterized using data from Fort Hood. Additional military training will increase the availability of low quality BCVI habitat, but at a loss of high quality habitats. However, prescribed fire and mechanical removal of taller shrubs and juniper as well as climate-induced increases in naturally occurring fires may help maintain populations in high quality habitats.
HEXSIM: A FLEXIBLE SIMULATION MODEL FOR FORECASTING WILDLIFE RESPONSES TO MULTIPLE INTERACTING STRESSORS

DR. NATHAN SCHUMAKER
U.S. Environmental Protection Agency
200 SW 35th Street
Corvallis, OR 97333
(541) 754-4658
schumaker.nathan@epa.gov

CO-PERFORMERS: Dr. Joshua Lawler and Dr. Allen Brookes (University of Washington)

With SERDP funding, this work has improved upon a popular life history simulator (PATCH), and in doing so produced a powerful new forecasting tool (HexSim). PATCH, the starting point for this project, was spatially explicit and individual-based, and was useful for evaluating a range of terrestrial life histories, landscapes, and disturbance regimes. But PATCH had significant limitations. It was a single-population females-only model whose individuals were all identical. It had a modern but cumbersome interface, and it could not capture stressor interactions. These limitations compromised the model's realism and utility. In constructing HexSim from PATCH, these and many other constraints have been relaxed. HexSim is a true multi-population and multi-stressor program. In addition, HexSim’s populations are trait-based, which means individuals can have unique and dynamic properties. Traits can be genetic, probabilistic, or experiential in nature, and they can influence individual vital rates and behaviors. This poster will illustrate the design, features, and use of the new (and freely available) HexSim model.

This work is funded under SERDP Project SI-1541.
MAPPING THE ABUNDANCE AND OCCURRENCE OF BIRDS AT FORT BLISS AND FORT MCCOY USING LANDSAT TM/ETM+ IMAGERY

DR. ANNA PIDGEON
University of Wisconsin-Madison
Department of Forest and Wildlife Ecology
1630 Linden Drive
Madison, WI  53706
(608) 262-5628
apidgeon@wisc.edu

CO-PERFORMERS:  Veronique St-Louis, Eric Wood, and Dr. Volker Radeloff (University of Wisconsin); Dr. Brian Locke and Dallas Bash (Fort Bliss)

Species distribution maps are important tools for conservation. These maps are often produced using land cover classes from classified imagery. The spatial resolution of maps thus derived is often too coarse to be useful for managers faced with land management questions occurring at a more local level. This project evaluated a methodology for producing distribution maps for migratory bird species at a broad spatial extent while retaining a high degree of spatial detail. This work was performed in two ecosystems, the northern Chihuahuan Desert of New Mexico (Fort Bliss), and the short grass prairie-savanna mosaic of western Wisconsin (Fort McCoy). Image texture was incorporated in habitat models. Image texture is strongly correlated with both horizontal and vertical plant structure, and complements the ecological information inherent in landcover classifications and digital elevation models. Metrics of image texture integrate the variability of spectral values within a window, or neighborhood scale, with pixel-level information. In initial validation tests, it was found that generally, models built using image texture were superior to models built using landcover variables for bird species that are habitat specialists, and that performance was less successful for habitat generalists. Incorporation of image texture in habitat models enhances the spatial detail of habitat use maps, and thus is a useful tool for managers tasked with the dual goals of sustaining military ranges for personnel training while sustaining their ecological integrity.

This work is funded under SERDP Project SI-1438.
BROADBAND, MULTI-ASPECT SCATTERING FROM UXO

DR. BRIAN HOUSTON
Naval Research Laboratory
4555 Overlook Avenue
Code 7130
Washington, DC 20375-5350
(202) 404-3840
brian.houston@nrl.navy.mil

CO-PERFORMERS: J. A. Bucaro (Excet, Inc.); M. Saniga and H. Simpson (Naval Research Laboratory); T. Yoder and L. Kraus (Global Strategies Group, NA); L. Carin (Duke University)

Sonar approaches which form images operate at high frequencies since image resolution is proportional to the acoustic wavelength. In this regime, acoustic wavelengths are short compared to the target dimensions, and the waves are scattered predominately from the geometric target boundary. In contrast, in the structural acoustic regime, acoustic wavelengths are comparable to the target dimensions. Sound penetrates the target, and the acoustic scattering is related to the vibrational dynamics of the object. The time-frequency features in the echoes can then be used to “fingerprint” the target without forming an image. In order to evaluate the potential for the detection and identification of unexploded ordnance (UXO) in coastal and inland waters by exploiting their structural acoustic response, this project has made broadband multi-aspect scattering measurements on a number of UXO objects and several false targets. The UXO scattering data bases include both mono-static and bi-static geometries, with the special case of forward scattering included in the latter. Measurements on a subset of the UXO’s include the target in the free-field and proud on a sediment using the two NRL laboratory-based structural acoustic facilities. In addition to measurements in the sediment laboratory pool facility, proud measurements were also carried out in the “real world environment” of St. Andrew’s Bay, Florida. Echoes obtained in the sediment facility have been processed using the NRL Range-Dependent Acoustic Model (RAM) acoustic propagation model with the environmental parameters of the shallow water, 8m deep, sandy-mud bottom of St. Andrew’s Bay. The scattering target strengths versus frequency and aspect angle predicted using the pool measurements processed with the RAM model compared favorably with actual scattering measurements carried out in the Bay. This success serves as a validation of the use of laboratory data, together with a high fidelity environmental acoustics model, that allows us to apply the structural acoustics approach to other real world environments. Further, in the particular case of forward scattering of UXO measured in the sediment pool facility, this project has been successful in explaining the levels and frequency dependence using a forward scattering model developed for radar scattering. In addition, preliminary success has been achieved in separating the strong incident field from the forward scattered echo based on numerically generated data. This project is currently extending the measurements made in the sediment pool facility to the down-looking, above critical angle sonar case, and these studies will include both in-plane (horizontal) and out of plane target orientations.

This work is funded under SERDP Project MM-1513.
**REVEAL LIDAR FOR HIGH-RESOLUTION 3D UNDERWATER UXO DETECTION**

DR. MICHAEL DEWEERT  
BAE Systems Spectral Solutions  
999 Bishop Street, Suite 2700  
Honolulu, HI 96813  
(808) 441-2511  
michael.deweert@BAESystems.com

The Rapid Efficient Volumetrically-EnAbled Lidar (REVEAL) imaging method offers the potential for determining the shape of ordnance on the bottom of the ocean, detecting indicators of ordnance such as scour pits, and classifying ocean bottom features. Because REVEAL is implemented with commercial-off-the-shelf (COTS) range-gated cameras, large array sizes (on the order of a megapixel) are possible, providing detailed spatial information. In addition, the REVEAL technique operates the cameras in a novel way, so that two range-gated snapshots can be used to extract the range to each pixel while automatically correcting for variations in illumination and reflectance. Thus, REVEAL LiDAR can work in situations, such as imaging through a distorting medium, in which purely passive shape-from-shading or stereoscopic methods are inapplicable. In addition, the REVEAL range resolution can use inexpensive long-pulse (nanoseconds) lasers to achieve resolution that would normally require picosecond laser with standard ranging lidar methods.

This work is funded under SERDP Project MM-1630.
UNDERWATER ORDNANCE CHARACTERIZATION USING AUV TECHNOLOGY

DR. GREGORY SCHULTZ
Sky Research, Inc.
445 Dead Indian Memorial Road
Ashland, OR  95720
(541) 552-5194
greg.schultz@skyresearch.com

CO-PERFORMERS: Ian Monteith (Bluefin Robotics); Dr. Jack Foley and Tom Glenn, PE (Sky Research, Inc.)

Current methods for detecting underwater ordnance include sensor systems such as marine magnetometers or gradiometers towed from surface vessels. These surface-tow fish configurations are often limited to very shallow depths (<10 m), have coarse depth and attitude control and limited deployment range, and may experience significant logistical difficulties if deployed in crowded surface environments or eventful sea states (e.g., >sea state 1). Moreover, they lack the accuracy provided by long-baseline acoustic positioning systems and cannot follow ocean-bottom terrain at low altitudes. This project explores the opportunity to overcome these limitations by integrating land-based UXO geophysical surveying and data processing methodologies with mature Autonomous Underwater Vehicle (AUV) technologies. The goal of this research and engineering analysis effort is to fully develop the synergies between existing AUVs and geophysical systems that exploit advanced sensor arrays and precise positioning, such as those used for terrestrial vehicular deployed UXO detection. By leveraging existing AUV platforms, a flexible marine/lacustrine surveying capability can be developed that not only provides wide area assessment capability in varied aquatic environments, but also can provide full coverage mapping that results in individual UXO detection.

The initial research stage of this work resulted in the creation of a database that documents and inventories existing information from over 100 underwater ordnance (UWO) sites and reveals the benthic conditions that will challenge prospective AUV-based UWO systems. A number of integrated system design tradeoffs were also developed that compare candidate AUV configurations and quantify performance and suitability with respect to UXO detection objectives, cost and logistical considerations, and AUV-sensor interoperability. Magnetic signatures from thruster amplifiers and DC motors were also evaluated. This project will investigate various sensor types, configurations, and survey mission plans to determine detection sensitivity, optimal sensor arrangements, integration and acquisition constraints, and most applicable survey modalities (e.g., wide area assessment or grid-based detection). Time and frequency-domain electromagnetic induction and magnetic data processing, and inversion strategies will be evaluated and tested to optimize the collection and analysis of low-noise data and UWO detection. Recommendations for an AUV-based system that includes configurable mapping technology with an array of geophysical sensors (including acoustic and optical modes) applicable in a wide range of underwater environments (both shallow and deep) will be presented. The results indicate that AUVs are well-suited for UXO surveys, and can become valuable tools for UXO mapping at DoD marine facilities.
DETECTION AND CLASSIFICATION OF UNDERWATER UXO USING RESONANCE SCATTERING SONAR

DR. ROLAND GRITTO
Array Information Technology
5740 Hollis Street
Emeryville, CA 94608
(510) 428-0400
roland.gritto@arrayinfotech.com

CO-PERFORMER: Dr. Valeri Korneev (Lawrence Berkeley National Laboratory)

Unexploded ordnance (UXO) present a worldwide hazard in locations of previous military confrontations and at military training facilities. In particular, the presence of unexploded ordinance in coastal regions poses a severe risk that must be addressed before sites can be turned over to the public or coastal areas made available for commercial traffic. Although progress has been made in detecting UXO in underwater areas, there still exists a need for technologies that can detect and locate UXO buried in seafloor sediments and reliably distinguish munitions from clutter. This project investigates a method based on resonance scattering using small data sets in a controlled pond environment. The use of resonance scattering allows for deeper bottom penetration than in the case of the generally-used acoustic imaging, because in the former case the wavelengths are longer than in the latter. Furthermore, in the resonance scattering regime the geometry, to a certain degree, is independent of the target orientation. The sonar data sets were acquired in 2008 by the Applied Physics Laboratory, University of Washington, at the Naval Surface Warfare Center, Panama City (NSWC-PC), FL, and included an aluminum cylinder and sphere, as well as an artillery shell and mortar round located proud on, and buried in, the sandy pond bottom. Data analysis was performed by personnel from Array Information Technology and Lawrence Berkeley National Laboratory in 2009. The results show that resonance scattered waves, although smaller in amplitude than the specular reflected signal, dominate much of the recorded traces in time. These signals can be used to determine the propagation velocities in the pond sediments, to locate the UXO in the subsurface and to characterize the UXO type by its size and filler velocities.

This work is funded under SERDP Project MM-1668.
DEMONSTRATION OF THE LASER LINE SCAN SYSTEM FOR UNDERWATER UXO CHARACTERIZATION

MIKE PUTNAM
SPAWAR Systems Center Pacific
53560 Hull Street
San Diego, CA 92152
(619) 553-2926
mike.putnam@navy.mil

CO-PERFORMER: Greg Tracey (SAIC)

This project will demonstrate the utility of the SM-2000 Laser Line Scan System (LLSS) for improved wide-area unexploded ordnance (UXO) detection, identification, localization and assessment in underwater environments. A survey utilizing LLSS technology would provide a visual image of individual UXO to more effectively identify site boundaries where UXO proud of the seafloor exist and more clearly discriminate its condition (intact or clutter). The SAIC SM-2000 Laser Line Scan System is composed of an underwater optical sensor consisting of a solid-state Nd-YAG (blue-green) laser with synchronized rotating mirrors and an optical receiver. As such, the SAIC LLSS is unique in that it can collect accurately georegistered high resolution images of underwater visual data at very high coverage rates. The underwater areas that are inaccessible to standard UXO search technologies are poorly defined; however, they potentially exceed 10-million acres. The LLSS will benefit UXO surveys as it combines the efficiency and spatial coverage of a remote survey system with an image resolution approaching that of visual observations.

This work is funded under ESTCP Project MM-0911.
HIGH ACCURACY POSITIONING AND NAVIGATION FOR UNDERWATER MEC OPERATIONS

MR. ANDREW SCHWARTZ
U.S. Army Corps of Engineers
4820 University Square
Huntsville, AL  35816
(256) 895-1644
andrew.b.schwartz@us.army.mil

CO-PERFORMER: Marco Flagg (Desert Star Systems, LLC)

This project demonstrates the use of two long baseline positioning systems, AquaMap Seafloor (wireless system) and RangeNav (cabled system), for use in high-precision underwater MEC detection and reacquisition operations. Numerous magnetometer and reacquisition (diver and ROV) datasets were collected to assess tow-speed and diver-speed dynamic accuracy and repeatability of both systems. Data analysis is on-going, preliminary assessments show the AquaMap produces accuracies between 2cm and 94cm with an average of 44cm in re-acquisition trials, and RangeNav produces accuracies between 20cm and 1m in mapping trials at speeds between 3 and 5 knots. The better RangeNav accuracies are achieved when operating in the center of the acoustic array field. Accuracy degrades to roughly 1.5m when operating near the field boundary. Relative repeatability of the RangeNav system is currently estimated between 30cm and 80cm. The AquaMap Seafloor did not work as anticipated at tow speeds between 3 and 5 knots. Timing errors caused variable accuracy and repeatability errors up to several meters. Some RangeNav trials show a wholesale shift in positions of up to a meter, likely caused by the current pushing the transducers suspended in the water column.

The second phase of this project has been finalized for the Nautical Ordnance Mapping And iDentification (NOMAD) program, which will employ the best features of both the Aquamap Seafloor and RangeNav systems, and integrate high-accuracy time synchronization and wireless radio-modem telecommunications between reference stations and the vessel-mounted surface station. Preliminary error budget calculations suggest this work should achieve just under 30cm positioning accuracy in all modes of operation. Many of the electronic components of this system are now being used in the Antarctic as part of an unrelated project. This project will leverage lessons learned from the Antarctic work to refine NOMAD functionality and operability.

This work is funded under ESTCP Project MM-0734.
POND MEASUREMENTS TO INVESTIGATE SONAR DETECTION AND CLASSIFICATION OF UNDERWATER UXO

DR. RAYMOND LIM
Naval Surface Warfare Center Panama City Division
110 Vernon Avenue
Code T11
Panama City, FL 32407
(850) 235-5178
raymond.lim@navy.mil

CO-PERFORMERS: Dr. Joseph Lopes, Ms. Iris Paustian, Mr. Rudy Arrieta, Dr. Gerry Dobeck, and Dr. David Burnett (Naval Surface Warfare Center Panama City Division [NSWC-PCD])

Monostatic and bistatic scattering by targets resting on or buried under a seafloor was measured earlier this year to study both the relative advantages of these detection modes with sonar and to produce a controlled data set for classification studies and validation of finite element models under development. The measurements were performed in NSWC-PCD’s freshwater pond facility, which is 13.7-m deep, 110-m long, and 80-m wide with a 1.5-m layer of sand on the bottom. In one set of measurements, two Synthetic Aperture Sonar (SAS) rail systems were placed perpendicular to each other and oriented so as to look at proud targets on the same region of the bottom at a shallow grazing angle. This strategy allowed a particular target and environment configuration to be set up and studied for both monostatic and bistatic geometries. In a second set of measurements, a SAS rail was configured to inspect a region of the bottom at well above the critical grazing angle of the sediment to optimize SNR on buried targets. Targets included three UXO, a 0.61-m diameter stainless steel shell, two 0.3-m diameter solid aluminum cylinders with lengths of 0.61 m and 1.52 m, and several 0.3-m diameter open-ended metal shells. Samples of the processed data will be presented. For initial classification studies, data associated with detections were isolated and processed into plots of scattering intensity as a function of frequency and target aspect angle. Variations in these scattering plots are analyzed to identify the physical effects presented in the data. A database of these plots for targets is also being used to test classification performance of existing algorithms in this feature space. Results of these studies are presented.

This work is funded under SERDP Project MM-1666.
By estimation, there are approximately one million acres of underwater land potentially contaminated with unexploded ordnance (UXO). The detection and remediation of underwater UXO are costlier and more difficult than on land. To accurately and reliably detect and distinguish between hazardous UXO and non-hazardous submerged metallic items, it is necessary to study in detail the underlying physics of electromagnetic induction (EMI) scattering phenomena. One must investigate the conditions (e.g., conductivity or conductivity gradient) at which the underwater environment becomes more challenging and complicated for EMI sensors than conventional ground. The main objective of this work is to assess the noise level due to the marine environment. Marine environments tend to exhibit several electrically different layers ("pancakes") because of salt intrusions, haline fronts in shallow areas like river estuaries, and bottom layers. Salt intrusions and fingers as well as haline fronts are typical of the coastal ocean and result in high salinity gradients. The EMI field thus behaves in a marine environment much as it does in a layered medium. Strong vertical gradients of salinity may increase the false-alarm ratio and reduce the effectiveness of the detection and discrimination process. Consequently, seafloor haline structures must be taken into account and their effects suppressed during both wide-area assessment and detailed surveys. To carry out this study we combine the frequency-domain MAS with a surface impedance boundary condition. Time-domain data are obtained using a Fourier transform based on the log-frequency discretization known as the Anderson filter. Virtual GEM-3D and TEMTADS sensors are used to illuminate objects at various locations and orientations both in free space and in conducting host media. The dielectric permittivity of a conducting medium is modeled using the Debye dielectric relaxation model. In particular, the conductivity of saltwater is determined using realistic values of temperature and salinity. The method is also adapted to rough surfaces in order to investigate the noise associated with surface roughness and with moving targets and surfaces. Finally, to support our theoretical studies with experiments, frequency-domain EMI data at the CRREL UXO test-stand site were collected on a measurement grid for different UXO placed inside a tank filled with saltwater. Comparisons between modeled and measured data will be demonstrated.

This work is funded under ESTCP Project MM-1632.
BELIEF THEORETIC MULTI-SENSORY DATA FUSION FOR UNDERWATER UXO IDENTIFICATION

PROFESSOR SHAHRIAR NEGAHDARIPOUR
University of Miami
Department of Electrical and Computer Engineering
1251 Memorial Drive, Room 406
Coral Gables, FL 33146
(305) 284-3352
shahriar@miami.edu

CO-PERFORMERS: Professor K. Premartne and Mr. T. L. Wickramarathne (University of Miami); Professor P.P. Beaujean and Ms. L.N. Brisson (Florida Atlantic University)

This project aims to: (1) deploy state-of-the-art optical and acoustic sensing and processing technologies; and (2) assess application of a novel data fusion paradigm for UXO and munitions site detection, by enabling decision making based on imperfect heterogeneous data comprising multi-modal imagery. The acoustic imaging technologies that will be utilized in this project include: (1) 675KHz 3-D scanning sonar; and (2) short-range high-resolution dual-frequency 2-D sonar video imaging systems operating at 4 frequencies within 0.9 - 2.25MHz. The optical technology systems include: (1) high-resolution digital video; (2) composite 2-D mosaics; and (3) 3-D topographical information from stereovision.

High-resolution sonar cameras are state-of-the-art systems that provide effective tools for the detection and mapping of small targets in highly turbid waters, having been previously deployed for detecting potential explosives on ship hulls, ports, harbor piling, etc. Optical video cameras, despite visibility limitations in turbid conditions, are deployed as a powerful sensing modality for target mapping, localization, and recognition because of high resolution, rich visual cues and object details. Photo-mosaics, constructed from the video of a potential munitions site, may encode cues for UXO detection by providing global information that are not readily available in single frames. Finally, topographical views extracted from optical stereo images give 3-D shape information.

Preliminary results of our work include: (1) acoustic and optical data, such as acoustic signatures of single targets at various orientations relative to the sonar camera over 360 degree views; sample images of a field with false targets as well as inert UXO-type objects; and mosaics of fields with and void of targets; and (2) pre-processing and data fusion. This includes registration of multi-modal optical and sonar images by manual control point selection; classification using k-means algorithm; assignment of Dempster-Shafer theoretic masses for different object classes; implementation of basic Dempster-Shafer theoretic fusion methods; testing of alternate strategies for mass assignment and fusion; and testing the effectiveness of Dempster-Shafer theoretic fusion of images.

This work is funded under ESTCP Project MM-1660.
UNDERWATER SIMULTANEOUS EMI AND MAGNETOMETER SYSTEM (USEMS)

ROBERT SIEGEL
SAIC
104 Clematis Avenue
Waltham, MA 02453
(617) 618-4662
siegelrm@saic.com

CO-PERFORMERS: Andrew Schwartz and Kelly Enriquez (U.S. Army Corps of Engineers)

Since most munitions or explosives of concern (MEC) detection research, development and clean-up efforts have concentrated on tackling the land-based MEC problem, few advances have been made in developing viable underwater detection tools. Although the basic technologies for detecting underwater MEC are the same as those used on land (e.g., metal detectors and positioning systems), the underwater environment poses distinct challenges not encountered on land. These include housing detectors in watertight containers, deploying sensors close to the water bottom without interference from the survey vessel, and calculating accurate sensor positions when a global positioning system (GPS) antenna cannot be directly affixed to the sensor platform. Many underwater MEC sites are small or have intricate coastline that are difficult to follow with towed sensors. Compounding these challenges are irregular bottom topography and underwater vegetation, both of which make it very difficult to deploy sensors close enough to the water bottom to be effective.

Under ESTCP Project MM-0733, SAIC, in partnership with the U.S. Army Corps of Engineers Huntsville Center (USACE), has developed an Underwater Simultaneous electromagnetic induction (EMI) and Magnetometer System (USEMS) that utilizes the two sensors most frequently accepted by regulators (a Geonics EM61 Mk2 pulsed induction sensor and a total field magnetometer) coupled to a boat via a 20’ rigid boom. By deploying a GPS over the boom attachment point and instrumenting the boom’s pivoting points with inclinometers and rotary positioning sensors, the boom geometry is directly measured, eliminating the positioning uncertainty inherent in cable-towed systems. In addition, the design of the rigid mechanical attachment allows the sensor towfish to be driven down and positioned close to the bottom and operated in near-shore environments where cable-towed operation is ungainly or simply impossible. A mag/EM61 towfish has been developed that takes advantage of the four-foot mag/EM61 sensor separation that is possible through use of the interleaving electronics developed under ESTCP Project MM-0414 (sampling the magnetometers in the short intervals between pulses from the EM61). USEMS also leverages the successful design of an EM61-specific towfish designed as an NACA0027 airfoil that SAIC designed and built for Huntsville that has proven to be hydrodynamically stable. The system will undergo in-water testing during Summer and Fall 2009.
MUNITIONS MANAGEMENT

Poster Number 131 – Tuesday
Underwater

ESTCP Project MM-0736

F-97

MITIGATION OF U/W UXO BLOW-IN-PLACE EXPLOSIONS WITH BUBBLE CURTAINS

MR. WILLIAM WILD
SPAWAR Systems Center Pacific (Code 17151)
53475 Strothe Road
Building 111 (BS)
San Diego, CA 91252
(619) 553-2781
bill.wild@navy.mil

CO-PERFORMERS: Dr. Kimo Zaiger (NFESC); Mr. Matt Zalesak (EODTECHDIV); Dr. Thomas Keevin and Dr. Greg Hempen (USACE); Russ Wilcox (DEMEX International, Inc.); Peter Dzwileski and Peter Weiss (ARARMD); Marissa Brand (SPAWAR Systems Center Pacific)

A blast attenuation-barrier and mitigation technology are being demonstrated/validated for potential use at DoD Underwater Munitions Response sites and Explosive Ordnance Disposal (EOD) training sites. This technology focuses on the use of bubble curtains. Their effectiveness at reducing blast pressure, acoustic energy, and minimizing environmental impacts is being documented. Bubble curtains represent the most mature underwater blow in place (BIP) mitigation attenuation-barrier technology for field demonstration. A bubble curtain technology for different net explosive weight (NEW) ordnance items will be demonstrated at appropriate depths. Singular use of this technique is expected to provide blast mitigation and will also be considered with the following issues in mind: personnel safety, ease of use, potential reuse, and total cost (including labor, placement, and equipment).

A validation effort was conducted at the Glendora Lake Facility to determine the feasibility of the air curtain, validate the air flow aspects of a bubble curtain design, experimentally evaluate the efficacy of the prototype in mitigating the peak pressure and energy flux, and provide high-quality data for the continued design and development of a prototype bubble curtain. Twenty-eight tests were conducted: 16 water gun tests on April 8, 2008 and 12 explosive tests on April 9, 2008. The instrumentation system including the triggering and data capture performed well and a total of 270 channels of pressure data were recorded.

The bubble curtains reduced the peak pressure in each of the four tests with a triple curtain low-volume bubble curtain setup providing more mitigation than a single high-volume bubble curtain. The peak Energy Flux Density (EFD) was reduced by 87% for the triple low-volume bubble curtain tests while the EFD was reduced by 75% for the single high-volume bubble curtain tests. In addition, the measured EFD reductions are very similar to those from the modeling and numerical simulation results of 87% and hence provides partial validation of the modeling effort and indicated that there are no major model misfits.

This work is funded under ESTCP Project MM-0736.
RVM CLASSIFIER PERFORMANCE FOR BURIED MUNITIONS USING BURIED OBJECT SONAR SYSTEM (BOSS) LOW-FREQUENCY DATA

EUGENE LAVELY
BAE Systems AIT
6 New England Executive Park
Burlington, MA 01803
(781) 262-4294
eugene.lavely@baesystems.com

CO-PERFORMERS: Dr. Matthew Nelson and Dr. Kent Harbaugh (Applied Signal Technology); Dr. Peter Weichman (BAE Systems AIT)

This objective of this project is to improve low-frequency sonar detection and classification of buried underwater munitions (e.g., 80mm mortar rounds, 155mm artillery shells, 5 inch rocket warheads, etc.) using a combination of image-based and physics-based features. The data acquired with the BOSS has been processed to form 3D delay-and-sum beamformed images, and from these images geometric and intensity-related features have been derived for use in target/clutter separation. The inclusion of all possible features in the training phase leads to poor generalization when the classifier is applied to test data sets. Therefore, the feature subset selection problem has been considered, and a Re levance Vector Machine was applied to various feature subsets. ROC curves over various target and clutter types were derived and show that several features are highly diagnostic. These include the radii of best-fitting ellipsoids to intensity images segmented on the basis of defined thresholds. While the results demonstrate significant false alarm rejection, there is still room for improvement. For this reason, an investigation has begun to determine how the image-based features may be augmented with physics-based features. A number of choices are possible, but one efficient representation is the frequency-dependent, T-Matrix coefficients which fully characterize the acoustic/elastic scattering response of targets in the free-field or in layered media. The coefficients capture the resonant response of targets and are diagnostic of target shape and target composition. Inverse estimation of these coefficients from sonar systems such as BOSS could potentially yield improved classifier performance. This project considers methods to pose the inverse problem for these coefficients, and evaluate coefficient uncertainties as a function of noise, platform positioning errors and errors in the reference background model.

This work is funded under SERDP Project MM-1533.
BRINGING THE FULL DUAL-COIL EM61-MKII HIGH POWER UNDERWATER FOR MEC DETECTION

RICHARD FUNK
Tetra Tech, Inc.
19803 North Creek Parkway
Bothell, WA 98011
(425) 482-7629
richard.funk@tetratech.com

CO-PERFORMERS: Ryan Cross, Burton Bridge, and Robert Feldpausch (Tetra Tech, Inc.)

The industry standard for ferrous and non-ferrous munitions or explosives of concern (MEC) detection on land is the Geonics Limited EM61. Building on the experience gained during development of our land-based vehicle towed array (VTA) and marine gradiometer array (MGA), Tetra Tech is currently developing a bottom towed array (BTA) to bring the EM61 to the marine environment.

The BTA is a modular towfish which incorporates up to three standard dual-coil (top and bottom) EM61-MKII HP units configured into a 1-4 meter wide array. Lateral coil separation (center to center) can be varied from 1.1 to 1.5 meters based on site detection requirements. Each of the units is synchronized allowing for simultaneous operation. The EM61s are configured to collect data just as is done on land, with top and bottom coil co-located with a 30cm separation. This will allow for the collection of 3 time gates (of 216 microseconds $[\mu s]$, 366 $\mu s$ and 660 $\mu s$) as well as the differential signal. By having dual coil differential data, size and depth estimates can be calculated more accurately than with single coil data alone, and allows for seamless integration with terrestrial EM61 data.

The BTA is capable of performing in standard-power mode, or in high-power mode. Operation in high-power mode will allow for detection of items at greater stand off distances (45-80% depending on target characteristics), which is highly desirable when surveying in a marine environment where near or on bottom towing presents a challenge.

To enable underwater operation, Tetra Tech has developed a number of hardware and systems level adaptations. These include underwater housings for the arrays and electronics, an integrated heading and attitude sensor for the towfish, and integration of the array(s) with a winch, umbilical cable and a high precision vessel navigation and data collection system. The integrated system will operate to water depths of approximately 40 meters and provide sub-meter level towfish positioning.

The prototype towfish has undergone hydrodynamic testing and system refinement is ongoing. The system is scheduled for additional testing in August and September 2009. A summary of the tests performed to date and associated results, as well as survey work conducted for systems validation at active MEC remediation site(s) will be presented.
UNDERWATER UXO DETECTION AND CLASSIFICATION VIA SYNTHETIC APERTURE SONAR AND ACOUSTIC TEMPLATES

DR. STEVEN G. KARGL
University of Washington
Applied Physics Laboratory
1013 NE 40th Street
Seattle, WA  98105
(206) 685-4677
kargl@apl.washington.edu

CO-PERFORMERS:  Dr. Aubrey L. Espana and Dr. Kevin L. Williams
(University of Washington)

During February 2009, acoustic responses from two inert unexploded ordnances (UXO, i.e., 81-mm mortar and artillery shell) and a solid aluminum cylinder were collected at the test pond facility of the Naval Surface Warfare Center, Panama City Division (NSWC-PCD). In these initial measurements, the UXO were either proud on a flat sandy sediment or buried just beneath the sediment interface. Synthetic aperture sonar (SAS) data sets were taken for several orientations of the UXO with respect to the path of the SAS platform. The relatively steep grazing angle of approximately 40 degrees permitted the incident acoustic field to penetrate to a buried UXO via ordinary refraction. Two frequency bands were used to span the 1 to 50 kHz range. The design and execution of the experiment will be presented as well as a brief description of the data set storage format. SAS images for the UXOs at various orientations will be displayed, and a reduction of the data sets to aspect angle versus frequency (AAF) plots will be discussed. The AAF plots provide acoustic templates, which can be used by classification schemes to determine whether a detected object is a UXO-like target.

This work is funded under SERDP Project MM-1665.
HANDHELD GEOLOCATION SYSTEM (HGS) FOR UXO DETECTION AND DISCRIMINATION USING LOW-COST IMU

JONG KI LEE
The Ohio State University
125 South Oval Mall
275 Mendenhall Laboratory
Columbus, OH 43220
(614) 329-2141
lee.2608@osu.edu

CO-PERFORMERS: Adem G. Hayal and Dr. Christopher Jekeli (Ohio State University)

The position and orientation of unexploded ordnance (UXO) sensors should be known precisely for the discrimination of buried UXO and clutter. A GPS-based geolocation system is especially challenged where satellite signal reception is compromised and when high resolution positioning is required for dynamic motions of the sensor system. A Handheld Geolocation System (HGS) using low-cost inertial measurement unit (IMU) was designed to overcome these limitations and to be applied in relatively small areas. The HGS has only one tactical-grade micro-electric mechanical sensor (MEMS) IMU (HG1900) to satisfy low-cost and low-weight requirements. The test is operated in a closed environment that has no GPS signal available. To improve geolocation accuracy in this GPS-denied environment, multi-position data calibration techniques are employed first and then nonlinear filters based on forward/backward filtering techniques (extended kalman filter [EKF]-based racer tung striebel [RTS] smoothing, unscented kalmer filter [UKF]-RTS smoothing, and unscented particle filter [UPF]-RTS smoothing) were tested and analyzed using typical local handheld detector trajectories (straight, curved, and swing, etc.). The results show that this handheld geolocation system can approach discrimination precision level in geolocation of a few centimeters (in a small area, e.g., 1m by 1m).

This work is funded under SERDP Project MM-1565.
PERFORMANCE ASSESSMENT OF QUADRUPLE SENSOR INTEGRATION BASED GEOLOCATION TECHNOLOGY FOR GEOPHYSICAL SENSORS FOR DETECTION AND DISCRIMINATION OF UNEXPLODED ORDNANCE

PROFESSOR DOROTA GREJNER-BRZEZINSKA
The Ohio State University
2070 Neil Avenue
470 Hitchcock Hall
Columbus, OH 43210
(614) 292-8787
dbrzezinska@osu.edu

CO-PERFORMER: Dr. Charles Toth (Ohio State University)

The concept and initial performance results of a high-accuracy hybrid navigation system that can address the stringent requirements of a man-portable geophysical mapping system and is able to maintain high relative positioning accuracy in impeded environments was reported in 2008. The system is based on a novel quadruple-integration of global positioning system (GPS), inertial navigation system (INS), pseudolite (PL), and terrestrial laser scanning (TLS) to assure accuracy, continuity and integrity of the navigation solution. In practical terms, the three-tier munitions of explosives of concern (MEC) site survey concept include standard GPS/inertial measurement unit (IMU)-based absolute navigation in open-sky environment, relative navigation with medium accuracy in GPS-challenged situation, and high-precision local navigation in total GPS-denied environment. The novel component of the integration approach is the incorporation of TLS technology to facilitate high relative positioning accuracy in GPS-challenged environments. The analysis provides the first full performance evaluation of the new technology, based on a prototype implementation of the system, including all the four sensors.

This work is funded under SERDP Project MM-1564.
FIELD DEMONSTRATION OF AN EMI/IMU SYSTEM TO LOCALLY INTERROGATE BURIED UXO

DR. BRUCE BARROW
SAIC
200 12th Street, Suite 1500
Arlington, VA 22202
(703) 414-3884
bruce.j.barrow@saic.com

CO-PERFORMER: Dr. Dean Keiswetter (SAIC)

An electromagnetic induction sensor and an inertial measurement unit (IMU) have been integrated to provide tightly coupled sensor and position data over a localized area. The Small Area Inertial Navigation Tracking (SAINT) system contains the IMU and a single board computer. This computer records the IMU data plus has a variety of I/O options to record sensor data or provide time stamped output. Currently, the SAINT is attached and interfaced to an EM61-HH. The SAINT computer collects and time stamps the EM61 data over the serial line between the EM61 and a handheld computer running standard software. By collecting both data streams on a single computer, the relative timing of each can be closely matched. Both sets of data are downloaded to a PC for post-processing.

Three dimensional positioning information of the EM61-HH coil head (x, y, z, and orientation) is calculated from the IMU acceleration and angular rate data. The system is constrained to starting and stopping at a fixed location on a tripod. For short data runs (<30 seconds), the integration of the IMU data results in sensor positioning accuracy of 1 centimeter or less. In this time frame, the EM61-HH coil head can be swept back and forth 4-6 times, covering about 1 m² over the position of a previously flagged buried object.

The positioning and EMI data can be used in a model-based inversion. Accurate inversion of model parameters depends on centimeter positioning provided by the IMU system. With these parameters well determined, the system can be used to classify objects as either unexploded ordnance or as clutter. Controlled measurements and simulation have found that the model-based inversion is much more sensitive to the drifting/systematic errors of IMU positioning than to random errors of other positioning systems. Despite this limitation, reasonable inversions can be obtained with the system.

As a realistic field test, the system was taken to the standardized UXO test site at Aberdeen Proving Ground. Measurements were taken over the known objects in the calibration area and over the unknown objects in the blind area. As a practical comparison, the same anomalies were measured using the EM61-HH with a simple wooden template to measure a 6 point by 6 point grid over roughly the same area. Both sets of data will be inverted and used to generate a target report. These two separate reports will be handed in, graded, and compared.

This work is funded under ESTCP Project MM-0810.
**IMPROVED USE OF HISTORICAL PHOTOGRAPHY FOR FUDS ASSESSMENTS**

MR. LARRY TINNEY  
TerraSpectra Geomatics  
2700 E. Sunset Road  
Suite A-10  
Las Vegas, NV  89120  
(702) 795-8254  
larry.tinney@terraspectra.com

**H**istorical aerial photography can be used more effectively in support of Department of Defense (DoD) Military Munitions Response Project (MMRP) site assessments. This project specifically addresses practice and demolition bombing range delineation in large areas at Formerly Used Defense Sites (FUDS) located in the southwestern United States (New Mexico and Texas). These sites were used during and shortly after World War II to support bomber flight crew training. Both practice and high explosive bombs were used at these sites. This project demonstrates the benefits of best practices and more advanced digital image processing and photogrammetry techniques using historical photography. Increasing amounts of historical photography are becoming available from various public and private archive holdings.

Prior and ongoing work has identified significant errors in many existing FUDS locations that can be resolved through the more systematic use of current best practices as well as the digital techniques demonstrated. Resolving locational errors prior to more expensive field investigations can reduce costs and increase stakeholder confidence in cleanup and restoration programs.

This work is funded under ESTCP Project MM-0812.
EXAMINATION OF AIRBORNE FDEM SYSTEM ATTRIBUTES FOR UXO MAPPING AND DETECTION

DR. WILLIAM DOLL
Battelle
105 Mitchell Road, Suite 103
Oak Ridge, TN 37830
(865) 483-2548
dollw@battelle.org

CO-PERFORMERS: Bruce Barrow, Thomas Bell, and Nagi Khadr (SAIC); J. Scott Holladay and James L. C. Lee (Geosensors); Les P. Beard and T. Jeffrey Gamey (Battelle)

The value of airborne geophysical sensor systems for wide area assessment and UXO mapping and detection has been demonstrated with magnetometer systems such as the Battelle VG-16 and VG-22 systems (ESTCP Project MM-0633). Previous and ongoing efforts have been devoted to development of complementary time-domain electromagnetic (TEM) systems (ESTCP Projects MM-0101 and MM-0743) for applications where geologic conditions inhibit successful magnetometer surveys, or where non-ferrous ordnance is to be detected.

Frequency-domain electromagnetic (FDEM) systems potentially offer an attractive alternative to transmission electron microscopy (TEM) systems for UXO detection. In this project, computer modeling and ground-based mock-up testing are used to evaluate optimal FDEM configurations. Five general cases were considered. Model results show preferred performance for two cases where both transmitter and receivers are mounted on the helicopter booms: (1) a vertical transmitter coil with a concentric and coaxial receiver; and (2) a design equivalent to Case 1, with an additional nulling coil that is concentric with the other coils. Alternatives that were assessed included pairs of coaxial receiver coils that measure vertical and horizontal gradients, as well as a design with a single horizontal receiver coil. Perturbation of the models was used to evaluate the sensitivity of each design case to movement, flexure, or vibration, which would be expected in an airborne deployment. For several reasons, it is expected that a FDEM system will perform better if it measures the quadrature, rather than the inphase component of the received signal.

Mock-up tests have been conducted for the preferred cases for confirmation. These tests have shown excellent correlation with the computed results. The mock-ups have also been used to assess primary field nulling methods, which are critical for FDEM systems.

To baseline the FDEM assessments, this research compared the estimated FDEM signal-to-noise (S/N) with S/N determined from physical and computer models of TEM systems, using the Battelle TEM-8 system as a representative TEM design. This allows for the relative capabilities of TEM and FDEM systems to be compared. The modeled S/N for TEM systems is also compared with the observed S/N of the TEM-8 system from survey data sets.

This work is funded under SERDP Project MM-1633.
DEMONSTRATION OF THE BATTELLE TEM-8 AIRBORNE ELECTROMAGNETIC SYSTEM FOR MAPPING AND DETECTION OF UXO

DR. WILLIAM DOLL
Battelle
105 Mitchell Road, Suite 103
Oak Ridge, TN 37830
(865) 483-2548
dollw@battelle.org

CO-PERFORMERS: T. J. Gamey, J. R. Sheehan, J. Norton, and L. P. Beard (Battelle); A.E. Hanson and R. Lahti (AMEC); Nathan Eklund (Consultant)

Battelle’s TEM-8 system is a helicopter-mounted time-domain electromagnetic induction system with eight receiver coils distributed in two groups of four (one group on each side of the aircraft) and 1m spacing within each group. It was designed as an alternative to magnetometer systems where geologic conditions or ordnance composition render magnetometer systems ineffective for unexploded ordnance (UXO) mapping and detection. In early 2009, the system was demonstrated for ESTCP at two sites at the Former Kirtland Precision Bombing Range (FKPBR), New Mexico. The first site was a 617-acre portion of a former range with moderate geologic interference, and included a 100-acre blind-seeded area. The second site was a 444-acre portion of a bombing target (PBR-S12) located on a basalt flow in Pueblo of Laguna property where geologic interference is severe.

A total of 110 seed items were emplaced by an ESTCP contractor in the blind-seeded area. These included 155m projectiles, 105mm projectiles and HEAT rounds, 81mm mortars, and 4.2-in mortars. A dig list was provided to ESTCP subsequent to airborne data collection. The data set contained 1,292 anomalies categorized as high (477 picks), medium (344 picks) and low (471 picks) priority targets. Independent analysis of the TEM-8 performance was conducted by the Institute for Defense Analyses (IDA). IDA determined that 109 out of 110 seed items were detected by the TEM-8 using a 1.5m search radius, with all but five of these in the ‘high priority’ group. Mean miss distance was 0.34m, with a standard deviation of 0.23m.

Previous air and ground-based magnetometer surveys at the PBR-S12 target were unable to detect any of the M38 (110 lb practice bomb) ordnance or frag (some of which is at the surface) because of the dominance of anomalies associated with a basalt flow at the site. TEM-8 data were used to develop a map that clearly defines the extent of the target. Dig lists were prepared from the TEM-8 data for two 100m × 100m areas peripheral to the center of the target. EM-61 ground-based data were acquired within those two areas and a composite dig list was prepared from the combination of EM-61 and TEM-8 dig lists. In all, 327 anomalies were intrusively sampled. Of these, TEM-8 detected 36 of 38 ‘largely intact M38s’ (95%), and 49% of the smaller frag, which included M38 initiators, nose cones, fins, and 2-inch bands. Mean miss distance was 0.58m with a standard deviation of 0.31m. There were 36 no-finds among the digs derived from the TEM-8 data.

This work is funded under ESTCP Project MM-0743.
WIDE AREA ASSESSMENT FOR MARINE MUNITIONS AND EXPLOSIVES OF CONCERN

BURTON BRIDGE
Tetra Tech, Inc.
19803 North Creek Parkway
Bothell, WA 98011
(425) 749-1074
burr.bridge@tetratech.com

CO-PERFORMERS: Richard Funk and Robert Feldpausch (Tetra Tech, Inc.)

There are well-developed methodologies and approaches for assessment of terrestrial munitions or explosives of concern (MEC). However, there are currently no “standardized” approaches for wide area assessment (WAA) for MEC in the marine environment. Detecting submerged and buried objects in a freshwater or marine environment requires a new and different set of technologies and procedures, since standard terrestrial-based survey methods such as helicopter-based magnetometer, aerial photography, LiDAR and even site walks are not typically appropriate or possible at underwater sites. Additionally, positioning of sensors—which are commonly towed below the water rather than being mounted on the survey vessel—often not possible with global positioning system (GPS) alone. The water environment, if not mapped in high resolution, pose unforeseen risks to equipment and personnel. However, by combining extensive marine geophysical survey experience, and some innovative sensor development, it is possible to perform efficient, cost effective, wide area assessment surveys for MEC underwater.

Tetra Tech has developed and is continuing to refine methodology to combine high resolution acoustic survey data, including multibeam sonar bathymetry, sidescan imagery, and subbottom profiling, with their independently developed Marine Gradiometer Array (MGA) and submersible electromagnetic (EM) systems to reliably and accurately detect underwater MEC. These methods can be combined with a man portable remotely operated vehicle (ROV), with a high resolution camera and forward looking imagery sonar, and/or a diver to inspect prioritized targets of interest.

The combination of sensors, along with appropriate sampling strategies and data fusion software, can be used to: (1) determine the distributions of possible MEC within the survey area; (2) aid in the discrimination of background geologic anomalies and debris; and (3) localize the targets of interest with sufficient accuracy to minimize remediation costs. These systems will provide this capability from very shallow depths to several hundred feet in the current operational configuration, and in a range of weather conditions and sea states that ensures an efficient production level survey.

A summary of the testing performed to date, and results, for survey work conducted for systems validation and during field survey at an active MEC remediation site will be presented.

This work is funded under ESTCP Project MM-0808.
Wide Area Assessment Cost-Benefit Analysis - Active Army MMRP

Ms. Victoria Kantsios  
URS Corporation  
2450 Crystal Drive, Suite 500  
Arlington, VA 22202  
(703) 418-3030  
victoria_kantsios@urscorp.com

Co-Performers: Mr. Brian Helmlinger (URS Corporation); Ms. Kimberly Watts and Dr. Bonnie Packer (U.S. Army Environmental Command)

Extensive research and technology demonstrations have shown that wide area assessment (WAA) methods can characterize large areas of munitions response sites (MRSs) rapidly and at relatively low cost. To date, most of this work has focused on air-to-ground training ranges. The U.S. Army Environmental Command (USAEC) sought to determine which WAA methods were most relevant, appropriate, and cost-effective to support remedial investigations within the Active Army Military Munitions Response Program (MMRP). This project summarizes the capabilities, limitations, and costs of four WAA methods: LiDAR/orthophotography, helicopter-borne magnetometry, towed arrays (magnetometer or electromagnetic induction), and man-portable arrays. The project team categorized all sites and then screened these Active Army MMRP inventory sites to identify MRSs with representative size, vegetation, terrain, and munitions-types. Four representative sites were selected.

Additionally, the project team developed a site-specific WAA cost estimating tool. Based on detection capabilities, percentages of sites characterized, and coverage approaches (i.e., transect-based or full coverage); the project team assessed each WAA method’s ability to identify all areas of concentrated munitions use and assigned a level of confidence in those conclusions. The man-portable array deployed on a transect basis was found to be the most cost-effective method at all four MRSs evaluated. Key characteristics that led to its selection include: (1) ability to characterize high percentages of MRS acreage, to include dense vegetation, steep terrain, and developed areas (i.e., within cantonment areas); (2) high detection probability for the small munitions common to Active Army MRSs; and (3) deployment along statistically valid transects, which turns a labor intensive, low production rate technology into a relatively quick, cost-effective WAA method.

This desktop analysis demonstrated how site conditions at Active Army MRSs may be inconsistent with the effective implementation of many promising technologies. Due to the desktop nature of the work, assumptions about survey design and data representativeness require testing in a “production” environment. The purposes of WAA field demonstration effort are to: (1) identify areas of concentrated munitions use; (2) identify areas with no indication of munitions use; and (3) improve the understanding of relative densities of munitions and explosives of concern (MEC) across an Army MRS, where ground-to-ground training took place.

The WAA methods will be implemented in a manner that ensures the resulting data quality allows maximum utilization of characterization data in subsequent MMRP investigations at the MRS.
LiDAR AND ORTHOPHOTOS IN UXO/MEC WIDE AREA ASSESSMENT: 
LESSONS LEARNED

MR. DALE BENNETT
URS Corporation
1501 4th Avenue, Suite 1400
Seattle, WA  98101-1616
(206) 438-2026
dale_bennett@urscorp.com

CO-PERFORMER:  Bob Selfridge (U.S. Army Corps of Engineers)

SACE and URS Corporation were awarded ESTCP funding to develop parameters for the use of LiDAR and orthophotography as one component of a multi-technology approach to unexploded ordnance (UXO)/munitions or explosives of concern (MEC) Wide Area Assessment (WAA). This work was an extension of an earlier demonstration by URS of the utility of LiDAR and orthophotos, which along with the work of other demonstrators showed that LiDAR and orthophotos could be a cost-effective and useful addition to WAA. These two studies have provided information which can result in better performance and guide government end users of these technologies. The demonstration produced technical papers on LiDAR point classification methods and LiDAR error, and a guidance document for government end users on the acquisition, processing, and analysis of LiDAR and orthophoto data. Lessons learned included:

1. LiDAR and orthophotos can help detect and delineate munitions response areas. Indicators of munitions use, including craters and aiming targets, were visible in ground surface models even many years after their last use. By locating these areas, LiDAR and orthophotos served as a cost-effective method to confirm or correct the initial CSM, to focus the use of mag or EMI surveys, and to provide site data for subsequent investigation; (2) vegetation will impact the use of both technologies. LiDAR will produce good surface models in most vegetated conditions, however the density of ground returns will be lower, which will reduce the confidence level for feature detection. Orthophotos will be less useful at vegetated sites; (3) density of LiDAR and orthophoto data makes a difference. One of the most important parameters in achieving good feature detection—data density—is also complex. In the case of orthophotos, higher data density (smaller pixel size) can increase costs substantially, and its usefulness can be diminished by vegetation. For LiDAR, point density can vary with altitude, flightline overlap, weather conditions, and other data collection parameters. These variations can and should be taken into consideration in contract specifications; (4) LiDAR point classification methods can improve performance. Vendors’ standard point classification methods can result in significant under-classification of ground points. Simple changes to point classification methods can result in increased resolution in the ground surface model and increased likelihood of feature detection; and (5) confidence levels for feature detection with LiDAR vary and can be mapped. Density variations which influence feature detection can be mapped, these will provide regulators with important information on confidence levels.

This work is funded under ESTCP Project MM-0737.
**DEVELOPMENT OF AUTONOMOUS MAGNETOMETER ROTORCRAFTS FOR WIDE AREA ASSESSMENT**

DR. ROELOF VERSTEEG  
Idaho National Laboratory  
P.O. Box 1625  
Idaho Falls, ID  83415-2107  
(208) 526-4437  
roelof.versteeg@inl.gov

CO-PERFORMERS:  Mark McKay and Matt Anderson (Idaho National Laboratory);  
Ross Johnson (Geometric); Les Beard (Battelle)

Helicopter-based magnetometry of areas contaminated with unexploded ordnance has proven to be an effective tool for wide area assessment. However, the cost and risk associated with helicopter based data acquisition (and the limitations on areas which are suited for such an approach) has led to the exploration of alternatives. Under the SERDP-funded project MM-1509, an investigation is being conducted as to the feasibility of developing unmanned, semi autonomous rotorcraft systems which can be used for low altitude (~6 ft above ground) magnetic data acquisition. Such systems could potentially be used on a large number of sites which are currently (for either cost, risk or site topography and vegetation reasons) off limits for manned helicopter systems. Such systems require the integration of rotorcraft, control software, terrain following and obstacle avoidance sensors, magnetometer arrays and real time acquisition and data processing tools. In previous work, the theoretical feasibility of such an approach was demonstrated using existing components. Over the last several months the project has extended previous work to successfully demonstrate near ground (6 ft) terrain following abilities in a semi autonomous unmanned rotorcraft which collected and transmitted magnetic data. The demonstration system had a small payload and used a fluxgate magnetometer. Currently, this effort is being expanded to include an array of cesium gradiometers on a range of different (more realistic) rotorcrafts with different payloads and performance characteristics.
INTEGRATION OF UXO SOFTWARE SUITE

MRS. AMY WALKER
U.S. Army Engineering & Support Center, Huntsville
ATTN: ED-CS-G
4820 University Square
Huntsville, AL 35816
(256) 895-1604
amy.n.walker@usace.army.mil

CO-PERFORMERS: Nick Valleau, Hossein Madjidi, and Elizabeth Baranyi (Geosoft, Inc.)

For the last several years, supported by ESTCP funding under Project MM-0131, the Huntsville Center has worked with Geosoft, Inc. to develop an extensive suite of freely available software tools for the industry to assist with specialized requirements for unexploded ordnance (UXO) detection and discrimination. The project provides a standardized tool set to assess data quality, helps improve data processing and analysis, and provides a standard software platform for sharing analysis algorithms.

The software package, named UX-Process, operates within Geosoft’s commercial Oasis montaj™ data processing environment and currently contains over 70 menu items. UX-Process has been supported and applied in the field for several years, with updated versions released annually. It is currently available at no cost for U.S. government UXO personnel and their contractors, and existing Oasis montaj™ license holders. Requests for this free license can be submitted at: http://www.geosoft.com/pinfo/industry/uxo/uxprocess.asp.

The UX-Process tools, currently used on UXO projects by contractors and government personnel, improve the utilization of field data by identifying and correcting instrument and acquisition errors and providing documentation of the data quality. In addition, UX-Process provides a consistent and logical structure for adding new target analysis and discrimination capabilities, as they become available. The standard tests and tools developed under this project enable the contractors tasked with collecting, processing and analyzing the data to be more effective in meeting government data quality standards, and allow the government to be more efficient in assessing and documenting the quality of the product delivered.

This project will focus on the new developments and updates in the latest release, and the plans for continued availability and maintenance after this final year of ESTCP support.
QUALITY CONSIDERATIONS FOR MUNITIONS RESPONSE PROJECTS

MR. BILL HARMON
Michigan Department of Environmental Quality
P.O. Box 30426
Lansing, MI 48909
(517) 335-6237
harmonw@michigan.gov

CO-PERFORMER: Guy Warren (Alaska Department of Environmental Conservation)

In this document and companion Internet-based Training (IBT) the Interstate Technology and Regulatory Council (ITRC) Unexploded Ordnance (UXO) Team provides guidance to environmental regulators on how to define quality, how to systematically plan for, manage, and achieve quality results, and how to apply these concepts to processes common to a munitions response (MR) project. The document also provides real-world examples to illustrate how the proper or improper application of the quality concepts presented in this document affect the quality of MR projects.

To manage and achieve quality, it first must be defined. In this document, quality is defined as “conformance to requirements.” Requirements must be precisely stated and clearly understood by everyone involved. Measurements and observations are then performed to determine conformance to those requirements. Any non-conformance detected indicates the absence of quality. Quality problems become non-conformance problems, and quality becomes definable.

The UXO Team emphasizes taking a whole-system approach to designing and managing an MR project to optimize quality. Whole-system design means optimizing not just parts, but the entire system (in this case the MR). Practically speaking, the UXO Team views MR as a system made of processes, sub-processes, and tasks. Therefore, a process approach to planning and managing MR projects is recommended.

MR planners using the "process approach" to plan an MR project identify key processes, and the logical flow and interaction of these processes. Planners also identify process and product checkpoints to ensure “conformance to requirements”. The checkpoints identified during the planning process prompt the quality assurance (QA) and quality control (QC) activities that must be performed and documented to monitor the quality of the processes and the products produced.

QA activities focus on the process used to create the deliverable while QC activities focus on the deliverable itself. QA and QC are both powerful techniques, and both must be performed to ensure that the deliverables meet the customer’s quality requirements.

Through the proper application of a process approach to plan and manage an MR project, the MR project should produce results of verifiable quality with sufficient QA and QC documentation to support defensible decision making.
Time Critical Removal Actions require a streamlined, dynamic data tracking system to engage stakeholders and plan upcoming activities. This type of data tracking also ensures data quality and project success. When tracking varying types and amounts of data, the multiple data tracking systems and software applications need to be integrated. During the Multiphase MEC Removal Action at Surf City, various GIS procedures and a custom built Relational Database Management System (RDMS) worked together to track and display MEC and Geophysical data through the three-phased removal action. The GIS and RDMS systems were continuously adjusted to fit the changing procedures used during each phase of data collection. This allowed for current mapping and dynamic data tracking which could be viewed by all stakeholders and the project team during all three phases of the project.
WHEN CAN I STOP DIGGING?
A BAYESIAN METHOD FOR QUANTIFYING THE PROBABILITY OF NO UXO REMAINING AS REMEDIATION PROGRESSES

MR. JOHN HATHAWAY
Pacific Northwest National Laboratory
P.O. Box 999
MSIN K6-08
Richland, WA 99352
(509) 372-4970
john.hathaway@pnl.gov

CO-PERFORMERS: Stephen Walsh, Kevin Anderson, and Brent Pulsipher (Pacific Northwest National Laboratory)

Current analysis routines for classification of geophysical anomalies generate a metric that reflects the degree of belief that the anomalies are targets of interest (TOI). These metrics are then used to determine the anomaly digging order. The metrics are unable to exactly classify each anomaly as TOI/Not-TOI due to measurement error (including machine noise and environmental nuisance factors). Therefore, analysts are required to identify a “conservative” threshold at which, after digging anomalies with large metrics, they believe the remaining anomalies are Not-TOI.

Pacific Northwest National Laboratory is developing a framework to provide statistical statements which quantify the probability of no TOI remaining in the undug anomalies based on the ranking metrics, dug anomalies, and threshold for the site of interest. The Bayesian Dig-Stop (BDS) model can be used sequentially as anomalies are dug to calculate the probability that no TOI remain in the undug anomalies along with the certainty on that probability estimate. Once the BDS model provides sufficient confidence that the probability of no TOI remaining reaches some acceptable level, digging can cease.

This project will use two data sets from the ESTCP Camp Sibert classification demonstration to illustrate the use of the BDS model.

This work is funded under ESTCP Project MM-0837.
ENHANCEMENT OF TEM DATA AND NOISE CHARACTERIZATION BY PRINCIPAL COMPONENT ANALYSIS

MR. M. ANDY KASS
Center for Gravity, Electrical, and Magnetic Studies
Colorado School of Mines
Department of Geophysics
1500 Illinois Street
Golden, CO 80401
(303) 273-3904
mkass@mines.edu

CO-PERFORMER: Yaoguo Li (Colorado School of Mines)

Transient electromagnetic (TEM) surveys in unexploded ordnance (UXO) application are often subjected to a multitude of noise contaminations. Noise from a particular source can be either uncorrelated, such as those originating from radio frequency (RF) interference and telluric sources, or it can be highly correlated over time or spatial locations, such as those from geology, coil orientation, and micro-topography. Each of these sources of noise (in addition to the signal from the target) contributes to the total response measured by the sensors. The effect of noise is especially strong at late-times in TEM data. Advanced UXO discrimination techniques require understanding of noise characteristics and enhancement of the signal. To address this issue, this project presents a method based on principal component analysis (PCA) for suppressing noise and separating signal sources in TEM data acquired in UXO applications. Typical TEM surveys in UXO are conducted using central-loop configuration over closely spaced stations or using multi-transmitter, multi-receiver instruments. The resultant data are ideal for decomposition by PCA. This project deals with the basics of PCA and its application to enhancement of such UXO data. In particular, it investigates the optimal organization of data and choices of principal components for removing two types of noise. It also demonstrates that PCA can clearly separate the background geologic noise due to magnetic soil and suppress incoherent noise contaminating data in late time gates.

This work is funded under SERDP Project MM-1640.
EVALUATING THE ORIGIN OF NATURAL PERCHLORATE USING STABLE ISOTOPE ANALYSIS

DR. PAUL HATZINGER
Shaw Environmental, Inc.
17 Princess Road
Lawrenceville, NJ 08648
(609) 895-5356
paul.hatzinger@shawgrp.com

CO-PERFORMERS: W. A. Jackson, Ph.D. and Balaji Rao (Texas Tech University); N. C. Sturchio, Ph.D., L. J. Heraty, and A. Beloso, Jr. (University of Illinois at Chicago); J. K. Böhlke, Ph.D. (USGS); B. Gu, Ph.D. (ORNL); G. Harvey (USAF)

Natural perchlorate (ClO₄⁻) has long been known to co-occur with nitrate and other anions in near-surface caliche deposits in the Atacama Desert of Chile. Nitrate from these deposits has been widely imported as an agricultural fertilizer. In addition to Chilean perchlorate, natural perchlorate has now been detected in caliche-type deposits near Death Valley, CA and in thick unsaturated-zone accumulations in other arid regions of the western United States. When such areas are irrigated, this natural perchlorate may be mobilized and transported to groundwater. SERDP Project ER-1435 and ESTCP Project ER-0509 are investigating compound-specific isotope ratio mass spectrometry (IRMS) as a method to distinguish indigenous natural perchlorate in the United States from Chilean perchlorate. Stable isotope ratios of Cl (³⁷Cl/³⁵Cl) and O (¹⁸O/¹⁶O and ¹⁷O/¹⁶O) were determined for perchlorate collected from the following sources: (1) Atacama Desert caliche salts and nitrate fertilizers derived from this material; (2) groundwater from the southern high plains (SHP) of Texas and New Mexico; (3) groundwater from the middle Rio Grande Basin in New Mexico; (4) unsaturated (vadose) sediments from the SHP of Texas; and (5) near-surface nitrate-rich salts in caliche-type deposits from four locations around Death Valley, CA. The Atacama caliche perchlorate and imported Chilean nitrate fertilizers have similar isotope values. These samples are characterized by positive Δ¹⁷O values, indicating that the perchlorate was formed, at least in part, by oxidation of volatile Cl species with atmospheric ozone. New data indicate that natural perchlorate in the southwestern United States has at least two isotope signatures that differ both from each other and from the Atacama perchlorate. The Death Valley perchlorate has high Δ¹⁷O values as observed for the Atacama samples, but the Death Valley δ³⁷Cl values and δ¹⁸O values are appreciably higher than the Atacama values. In contrast, perchlorate extracted from groundwater and unsaturated vadose samples in the SHP and Rio Grande Basin has only small positive values of Δ¹⁷O, nearly constant δ³⁷Cl values that are higher than any of the other natural samples, and moderately high δ¹⁸O values that overlap with those from Death Valley. The existence of large positive Δ¹⁷O values in the Death Valley and Atacama caliche samples indicates a similar origin. The absence of this characteristic in the other southwestern samples indicates either that the origin of this perchlorate was different or that the SHP perchlorate was modified by biological, physical, or geochemical processes after deposition. Additional studies are ongoing to explain the genesis of the SHP perchlorate and to determine if additional variations exist in the isotope values of natural perchlorate. Despite variation in the isotopic composition of natural perchlorate, the data so far indicate all varieties of natural perchlorate are distinguishable from synthetic perchlorate.
CHLORINE-36 AS A TRACER OF PERCHLORATE ORIGIN

NEIL C. STURCHIO
University of Illinois at Chicago
845 West Taylor Street, MC-186
Chicago, IL 60607-7059
(312) 355-1182
sturchio@uic.edu

CO-PERFORMERS: Professor Marc Caffee (Purdue University); Abelardo D. Beloso, Jr. and Linnea J. Heraty (University of Illinois at Chicago); Dr. John Karl Böhlke (U.S. Geological Survey); Dr. Paul B. Hatzinger (Shaw Environmental, Inc.); Professor W. Andrew Jackson (Texas Tech University); Dr. Baohua Gu (Oak Ridge National Laboratory); Dr. Jeffrey M. Heikoop (Los Alamos National Laboratory); Michael Dale (New Mexico Environment Department)

Perchlorate (ClO₄⁻) is ubiquitous in the environment; it is produced naturally by atmospheric photochemical reactions, and is synthesized in large quantities for military, aerospace, and industrial applications. Nitrate-enriched salt deposits of Chile’s Atacama Desert contain high concentrations of natural ClO₄⁻, and have been exported worldwide since the mid-1800’s for use in agriculture. The widespread introduction of synthetic and agricultural ClO₄⁻ into the environment has contaminated numerous municipal groundwater supplies. Stable isotope ratio measurements of Cl and O have been applied for discrimination of different ClO₄⁻ sources in the environment. This study explores the potential of ³⁶Cl measurements in order to further improve the discrimination of ClO₄⁻ sources. Groundwater and desert soil samples from the southwestern United States contain ClO₄⁻ with high ³⁶Cl abundances (³⁶Cl/Cl = 3,100×10⁻¹⁵ to 28,800×10⁻¹⁵), compared with those from the Atacama Desert (³⁶Cl/Cl = 0.9×10⁻¹⁵ to 590×10⁻¹⁵) and synthetic ClO₄⁻ reagents and products (³⁶Cl/Cl = 0.0×10⁻¹⁵ to 40×10⁻¹⁵). In conjunction with stable Cl and O isotope ratios, ³⁶Cl data provide a clear distinction between three principal ClO₄⁻ source types in the environment of the southwestern United States.

This work is funded under ESTCP Project ER-0509.
PERCHLORATE REDUCTION IN A BIOREACTOR PACKED WITH ZERO-VALENT IRON

DR. MARC DESHUSSES
Duke University
Department of Civil and Environmental Engineering
Hudson Hall
Box 90287
Durham, NC 27708
(919) 660-5480
marc.deshusses@duke.edu

CO-PERFORMER: Mark Matsumoto (University of California, Riverside)

There has been widespread concern about the contamination of drinking water with perchlorate ($\text{ClO}_4^-$). The very low concentrations at which perchlorate causes health effects and, consequently, the stringent treatment goals, present many technological and economical challenges. Biological treatment of perchlorate is a promising alternative to conventional treatment methods. During biotreatment, perchlorate is reduced by bacteria to harmless chloride without the generation of secondary contaminants. This project developed and demonstrated a new process for the treatment of perchlorate contaminated groundwater. Treatment relies on the reduction of $\text{ClO}_4^-$ by autotrophic organisms attached to zero-valent iron (ZVI). The process can be conducted in an ex situ vessel (pump and treat) or possibly below grade in a biobarrier setup. As iron corrodes, hydrogen is slowly released and used as a source of energy for the perchlorate-reducing bacteria attached at the surface of the iron particles.

The process was demonstrated in Rialto, California under ESTCP Project ER-0636. A trailer-mounted bioreactor system capable of treating up to 20 gpm of contaminated groundwater was designed and installed at the site. After an initial acclimation phase of one week, excellent treatment of perchlorate was observed for a duration of about 5 months. The influent perchlorate concentration ranged from 40 to 50 ppb, while the average effluent concentration was usually below 1 ppb. Effective nitrate treatment was also observed. While extended characterization of the process was underway, treatment performance deteriorated and efforts to recover full treatment performance failed. Subsequent research in the laboratory demonstrated that heterogeneities in the ZVI packed bed had developed as a result of ZVI corrosion and generation of corrosion by-products. This resulted in poor hydraulic conductivity, dead zones, and liquid short circuiting. The efforts were redirected towards understanding the rate of ZVI bed deterioration and the factors that promoted the presence of bacteria in particular water chemistry. Further modeling of the process was also conducted.
A SURVEY OF EUROPEAN SOIL PERCHLORATE LEVELS

GREGORY HARVEY
U.S. Air Force
1801 10th Street
Building 8, Suite 200
Wright-Patterson AFB, OH 45433
(937) 255-3276
gregory.harvey@wpafb.af.mil

CO-PERFORMERS: Greta Orris (U.S. Geological Survey); Andrew Jackson and Balaji Rao (Texas Tech University)

A sample set of European soils was acquired through the U.S. Geological Survey’s Geochemical Landscapes project from the Forum of the European Geological Surveys (FOREGS). The soil samples were collected as part of FOREGS Regional Geochemical Baseline Program. The soil samples were collected by the geological surveys of the European Union. Most samples represent composite samples from 0-25cm in depth or within a 50-200cm (C horizon) depth range; specific depth information for the samples could not be obtained. These soil samples were then extracted using distilled-de-ionized water at a 5:1 ratio (mass of water: mass of sample) followed by mixing the contents in a tumbler for 8 hours. The soil-water mixture was then centrifuged and filtered. Extracts were then analyzed for major anions and ClO$_4^-$ as described below. The moisture content of the individual samples was determined by drying in an oven at 105 °C for 24 hours and analyzed for perchlorate by ion chromatography tandem mass spectrometry (IC-MS-MS) at Texas Tech University. Major anions (Cl$^-$, NO$_3^-$, and Br$^-$) were analyzed following EPA Method 300.0. The analytical detection limit for major anions was 0.5 mg L$^{-1}$ and ClO$_4^-$ was 0.1 µg L$^{-1}$. The analysis of ClO$_4^-$ and major anions were performed in batches of 8, followed by a duplicate and spike from the batch. Soil perchlorate was found in a variety of different soil geochemistries, climates, and hydraulic regimes. The results obtained ranged from below the analytical detection level to approximately 95 ppb and are consistent with previous investigations of soils in North America. Many of the areas were farm areas, thus it is important to consider that the perchlorate might come from fertilizers, as well as human and animal waste.

This work is funded under SERDP Project ER-1435.
QUANTIFICATION OF PERCHLORATE AND CHLORATE REDUCING ENZYMES USING LIQUID CHROMATOGRAPHY AND MASS SPECTROMETRY (LC-MS/MS) BASED METHODS

REEMA BANSAL
Environmental Biotechnology Institute
University of Idaho
Food Research Center
Moscow, ID 84844-1052
(208) 885-5893
rbansal@vandals.uidaho.edu

CO-PERFORMERS: Lee A. Deobald, Ronald L. Crawford, and Andrzej J. Paszczynski (University of Idaho)

Perchlorate is used as a component of solid rocket and missile propellants, and adversely affects human health by interfering with iodine uptake. A number of microorganisms are known that can grow by anaerobic reductive dissimilation of perchlorate and chlorate into chloride; perchlorate reductase and chlorite dismutase are the two central enzymes involved in the reduction pathway. In research reported at the Environmental Biotechnology Institute, this project is using a qualitative and quantitative proteomics approach to obtain insight into the dynamics of microbial perchlorate and chlorate degradation in pure and enrichment cultures. A novel time-course cell lysis technique and a label-free LC-MS/MS-based mass spectrometry method are being used to enable simultaneous protein identification and quantification. This project quantitatively assesses the changes in the expression levels of the enzymes involved in perchlorate and chlorate degradation in several pure bacterial cultures (Dechloromonas hortensis, Dechloromonas agitata, Dechlorosoma sp. KJ, Azospira oryzae, Pseudomonas chloritidismutans, and Pseudomonas stutzeri) and environmental consortia grown under similar conditions using this approach. A known concentration of bovine serum albumin is being used as an internal standard for quantification. Quantification of the perchlorate reducing enzymes from different microbes can help to determine the most efficient pure strain(s) or natural consortia for in situ perchlorate bioremediation. This project is also using a proteomics-based approach to develop biomarkers that can be used to measure the exposure of the given environment to perchlorate contamination and determine the current perchlorate degradation status. Unique enzyme-derived peptide sequences will be detected and quantified even at very low concentrations (10^{-15}M). This pioneering technique can also be used in the future to develop protein biomarkers for monitoring of degradation processes for other recalcitrant pollutants in the environment.

This work is funded under SERDP Project ER-1562.
FIELD DEMONSTRATION OF THE MEMBRANE BIOFILM REACTOR FOR PERCHLORATE TREATMENT IN DRINKING WATER

DR. PATRICK EVANS
CDM
11811 NE 1st Street, Suite 201
Bellevue, WA  98005
(425) 453-8383
evanspj@cdm.com

CO-PERFORMERS: Daniel Berokoff (CDM); Dr. Bruce Rittmann (Arizona State University); David Friese and Ryan Overstreet (Applied Process Technologies); Ron Buchwald (East Valley Water District)

The membrane biofilm reactor (MBfR) is one of several technologies that have recently been demonstrated for the purpose of treating perchlorate in drinking water. This technology is physically comprised of numerous hollow fibers that are pressurized with hydrogen gas. Water containing perchlorate is pumped past the fibers and a biofilm of perchlorate-reducing bacteria, as well as others, grow on the exterior surface of the hollow fibers. The hydrogen serves as an electron donor for biological perchlorate reduction in the water.

The MBfR is being demonstrated at East Valley Water District (EVWD) well 28A in San Bernardino, California and the demonstration is funded by the Department of Defense Environmental Security Technology Certification Program (ESTCP), under Project ER-0541. In addition, downstream treatments—including aeration, media filtration, and chlorination—are being conducted for the purpose of producing drinking water.

The demonstration to date has indicated that while perchlorate destruction and attainment of drinking water quality was possible, excessive biofilm growth led to decreases in efficiency over time. The decreases in efficiency were attributable to a loss in effective membrane area caused by bridging of membrane fibers with biofilm. Various methods were tested to overcome this limitation. In the end, the membrane configuration used in the MBfR was determined to be suboptimal. Newer membrane configurations have been observed to overcome these limitations, and are planned for demonstration in the future.
**PERCHLORATE AND NITRATE BIOREMEDIATION IN VADOSE ZONE SOIL BY GASEOUS ELECTRON DONOR INJECTION TECHNOLOGY (GEDIT)**

**DR. PATRICK EVANS**  
CDM  
11811 N.E. First Street, Suite 201  
Bellevue, WA 98005  
(425) 453-8383  
evanspj@cdm.com

CO-PERFORMER: Rodney Fricke (Aerojet-General Corporation)

Perchlorate and nitrate in soil are potential sources of groundwater contamination. Currently, few, if any, in situ technologies are available for treatment of these contaminants in the deep vadose zone. For in situ bioremediation, a new process called gaseous electron donor injection technology (GEDIT) has been developed (U.S. Patent 7,282,149 and patent pending). This process involves injection of electron donors as a gas into the vadose zone in order to stimulate anaerobic biodegradation of perchlorate and nitrate. The technology is the reverse of bioventing, a process commonly used for bioremediation of hydrocarbons in vadose soil. GEDIT also has potential applicability to treatment of hexavalent chromium, radionuclides (i.e., uranium and technitium), and highly energetic compounds such as TNT, RDX, and HMX.

This technology is being demonstrated and validated through the Department of Defense Environmental Security Technology Certification Program (ESTCP) at the Inactive Rancho Cordova Test Site (IRCTS) near Sacramento, California. A mixture of hydrogen, liquefied petroleum gas (LPG or propane), carbon dioxide, and nitrogen was injected into vadose-zone soil for the first field demonstration of GEDIT. Results have shown that GEDIT is capable of distributing these electron donors to distances of at least 50 feet from the point of injection. Oxygen concentrations are also depleted, which is required for effective nitrate and perchlorate biodegradation. Soil sampling and analysis demonstrated that perchlorate and nitrate concentrations were reduced by over 90 percent within the target radius of influence when compared to pre-injection data. Reductions in perchlorate and nitrate concentrations were observed in varying soil moistures and lithologies. This work will address the field-scale results of the GEDIT demonstration at the IRCTS.

This work is funded under ESTCP Project ER-0511.
LAB-ON-A-CHIP SENSOR FOR MONITORING PERCHLORATE IN GROUND AND SURFACE WATER

DR. DON CROPEK
U.S. Army Corps of Engineers Construction Engineering Research Laboratory
2902 Newmark Drive
Champaign, IL 61822
(217) 373-6737
Donald.M.Cropek@usace.army.mil

CO-PERFORMERS: Dr. Charles S. Henry and Jana Gertsch (Colorado State University)

Lab-on-a-chip (LOC) devices offer the potential to integrate all steps of a chemical analysis method into a single inexpensive package that works autonomously, but few are plausible for the analysis of low abundance environmental contaminants. Our previous efforts have established one variant of LOC technology, microchip electrophoresis, as a viable sensing option for perchlorate at the sub-ppb level when samples contain low concentrations (sub-ppm) of interfering ions. When perchlorate water samples containing high levels of chloride and nitrate were tested, non-linear calibration curves were required and accuracy was greatly diminished. Here, a novel extraction chemistry that uses zwitterionic surfactants immobilized on either a conventional or membrane-based stationary phase (electrostatic ion chromatography) embedded at the injection end of a microfluidic device will be used to extract and concentrate perchlorate from contaminated water samples prior to analysis by microchip electrophoresis/contact conductivity.

During preliminary studies, it was found that perchlorate could be resolved from interfering anions in less than 3 minutes with detection limits at sub-ppb levels using direct injection of surface water. Tests using more complicated sample matrixes, such as wastewater, proved more difficult due to the general increase in sample conductivity and high concentrations of interfering compounds such as chloride and nitrate. To meet the needs of real-world environmental monitoring at military ranges, new chemistry must be adapted that allows use of miniaturized microchip capillary electrophoresis (MCE) techniques on more complex samples. This research presents a novel solution to this problem by integrating an extraction column for selective analyte binding using zwitterionic surfactants in the first dimension with MCE in the second dimension. A zwitterionic surfactant-coated stationary phase will bind perchlorate while passing common anions such as chloride and nitrate. After sample extraction, perchlorate will be eluted from the phase by changing the pH or eluting the surfactant with organic solvent. The MCE system uses a simple polymer microchip for electrophoresis with contact conductivity detection. A unique buffer system was developed with selective affinity for perchlorate over nitrate, sulfate, and chloride, providing very high resolution. Finally, although perchlorate is the model here, the proposed system is based on platform technology and could be extended to monitoring other munitions species of interest such as RDX, HMX, and TNT with appropriate introduction of modules with desired specificity to create an integrated multianalyte screening device.

This work is funded under SERDP Project ER-1706.
LARGE-SCALE DEMONSTRATION OF WEAK BASE ANION RESIN: REMOVING PERCHLORATE FROM DRINKING WATER

ANDREA DAVIS
430 West 5th Street
Suite 700
Panama City, FL 32401
(850) 914-3188
adavis@ara.com

CO-PERFORMERS: Edward Coppola (Applied Research Associates, Inc.); Francis Boodoo (The Purolite Company); Khalil Kairouz (Carollo Engineers)

Applied Research Associates, Inc. (ARA) and The Purolite Company have developed a perchlorate remediation ion exchange process using weak base anion (WBA) resins that are regenerable, as well as perchlorate-selective (patent pending). The ion exchange process takes advantage of the pH dependant nature of WBA resins. At low pH, functional groups on these resins have a positive charge (i.e., R-NH$_3^+$) allowing for anion exchange. However, at high pH, the resin functional groups lose a proton and are uncharged (i.e., R-NH$_2$) allowing for rapid and complete regeneration with high chemical efficiency. This regeneration approach is up to 50 times more efficient than regeneration of strong base anion resins, which typically require a large excess of salt brine. In addition, for many applications, the treated spent regenerating solutions generated contain no perchlorate.

Following two successful ESTCP pilot demonstrations including groundwater remediation and well-head treatment, the WBA process was selected for large-scale demonstration (1,000 gpm) at a well-site in the Rialto-Colton, California basin. ARA and Carollo Engineers (Carollo) are engineering the demonstration system and Carollo is performing construction management. Status of construction, integration with existing treatment equipment, and experimental design will be presented. Demonstration testing should be initiated no later than January 2010.

This work is funded under ESTCP Project ER-0312.
DEFINING MUNITION CONSTITUENT (MC) SOURCE TERMS IN AQUATIC ENVIRONMENTS ON DoD RANGES

PEI-FANG WANG
SPAWAR Systems Center Pacific
53475 Strothe Road, Code 71752
San Diego, CA 92152
(619) 553-9192
pei-fang.wang@navy.mil

CO-PERFORMERS: Robert George and Bill Wild (SPAWAR Systems Center Pacific);
Qian Liao (University of Wisconsin-Milwaukee)

The ability to characterize, and predict potential MC source loading and distribution has significant implications for Department of Defense (DoD) and Navy range sustainability initiatives. With such a capability, DoD would gain critical information for making scientifically defensible risk management decisions with regard to underwater unexploded ordnance (UXO) leave-in-place (LIP) mitigation and low order detonation vs. removal, or blow-in-place (BIP) options. In addition to explosive blast (safety) considerations, future regulatory emphasis may require a focus on the assessment of the ecological impact of MC on the marine environment. Defensible risk assessment, risk management, and risk communication relating to UXO or waste munitions on the seafloor requires characterizing, assessing, and predicting potential MC source loading and distribution of unexploded ordnance on underwater ranges.

This effort is focused on providing the information necessary for assessing fate and transport processes associated with munitions constituents leaching from breached shells into a shallow seawater environment. Our approach uses an empirical and modeling scenario wherein a single breached round is hypothetically introduced into the marine environment and subsequent MC release, fate, and transport is predicted. To understand the release behavior, we have developed a set of specific semi-analytical formulae that describe the leach rate of munitions constituents under various conditions of shell integrity and hydrodynamic situations. The MC leach rate is explicitly expressed within these formulae as a function of the following five parameters: (1) ambient current speed; (2) hydrodynamic dispersion coefficient; (3) size of the breach hole; (4) cavity volume inside the shell; and (5) dissolution rate of MC from the solid to aqueous phase. The semi-analytical leach rate formulae provide very important insight of MC release from breached shells under various shell integrity and hydrodynamic conditions. In order to make the semi-analytical solution fully verified under a broad range of conditions, and to validate the underlying assumptions and formulae used for this initial analytical/modeling study, modeling and empirical studies have been conducted. For the empirical effort, in-cavity circulation patterns were measured by Particle-Induced Velocimetry (PIV) and release rates of liquid dyes were measured by Laser-Induced Fluorometry (LIF). These measured circulation patterns and release rates were compared with both analytical and numerical results, with generally, excellent agreement, demonstrating that the semi-analytical function for MC release from breached shells has been confirmed. Release of MC from breached shells buried in sediment is currently under investigation. This work is funded under SERDP Project ER-1453.
MULTI-INCREMENT SAMPLING TO ESTIMATE THE ACCUMULATION OF PROPELLANT RESIDUES AT FIRING POINTS

MARIANNE WALSH
U.S. Army ERDC-CRREL
72 Lyme Road
Hanover, NH 03755-1290
(603) 646-4666
marianne.e.walsh@usace.army.mil

CO-PERFORMERS: Charles Ramsey (Envirostat, Inc.); Charles Collins, Alan Hewitt, Michael Walsh, and Thomas Douglas (CRREL)

Multi-increment sampling methods were optimized and applied to estimate the mass of energetic residues at howitzer and mortar firing points. The energetic compounds were 2,4-dinitrotoluene (2,4-DNT) and nitroglycerin (NG); ingredients in propellants used to fire projectiles down range. Research was initiated in 2001 at the Donnelly Training Area, Alaska where each of the firing points was found to have part-per-million concentrations of 2,4-DNT and/or NG. The nature and extent of deposition was unlike that on the impact areas, where energetic residues are usually undetectable except where ordnance has malfunctioned.

These studies also indicated that most of the residue was in the surface centimeter, but that the spatial distribution was extremely heterogeneous. Concentration estimates in co-located discrete samples varied by more than ten times. Discrete samples lacked sufficient mass to adequately represent the composition of the surface soil. There was also poor agreement between duplicate multi-increment field samples that were processed by the standard method SW846-8330.

Several studies were performed to minimize the uncertainty associated with field and laboratory sampling. The collection of replicate 50-increment samples, where the <2mm fraction was approximately 3kg, was adequate to estimate a statistically valid upper confidence limit of the mean concentration of 2,4-DNT from a 10,800m² sparsely vegetated firing point. Accurate estimation of 2,4-DNT required that the entire multi-increment sample be extracted with solvent or ground using a ring mill. Most of the 2,4-DNT was associated with fibers of the nitrocellulose-based propellant. These polymeric fibers resulted in unacceptably high laboratory subsampling error in samples that were either not ground or inadequately ground.

Vegetated firing points presented a much more complicated sample matrix. It was found that a mean concentration with a relative standard deviation of 25% could be obtained from 100-increment samples from a 10,000m² area. To acquire the increments, a coring devise was developed that provided consistent sampling depth and radius for each increment.

This poster will summarize the results from seven years of sampling at Alaskan firing points and assess how well multi-increment sampling methods met the sampling objectives.

The work is funded under SERDP Project ER-1481.
Sustainable management of training ranges requires understanding and predicting the transport and fate of ordnances components, whether they are propellants or explosives, in soil, surface and groundwater. Propellant formulations are usually composed of energetic compounds, binders and stabilizers, which are all susceptible to leak in the environment. Understanding the fate and impact of propellant formulations therefore implies determining various factors including volatilization, dissolution, sorption onto soils, (bio)transformation, photodegradation, and ecotoxicity for each component. In the present study, a new propellant formulation prepared by General Dynamics in Quebec, Canada, was assessed for its ability to dissolve and photodegrade in water. The formulation is composed of an energetic thermoplastic elastomer (ETPE: 8.9%), nitrocellulose (NC: 14.8%), triethyleneglycoldinitrate (TEGDN: 6.9%), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX: 51.3%), and a stabilizer (0.4%). Dissolution of all components from the formulation was measured in water at various temperatures. The only two water-soluble components, HMX and TEGDN, were then photolyzed at 300nm in water either individually or together and kinetics and degradation pathways were determined using high performance liquid chromatography with ultraviolet detector (HPLC-UV) and high performance liquid chromatography mass spectrometry (HPLC-MS). Photodegradation of HMX was accompanied by the formation of HCHO, NO\textsubscript{2} -, NO\textsubscript{3} -, NH\textsubscript{4} +, HCOO\textsuperscript{-}, methyledinitramine, and 4-nitro-2,4-diazabutanal, as previously observed from RDX photolysis. TEGDN photodegradation led to the concomitant formation of new monodenitrated compounds. The entire formulation was also photolyzed as a suspension in water and the various identified products were monitored in solution in order to assess the photodegradability of the formulation as a whole entity. Similar experiments were conducted in field groundwater to detect any potential enhancement by humic matter or other natural photosensitizers. The present data combined with additional transport, ecotoxicology, and biotransformation measurements will help understand the environmental fate and impact of this new propellant formulation.
BENCHMARK TOXICITY DATA FOR ENERGETIC MATERIALS FOR DEVELOPING THE TERRESTRIAL PLANT-BASED ECOLOGICAL SOIL SCREENING LEVELS (ECO-SSL)

SYLVIE ROCHELEAU, M.SC.A.
National Research Council Canada, Biotechnology Research Institute
6100 Royalmount Avenue
Montreal, QC H4P 2R2 CANADA
(514) 283-6447
sylvie.rocheleau@cnrc-nrc.gc.ca

CO-PERFORMERS: Roman Kuperman, Ph.D., Michael Simini, Ph.D., and Ronald T. Checkai, Ph.D. (U.S. Army Edgewood Chemical Biological Center); Myriamme Joly, B.Sc., Louise Paquet, B.Sc., Jalal Hawari, Ph.D. and Geoffrey I. Sunahara, Ph.D. (BRI); Sonia Thiboutot, Ph.D. and Guy Ampleman, Ph.D. (DRDC-Valcartier)

This project developed benchmark phytotoxicity data for nitrogen-based organic energetic materials (EM) hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaaazaisowurtzitane (CL-20), 2,4,6-trinitrotoluene (TNT), 1,3,5-trinitrobenzene (TNB), 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 2-amino-4,6-dinitrotoluene (2-ADNT), 4-amino-2,6-dinitrotoluene (4-ADNT), and nitroglycerin (NG) in accordance with ASTM 2002 and EPA 1996 protocols. Test species included dicotyledonous alfalfa (Medicago sativa L), and monocotyledonous barnyard grass (Echinochloa crusgalli (L) Beauv) and perennial ryegrass (Lolium perenne L). Toxicity tests were specifically designed to meet the criteria for EPA Ecological Soil Screening Level (Eco-SSL) derivation, outlined in the Eco-SSL Guideline (http://www.epa.gov/ecotox/ecossl/SOPs.htm). Plant species were exposed separately to individual EM in Sassafras sandy loam soil (SSL). Additional tests for RDX, TNT, and 2,4-DNT were conducted with Teller sandy loam soil to supplement the toxicity data established in studies with SSL. Both of these soils have physico-chemical characteristics (low organic matter and clay contents) that support high relative bioavailability of organic chemicals, according to Eco-SSL criteria. Studies were performed separately and independently for each EM weathered-and-aged in soil (hydrating/drying cycles in a greenhouse for up to three months). Plant growth data were analyzed using the appropriate regression models to determine the respective EM concentrations producing a 20 percent decrease (EC20) in the shoot growth (fresh and dry mass) endpoints compared with carrier (acetone) control. The terrestrial plant-based draft Eco-SSL value for each EM was calculated as the geometric mean of the EC20 values that were determined in the individual definitive tests. Using these benchmark phytotoxicity data, estimated interim draft terrestrial plant-based Eco-SSL values are (mg/kg): RDX (71), TNT (8), TNB (9), 2,4-DNT (6), 2,6-DNT (5), 2-ADNT (14), 4-ADNT (33), and NG (21), respectively. HMX and CL-20 were not toxic to the three plant species exposed up to the greatest concentration of 10,000 mg/kg. Benchmark data and the draft Eco-SSL values developed in these studies will be submitted to the EPA Eco-SSL Group for use in developing terrestrial plant-based Eco-SSL for the individual EM, and will be made available for use in Ecological Risk Assessment of terrestrial habitats at EM-contaminated sites. This work is funded under SERDP Project ER-1416.
DEVELOPMENT OF TOXICITY DATA FOR MUNITION COMPOUNDS TO SUPPORT TOXICITY REFERENCE VALUE DERIVATIONS FOR WILDLIFE

DR. MARK JOHNSON
U.S. Army Center for Health Promotion and Preventive Medicine
5158 Blackhawk Road
Attn: MCHB-TS-THE
Aberdeen Proving Ground, MD 21010-5403
(410) 436-5081
mark.s.johnson@us.army.mil

CO-PERFORMERS: C. A. McFarland, M. J. Quinn, Jr., M.A. Bazar, and E. M. LaFiandra (U.S. Army Center for Health Promotion and Preventive Medicine); L. G. Talent (Oklahoma State University); A. L. Hawkins (Naval Facilities Engineering Service Center); R. C. Porter (Noblis, Inc.); R. M. Gogal, Jr. (University of Georgia)

The Department of Defense (DoD) is the steward of extensive land holdings, many of which encompass land uses such as training (e.g., firing ranges), munition manufacturing, and demilitarization operations. Due to the large size of these areas, their relative habitat value, and the occurrence of munition compounds found in the soil, sediment, and surface water at these installations, it is important that the DoD can address issues associated with exposures to these substances to valued wildlife species. This work represents a tiered approach to providing these data, where needed for the most prevalent munition compounds and constituents for wildlife that would be useful in a risk assessment context. Wildlife laboratory models were developed and exposed to various munition compounds in a controlled regime and investigated for adverse effects. From these data, safe thresholds for exposure are determined for RDX, TNT, DNT, and amino-dinitotoluenes (A-DNT) for birds, mammals, reptiles and amphibians. Recent data for the A-DNT compounds are presented.

This work is funded under SERDP Project ER-1420.
THE EFFECTS OF 2,4-DNT, 2-ADNT, 4-ADNT, AND NG ON SOIL BIOLOGICAL PROCESSES

DR. ROMAN G. KUPERMAN
U.S. Army Edgewood Chemical Biological Center
RDCB-DRT-E E5641
5183 Blackhawk Road
Aberdeen Proving Ground, MD 21010-5424
(410) 436-4697
roman.kuperman@us.army.mil

CO-PERFORMERS: Ms. Sabine G. Dodard, Dr. Jalal Hawari, Ms. Sylvie Rocheleau, Ms. Myriam Joly, and Dr. Geoffrey I. Sunahara (Biotechnology Research Institute); Dr. Ronald T. Checkai, Mr. Carlton T. Phillips, and Dr. Michael Simini (ECBC)

This project investigated the effects of energetic materials (EM) 2,4-dinitrotoluene (2,4-DNT), 2-amino-4,6-dinitrotoluene (2-A-DNT), 4-amino-2,6-dinitrotoluene (4-A-DNT), and 1,2,3-trinitroglycerin (NG) on litter decomposition rates and enzymatic activity levels in Sassafras sandy loam (SSL). We assessed litter decomposition by exposing replicated clusters of Orchard grass (Dactylis glomerata) straw to individual EM treatments in soil for one-, two-, three-, four-, six-, and eight-month periods. The potential nitrification (PN), dehydrogenase (DH), acid phosphatase (AP), and N-acetyl-glucosaminidase (NAG) activities in the individual EM treatments were quantified during 8 to 25-hour assays. Decomposition rates were inhibited by 2,4-DNT in the 8830 mg/kg treatment throughout the eight-month study, and in the 1,274 mg/kg treatment lowest observed effect concentration (LOEC) after six and eight months; increased in the 4 and 62 mg/kg treatments after four and six months; all compared with control treatments. The EC20 and EC50 values for 2,4-DNT were 361 and 1,122 mg/kg, respectively. Decomposition rates were not statistically (p > 0.05) different among any 2-ADNT or 4-ADNT treatments by the end of the eight-month study. NG inhibited litter decomposition in 950 mg/kg (LOEC) and greater treatments compared with control. The EC20 and EC50 values for NG were 277 and 860 mg/kg, respectively. 2,4-DNT inhibited NAG (EC20=122 mg/kg), DH (EC20=16 mg/kg) and PN (LOEC=4 mg/kg) activities within the concentration range tested, but did not affect AP activity up to and including 8,830 mg/kg; the DH activity was the most sensitive endpoint for 2,4-DNT exposure. Soil treatment with 2-ADNT resulted in the respective EC20 values of 830, 406, and 175 mg/kg for the AP, DH, and PN activities; and the Maximum Allowable Toxic Concentration (MATC, geometric mean of the NOEC and LOEC values) of 355 mg/kg for NAG. Soil treatments with 4-ADNT yielded the respective EC20 values of 90, 28, and 113 mg/kg, for AP, DH, and PN activities; however 4-ADNT did not significantly (p > 0.1) affect the NAG activity at any concentration tested, yielding an unbounded NOEC of 13,000 mg/kg. NG inhibited the DH activity (EC20=34 mg/kg) at and above the lowest concentration tested compared with control, but did not affect NAG or PN activities (after 10 hours) at any concentration tested (NOEC>9,000 mg/kg). AP activity was inhibited by NG at 5,800 mg/kg (LOEC). These preliminary results suggest that soil contamination with either 2,4-DNT, 2-ADNT, 4-ADNT, or NG can alter the rates of biologically-mediated processes in soil by either inhibiting or stimulating the soil microbial activities.

This research is funded under SERDP Project ER-1416.
BENCHMARK TOXICITY DATA FOR ENERGETIC MATERIALS FOR DEVELOPING THE SOIL INVERTEBRATE-BASED ECOLOGICAL SOIL SCREENING LEVELS (ECO-SSL)

DR. ROMAN G. KUPERMAN
U.S. Army Edgewood Chemical Biological Center
RDCB-DRT-E E5641
5183 Blackhawk Road
Aberdeen Proving Ground, MD 21010-5424
(410) 436-4697
roman.kuperman@us.army.mil

CO-PERFORMERS: Dr. Ronald T. Checkai, Dr. Michael Simini, and Mr. Carlton T. Phillips (ECBC); Ms. Sylvie Rocheleau, Dr. Geoffrey I. Sunahara, and Dr. Jalal Hawari (BRI)

We developed benchmark toxicity data for nitrogen-based energetic materials (EM) hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetrinitro-1,3,5,7-tetrazocine (HMX), 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaaisowurtzitane (CL-20), 2,4,6-trinitrotoluene (TNT), 1,3,5-trinitrobenzene (TNB), 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 2-amino-4,6-dinitrotoluene (2-ADNT), 4-amino-2,6-dinitrotoluene (4-ADNT), and nitroglycerin (NG), separately exposing individual species of soil invertebrates to individual EM in natural soil. Toxicity testing for these EM was specifically designed to meet the criteria for Ecological Soil Screening Level (Eco-SSL) derivations outlined in the Eco-SSL Guideline (http://www.epa.gov/ecotox/ecoss/SOPs.htm). Testing was conducted in accordance with the International Organization for Standardization (ISO) protocols for soil invertebrates. Receptors tested included the earthworms Eisenia fetida (ISO 11268-2), collembolans Folsomia candida (ISO 11267), and potworms Enchytraeus crypticus (ISO 16387), each in Sassafras sandy loam (SSL) soil. Additional tests for RDX, HMX, TNT, and 2,4-DNT were conducted with Teller sandy loam soil to supplement the toxicity data established in studies with SSL. All of these soils have physico-chemical characteristics (low organic matter and clay contents) that support high relative bioavailability of organic chemicals, according to Eco-SSL criteria. Studies were performed separately and independently for each EM weathered-and-aged in soil (hydrating/drying cycles in a greenhouse up to three months). Reproduction endpoints data were analyzed using appropriate regression models to determine the EM concentration producing 20% decrease (EC20) in the measurement endpoint compared with carrier (acetone) control. In accordance with the Eco-SSL Guidelines, soil invertebrate-based draft Eco-SSL for each EM were calculated as the geometric mean of the EC20 values (minimum of three benchmark values) determined in the individual definitive tests. Using these benchmark toxicity data, estimated interim draft soil invertebrate-based Eco-SSL values are in mg/kg: RDX (72); HMX (16); CL-20 (0.09); TNT (15); TNB (18); 2,4-DNT (7), 2,6-DNT (18), 2-ADNT (43), 4-ADNT (18), and NG (13), respectively. Benchmark data plus draft Eco-SSL values developed in these studies will be submitted to the EPA Eco-SSL Group for use in developing soil invertebrate-based Eco-SSL for the individual EM, and will be made available for use in Ecological Risk Assessment of terrestrial habitats at EM-contaminated sites.

This research was funded under SERDP projects ER-1416, ER-1254, ER-1221, and ER-1210.
RESIDUAL DINITROTOLUENES FROM OPEN BURNING OF GUN PROPELLANT

DR. EMMANUELA DIAZ
Defence Research and Development Center – Valcartier
2459 Pie XI Blvd North
Quebec, QC G3J 1X5 CANADA
(418) 844-4000
emmanuela.diaz@drdc-rddc.gc.ca

CO-PERFORMERS: Dr. Sylvie Brochu, Dr. Isabelle Poulin, Mr. André Marois, and Ms. Annie Gagnon (DRDC-Valcartier)

A t the end of most military exercises involving large calibers ammunitions, such as 105- and 155-mm howitzers, there is a left-over quantity of unused bags of gun propellant. This is due to the fact that the propelling charges of various large caliber ammunitions are made of increments, which are selected depending on the target distance; the unused bags have to be destroyed on-site. This is done by open burning on the ground and this well-known procedure was demonstrated to be a source of pollution. For example, in 2001, 30,000 munitions of howitzer 105-mm ammunitions were fired in Canada on training ranges. As it was assumed that the propelling charges # 6 and 7 were not used during military training (i.e., 641 g per round or 50% in mass of the propelling mass), approximately 20,000 kg (641 g × 30,000) of single-base gun propellant were burned in Canadian ranges and training areas (RTA). Moreover, the single-base propellant formulation contains 10% of dinitrotoluenes (DNT) and, consequently, 2,000 kg of DNT were burned in 2001. As the combustion is rarely complete, this quantity is considered as a potentially significant source of pollution for RTA, and should be considered as a high potential threat. Past sampling campaigns at open burning sites have demonstrated that the burning of gun propellant generates a significant amount of contamination. The principal pollutants are 2,4- and 2,6-DNT, nitroglycerine (NG), and lead. These compounds are legislatively controlled by limit thresholds.

The objective of this study was to measure residual 2,4-DNT after the open burning of single-base gun propellant in live fire military exercises. Two sampling events and a trial were conducted to study the deposition rate of DNT from the burning of gun propellant. The February sampling event and the trial were conducted on snow, while the May sampling event was conducted on surface soil. Results showed that the combustion process is incomplete, and leaves residues on the soil and snow surfaces leading to a deposition of 1% of 2,4-DNT (or 0.1% of the initial mass of gun propellant burned). Finally, ashes from these trials are currently being used to evaluate the fate and behaviour of dinitrotoluenes in the environment through the project ER-1481. Residues were placed on large soil columns and the leaching of the selected contaminants will be studied.
PROTOTYPE TABLE FOR THE BURNING OF EXCESS ARTILLERY PROPELLANT BAGS

DR. SONIA THIBOUTOT
Defence Research and Development Center – Valcartier
2459 Pie XI Blvd North
Quebec, QC G3J 1X5 CANADA
(418) 844-4000, Ext. 4283
sonia.thiboutot@drdc-rddc.gc.ca

CO-PERFORMERS: Dr. Guy Ampleman, Dr. Isabelle Poulin, Mr. Michel Kervarec, Ms. Annie Gagnon, and Mr. André Marois (DRDC – Valcartier); Mr. Firmin Boucher (Munitions Environmental Test Centre – Valcartier)

Sampling work conducted in military training ranges across North America and deposition residue studies from the disposal of excess propellants conducted under SERDP Project ER-1481 have shown that the burning of excess propellant will result in accumulation of 2,4-DNT, NG, and other contaminants in the surface soil. To prevent the accumulation of these residues in the environment, this project proposed to build and test both a mobile and a fixed burn table. This poster will present the testing of the first fixed prototype burn table built and tested in Canada under this project. The objective was the fielding of a burn table that will replace the expedient burning of excess propellant directly on the surface soil. Researchers from DRDC Valcartier met with military users to discuss their needs and constraints and they agreed to provide DRDC with excess propellant bags for burn tests to be conducted in February 2009. The burn pan was constructed using high-temperature stainless steel, measured 3m by 1.5m with a height of 10cm, and was equipped with a lightweight reinforced aluminum removable cover. The height of the pan was kept low to avoid the risk of overloading the pan, which could lead to detonation of the propellant. A system involving an empty rectangular funnel at each end of the table was designed to ignite the propellant bed downwind using the accepted Canadian protocol which involves railroad warning flares and fuze blasting time cord. The burning test was conducted in February 2009, and over 830kg of excess single-base artillery propellant bags were burned over seven burns with residues amounting to <0.2% of the original DNT load. The burn pan reacted well to the high burning temperatures in these winter conditions with a cooling time of less than 15 minutes, leading to a high burning throughput and the collection of the post-burn residues was easy. A small proportion of propellant grains was projected outside the pan due to what we term the “pop-corn effect.” Other designs for pan prototypes are presently under development to minimize this phenomenon. Following this trial, the Canadian National Defence managers banned the burning of excess artillery propellant bags outside a controlled burn structure. Further testing with the newest prototypes will be conducted in Fall 2009 and Winter 2010.
METHOD 8330B AND MULTI-INCREMENT SAMPLING

MR. ALAN D. HEWITT
U.S. Army ERDC-CRREL
72 Lyme Road
Hanover, NH 03755
(603) 646-4666
Alan.D.Hewitt@erdc.usace.army.mil

CO-PERFORMERS: Marianne E. Walsh, Michael R. Walsh, and Susan R. Bigl (U.S. Army ERDC-CRREL); Sylvie Brochu (Defence Research and Development Canada–Valcartier); Mark A. Chappell (U.S. Army ERDC-EL); Charles A. Ramsey (EnviroStat, Inc.)

The initial product of ESTCP Project ER-0628 (Validation of Sampling Protocol and the Promulgation of Method Modifications for the Characterization of Energetic Residues on Military Testing and Training Ranges) was the documentation and subsequent November 2006 posting of Method 8330B (http://www.epa.gov/waste/hazard/testmethods/pdfs/8330b.pdf) on the U.S. Environmental Protection Agency website. This revised method was based on experiences gained through more than 50 training range studies conducted by ERDC-CRREL and DRDC-Valcartier under programs sponsored by SERDP (Projects ER-1155 and ER-1481), U.S. Army Garrison Alaska, and the Corps of Engineers’ Distributed Source program. Under these programs, Method 8330B addressed the uncertainty due to the heterogeneity of energetic residues on military training ranges, as well as in the samples collected to establish the presence and amount of these potentially hazardous constituents. Increased public awareness of the multi-increment sampling (MIS) protocol and necessity to thoroughly process samples to achieve reproducible and unbiased estimates for this class of compounds has helped to facilitate several programmatic changes. Recognition, technology transfer, and adoption of these scientifically sound methodologies were the principal objectives of this project.

State agencies that have already incorporated MIS or Method 8330B procedures in guidance documents for their environmental investigations include the Hawaii Department of Health Office of Hazard Evaluation and Emergency Response, and the Alaska Department of Environmental Conservation. In the military sector, the DoD Environmental Data Quality Workgroup has published guidance on implementing Method 8330B and the U.S. Army Corps of Engineers Environmental and Munitions Center of Expertise has published guidance regarding the selection of sampling areas and implementation of MIS for the Military Munitions Response Program (MMRP). Several agencies are currently in the process of developing Technical/Regulatory guidelines for incremental sampling methodology, including the Interstate Technology Regulatory Council (ITRC). Military organizations currently in the process of issuing or developing guidance for Method 8330B and MIS include the Army Environmental Command (AEC), the United States Army Military Munitions Response Program (in their Remediation / Feasibility Study Guidance), and the United States Department of the Navy.

This presentation will recognize the government agencies that adopted and further developed the application of this innovative technology for their environmental stewardship programs.
DEVELOPMENT OF A CONTINUOUS ELECTROCHEMICAL REACTOR FOR THE DESTRUCTION OF MUNITIONS CONSTITUENTS IN WATER

JARED JOHNSON
U.S. Army Corps of Engineers-Engineer Research and Development Center
3909 Halls Ferry Road
ATTN: EP-E
Vicksburg, MS 39180
(601) 634-3050
jared.l.johnson@usace.army.mil

CO-PERFORMERS: Dr. David Gent, Deborah R. Felt, and Dr. Steven L. Larson (U.S. Army Corps of Engineers-ERDC); Gregory O’Connor and Benjamin Smolinski (U.S. Army ARDEC)

Direct electrochemical reduction has been shown capable of destroying munitions constituents such as RDX, TNT, and DNT in aqueous solutions. This effort developed a functional continuous flow system based on direct electrochemical reduction to provide effective treatment of munitions constituents in wastewater. Initial batch testing was conducted to determine the efficacy of electrochemical reduction of RDX in a process wastewater matrix. Parameters such as reactive surface area, mass transfer, and current density were investigated at a small scale (500 mL). First order reaction kinetics were evaluated in batch systems varying current density and electrode surface area. Half-lives for RDX decomposition (from 10,000 µg/L to < 20 µg/L) were on the order of 15 minutes at optimum current density. The first order rate of reaction approached a maximum value 0.05 min⁻¹ as current density was increased, indicating mass transfer control of the reaction. Batch reaction rate information was used to design pilot-scale reaction systems in both batch and continuous modes based on the observed mass transfer-based kinetic rate, k_m. Two reactor configurations were evaluated: (1) a batch reactor tank with rotating electrode impellers and (2) a continuous flow reactor packed with electrode plates.

The rotating electrode batch reactor provided good mass transfer characteristics and efficient destruction of RDX. It was able to reduce RDX from 41 mg/L to 0.02 mg/L in 6 hours of treatment time. This system is very well suited for small flow and intermittent flow rates of wastewater. The packed electrode reactor was able to remove 97.4% of the RDX from an influent stream of 10-20 mg/L at a flow rate of 520 L/d. This was accomplished with an energy cost of less than 50 cents per day, or $3 per 1,000 gallons. Laboratory testing at scales of ½ L, 2 L, and 10 L yielded insight into the key operational parameters of a continuous packed electrode treatment system. A pilot system was constructed incorporating this knowledge. The system contains 18.9 m² of total electrode surface area in a 19 L rectangular flow channel. It is capable of removing 90% of the RDX from an aqueous waste stream at a flow rate of 464 gpd with a power input of 4.32 kW-hr per day. The system developed by this effort provides a proven electrochemical treatment for wastewaters containing munitions constituents.
TOXICITY TO FOLSOMIA CANDIDA OF ENERGETIC MATERIALS  
WEATHERED-AND-AGED IN A NATURAL SANDY SOIL

CARLTON T. PHILLIPS  
U.S. Army Edgewood Chemical Biological Center  
5183 Blackhawk Road  
Aberdeen Proving Ground, MD  21010-5424  
(410) 436-4694  
carlton.phillips@us.army.mil

CO-PERFORMERS: Dr. Ronald T. Checkai, Dr. Roman G. Kuperman, and Dr. Michael Simini  
(U.S. Army Edgewood Chemical Biological Center)

This project investigated the toxicity of the energetic materials (EM) 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 1,3,5-trinitrobenzene (TNB), 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaaazaisowurtzitane (HNIW; CL-20), and nitroglycerin (NG), respectively, to the soil collembolan species *Folsomia candida*.

These studies were designed to develop toxicity benchmarks based on the reproduction endpoint, production of juveniles, for use in deriving Ecological Soil Screening Level (Eco-SSL) values for Ecological Risk Assessment (ERA) of explosives at contaminated sites; plus, an acute endpoint, adult survival, not used in Eco-SSL derivation. All ecotoxicity tests were conducted under conditions maximizing compliance with Eco-SSL evaluation criteria, using Sassafras sandy loam soil that supports relatively high bioavailability of EM. Studies were performed separately and independently using EM weathered-and-aged in soil (hydrating/drying cycles in a greenhouse up to three months) to more closely approximate exposure and effects in the field. Toxicity testing was performed using the Inhibition of Reproduction of Collembola by Soil Pollutants method (ISO 11267:1998). The measurement endpoints, production of juveniles and adult survival, were both assessed after the 28-day exposures to the respective EM compounds weathered-and-aged in soil. Negative (no EM added), carrier (acetone), and positive (boric acid) control treatments were included. Analytically determined concentrations for each EM soil treatment were correlated with the respective measurement endpoints to develop toxicity benchmarks on the basis of concentration-response relationships. Data were analyzed using linear and nonlinear regression models to estimate the EC20 and EC50 values for those endpoints. Results showed that the order of toxicity (greatest to least) based on the preliminary EC20 values (mg/kg) for production of juveniles by *F. candida* was: 2,6-DNT (1) ≈ CL-20 (1) ≈ NG (1) > 2,4-DNT (15) > TNT (50) ≈ TNB (50) > RDX (100) > HMX (1,000). The order of EC50 values (mg/kg) for the same reproduction endpoint was: 2,6-DNT (4) > NG (6) > 2,4-DNT (23) > CL-20 (60) ≈ TNT (60) > TNB (90) > RDX (800) > HMX (10,000). Benchmark data developed in these studies will be submitted to the EPA Ecological Soil Screening Level (Eco-SSL) Group for use in developing soil invertebrate-based Eco-SSL values for the individual EM, and will be made available for use in ERA of terrestrial habitats at EM-contaminated sites.

This work is funded under SERDP Projects ER-1416, ER-1254, CU-1221, and CU-1210.
ROLE OF NITRITE IN NITROGLYCERIN (NG) INDUCED MICROPHTHALMIA IN QUAIL EMBRYOS

GHALIB BARDAI
National Research Council Canada, Biotechnology Research Institute
6100 Royalmount Avenue
Montreal, QC H4P 2R2 CANADA
(514) 283-6447
ghalib.bardai@cnrc-nrc.gc.ca

CO-PERFORMERS: Barbara F. Hales (McGill University); Jalal Hawari and Geoffrey I. Sunahara (National Research Council Canada, Biotechnology Research Institute)

Nitroglycerin (NG), a nitrate ester, is used by the military as a solid propellant in the manufacturing of explosives, and has resulted in widespread environmental release. Biotic transformation of NG results in the release of nitrite, which has been shown to post-translationally modify proteins and modulate gene expression. For example, we have shown that treatment with NG of quail embryos in ovo during a specific stage of organogenesis induces eye malformations. It is important to investigate the biochemical mechanisms underlying these teratological effects. We hypothesize that metabolism of NG by glutathione-S-transferases (GST) releases nitrite, and the nitration of macromolecules triggers ectopic aberrant signaling in the embryo, leading to eye malformations. Eye malformations were induced experimentally by treating the quail embryo ex ovo with NG (10 µg/µl; n=10) on one side of the 33 hour-developing eye field. We identified the NG metabolites formed in quail embryos using liquid chromatography/mass spectrometry (LC/MS), and purified the GST isozymes capable of metabolizing NG using reverse phase–high performance liquid chromatography (RP-HPLC). To determine the presence of nitrated proteins in NG-treated embryos, immunohistochemistry and western blots were used. Data indicated that embryos treated ex ovo with NG presented with a malformed eye. The LC/MS studies showed that embryos metabolized NG to both 1,2 and 1,3 glycerol dinitrate (1,2- and 1,3-GDN). GST isozyme purification and identification using RP-HPLC, sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE) and MS revealed the presence of multiple α- and μ-type GST. In fact, GSTα was the predominant family responsible for producing nitrite from GTN. Using a polyclonal 3 nitrotyrosine antibody (anti 3-NT) revealed the presence of nitrated proteins in histological sections of the treated eye. Western blotting analysis using a monoclonal anti 3-NT antibody demonstrated that multiple proteins were nitrated in treated embryos. These data indicate that GSTα can metabolize NG to nitrite, which post-translationally modifies proteins. This suggests a role for protein nitration as a possible cause of NG-induced eye malformation.

This work was funded under SERDP Project ER-1416.
A considerable amount of research has been performed in the last 15 years to evaluate practical remedial techniques for the treatment of organic explosives in soil and groundwater. The four organic explosive-related compounds which are of major environmental concern at army ammunition plants, ranges, and other locations are RDX, HMX, TNT, and DNT. All of these compounds possess a single-ringed organic structure, and contain nitrogen groups. Most of the earlier research and applications have focused on biological treatment (biotreatment) of these compounds using anaerobic (reductive) or sometimes aerobic (oxidative) conditions. While soil and groundwater are amenable to modification to induce reducing or oxidizing conditions, biotreatment has some limitations. Biotreatment generally takes a much longer time for contaminant destruction compared to chemical treatment and may not work at high concentrations.

Tetra Tech has recently designed and implemented two large-scale remediation efforts to treat organic explosives in soil via the process of alkaline hydrolysis at the Volunteer Army Ammunitions Plant (VOAAP), Chattanooga, TN and the Iowa Army Ammunitions Plant (IAAAP), Middleton, IA. These are the first field applications of this rapid cleanup technology for organic explosives of this magnitude.

At the VOAAP, over 100 tons of TNT and DNTs in 100,000 tons of soil have been treated. At the IAAAP, over 5,000 cubic yards of RDX- and TNT-contaminated soil have been successfully treated. At the VOAAP, soil is now being treated in-situ, making its implementation more sustainable and environmentally safer and green. Plans are currently underway to treat contaminated media at IAAAP in-situ as well. Bench-scale tests on saturated soil at VOAAP also indicated strong successes in this type of media, paving the way for groundwater treatment using alkaline hydrolysis.

This poster will present results of bench-scale, pilot-scale, and full-scale systems. Kinetic rates of treatment and dependant environmental factors will be described. These include moisture content, pH levels, temperature, and other factors. Design implementation processes including pH amendments, mixing procedures, moisture addition, equipment, material handling and storage, and effectiveness of monitoring procedures will also be presented.
FIELD PORTABLE GC-MS FOR SEMI-VOLATILE COMPOUND ANALYSIS IN GROUNDWATER

DR. ANTHONY BEDNAR
U.S. Army Corps of Engineers-Engineer Research and Development Center-
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39183
(601) 634-3652
Anthony.J.Bednar@usace.army.mil

CO-PERFORMERS: Dr. Robert Kirgan (ERDC-EL); Amber Russell and Charolett Hayes (Spec-Pro); Dr. Tom Georgian and David Splichal (CEHNC-EM-CX);
Dr. Louise Parker (ERDC-CRREL)

The Environmental Security Technology Certification Program (under Project ER-0922) has sponsored an evaluation/demonstration of the in-field analysis of groundwater samples using a field portable Gas Chromatograph-Mass Spectrometer (GC-MS) instrument. The production and use of munitions at military installations can result in explosives contamination in soil and groundwater. This contamination can be an environmental concern even long after training or manufacturing activities have ceased. Therefore, the concentration of munitions constituents in groundwater is an ongoing concern that requires periodic monitoring.

The traditional monitoring scenario for explosives in groundwater requires that large amounts of sample (2 to 4 liters) be shipped overnight, under chain of custody control, to a fixed laboratory for analysis by published methods, such as SW-846 8330B. Additionally, the samples must be packed on ice and shielded from light to prevent any degradation of the samples during transport and storage. Once in the laboratory, the typical analysis time can be as long as 47 days for groundwater and data reporting times can be even longer. This process results in data being unavailable to the customer for one to two months. Also, the expenses incurred for shipping large volumes of sample can be substantial.

The current project uses a field portable GC-MS for on-site analysis of explosives in groundwater. This methodology provides near real time data (i.e., within 1.5 hours of sampling). Furthermore, the use of the mass spectrometer as a detection technique provides absolute confirmation of the munitions constituents, and provides a means to identify unknown compounds present in the sample that might otherwise provide false positive detections. Detection limits for commonly used explosives, including RDX and TNT, are less than 1 μg/L when coupled with sample preparation by solid phase extraction (SPE). The objective of this project is to develop the guidance needed for deployment of field portable instrumentation that will have the capability to analyze for munitions constituents found on military installations, and provide laboratory-quality data.

This poster will describe results and challenges associated with this research, and applications for its use.
ENHANCING BACTERIAL DEGRADATION OF RDX IN THE RHIZOSPHERE

DR. STUART STRAND
University of Washington
Box 352700
Seattle, WA 98195
(206) 543-5350
sstrand@u.washington.edu

CO-PERFORMERS: David Stahl (University of Washington,); Astrid Lorenz, Liz Rylott, and Neil Bruce (University of York)

The use of explosives on live fire training ranges has resulted in widespread contamination of large areas of land and groundwater. Bacteria are capable of degrading a wide range of xenobiotics, but the bacterial activity in soil or groundwater is often too inefficient to remove the explosives effectively. The rhizosphere is a complex system of plant root-bacteria interaction, and bacteria have been shown to be highly abundant in the rhizosphere soil.

The objective of this project was to enhance rhizosphere bacterial degradation of RDX by modification of plant-bacterial interactions through root exudate alterations. To this end, root colonising bacteria containing XplA, the gene conferring the ability to degrade RDX, were engineered and isolated from the non-rhizospherial bacterium *Rhodococcus rhodochrous* 11Y. This was done by cloning XplA into pME6010, a vector known for its stability in bacteria in the absence of antibiotic selective pressure, and constitutively expressed under the tac promoter. The construct containing XplA was transformed into the root colonizing strains *Pseudomonas fluorescens* WCS365 and F113 and the ability to degrade RDX confirmed using resting cell assays. Alfalfa seedlings were then inoculated with the modified *Pseudomonas* strains and grown in quartz sand dosed with RDX in a gnotobiotic environment. Four weeks after inoculation, 70% of the RDX had been removed from the rhizosphere and the bulk sand from plants inoculated with bacteria expressing XplA. Significantly less removal of RDX was seen in the samples from plants inoculated with bacteria containing the empty vector or from sand samples inoculated with XplA-expressing bacteria but without plants. The number of bacteria growing on the roots increased after colonization; however, there was a substantial loss in bacterial numbers carrying the plasmid expressing XplA.

This work is funded under SERDP Project ER-1504.
REMEDIATION CHALLENGES AND SUCCESSES FOR RDX AND TNT IN SOIL: FIELD-SCALE BIOTREATMENT AND CHEMICAL TREATMENT AT THE IOWA ARMY AMMUNITION PLANT

STEVE MUFFLER, P.G., C.G.W.P.
Tetra Tech, Inc.
800 Oak Ridge Turnpike
Suite A-500
Oak Ridge, TN  37830
(703) 885-5448
michael.lepuil@tetratech.com

CO-PERFORMERS: Ronnie Britto, Ph.D., P.E., Madhu Patel, Michael LePuil, Ph.D., and Rick Arnseth, Ph.D., P.G. (Tetra Tech, Inc.)

Explosive-contaminated soil has been stockpiled in an on-site treatment cell for testing for the past 10 years at the Iowa Army Ammunition Plant (IAAAP, Middletown, Iowa). In 2008, over 15,000 cubic yards of soil were targeted for treatment with a remedial goal of a cumulative human health risk of 10-6 or below. Here, the sequential field-scale application of two different treatment approaches and corresponding results are discussed. First, enhanced bioremediation with high fructose corn syrup (HFCS) was implemented in 2008 following the successful completion of a field-scale pilot test in 2006. Although very limited information exists for its application to soil bioremediation, HFCS was used to stimulate biologically-induced reduction of Royal Demolition Explosive (RDX) and 2,4,6-trinitrotoluene (TNT) in soil, as it has been shown to promote the anaerobic biodegradation of these explosives in groundwater at the site. Trend analysis was used to demonstrate reductions in RDX, TNT, and cumulative human health risk in conjunction with the production of daughter products. Monitoring conducted for a 75-day period clearly demonstrated that RDX could be more easily biodegraded than TNT. Recalcitrance of TNT to biotreatment, particularly at high concentrations, caused bioremediation with HFCS to be discontinued in favor of chemical remediation for the remainder of the soils. Chemical treatment was performed via alkaline hydrolysis using sodium hydroxide (NaOH) as the amendment. Alkaline hydrolysis is a chemical treatment process whereby a strong alkaline agent (e.g., NaOH) is added to the soil to raise its pH to very high levels and produce an excess of hydroxyl ions with very potent chemical destructive ability. Hydroxyl ions react by nucleophilic substitution of nitro and methyl groups in nitroaromatic compounds to produce innocuous end-products such as formate and nitrite. NaOH was added to the soil treatment areas and thoroughly mixed into the clay-rich glacial till soil to ensure homogeneous distribution of the amendment in the soil. To facilitate rapid destruction of RDX and TNT, the soil pH was raised from baseline conditions (pH 6-8) to greater than 12.5 at an amendment rate of 2% (weight by weight), to produce a large excess of hydroxyl ions. Results demonstrate that alkaline hydrolysis is capable of completely destroying RDX and TNT (at concentrations up to 1,500 mg/kg) within 5 days. Findings from this effort indicate that rapid destruction of explosives to levels below remedial goals via alkaline hydrolysis can be achieved even in clay-rich glacial tills, where significant heterogeneities exist.
PHYTOREMEDIATION FOR THE CONTAINMENT AND TREATMENT OF ENERGETIC AND PROPELLANT MATERIAL ON TESTING AND TRAINING RANGES

DR. JERALD SCHNOOR
The University of Iowa
4119 Seamans Center
Iowa City, IA 52242
(319) 335-5649
jerald-schnoor@uiowa.edu

CO-PERFORMER: Travis Anderson (University of Iowa)

Phytoremediation, the use of green plants for the in situ treatment of contaminants, may be the most appropriate means of treating energetic compounds such as RDX, HMX, and TNT which contaminate many military testing ranges. Plants and associated bacteria have been shown to degrade these compounds to innocuous end products either through uptake and transformation in stems and leaves, or through degradation in the rhizosphere. Eglin Air Force Base (EAFB) near Niceville, FL has been established as the site where these phytoremediation processes will be explored. The soils collected from EAFB, Lakeland Soil and Dorovan Muck, have been characterized and analyzed for their physical-chemical properties and behavior with TNT and RDX. TNT is slightly more hydrophobic and therefore sorbs readily to both soils and most strongly to the organic-rich, Dorovan Muck soil. RDX was shown to sorb to Dorovan Muck, but does not sorb readily to the sandy Lakeland Soil. Native or non-invasive plants, including Panicum vigratum (Alamo Switchgrass), Popsalum notatum Pensacola (Bahiagrass Pensacola), and Populus deltoides x nigra DN34 (poplar), were combined with native soils in a microcosm study to assess phytoremediation of TNT. Soil type and aging play important roles in biodegradation of TNT. Another microcosm study performed with unplanted soils has shown that RDX and HMX are recalcitrant under moist, aerobic conditions in the laboratory. The role of the transferase enzymes, glutathione-S-transferase (GST) and glucosyltransferase (GT), in phytoremediation of TNT was investigated using gene expression analysis in Populus deltoides x nigra DN34 (poplar) and Glycine max (soybean).

The field-based phytoremediation sustainability project at EAFB is well under way. The overall purpose of this research effort is to determine whether phytoremediation can be used to prevent the leaching of energetics at EAFB, thus making the site more sustainable. Also, an attempt will be made to understand the mechanisms by which RDX, HMX and TNT are actually degraded in soil at EAFB, either by plant uptake and transformation or by microbial degradation in the rhizosphere. Three plots (two impacted and one “control”) located in the vicinity of the open detonation area have been planted with Bahiagrass Pensacola (Paspalum notatum) sod. Bi-annual sampling will take place over 2 years to determine the effectiveness of Bahiagrass Pensacola on degrading energetic compounds. Soil and plant samples will be analyzed for contaminant concentrations (with time), and measurements of biomass per square meter, root density, and root depth will be performed in the bi-annual samples. This work is funded under SERDP Project ER-1499.
ENGINEERING TRANSGENIC GRASSES FOR IN SITU TREATMENT OF RDX AND TNT

NEIL C. BRUCE
University of York
Centre for Novel Agricultural Products
York, YO10 5YW UNITED KINGDOM
+44 1904 328777
ncb5@york.ac.uk

CO-PERFORMERS: George Zhang, Sharon Doty, and Stuart Strand (University of Washington); Antonio Palazzo (ERDC-CRREL); Elizabeth Rylott (University of York)

Severe contamination of land and groundwater by explosives has occurred following decades of military activity on live-fire training ranges. The explosive hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) is both resistant to degradation and highly mobile through soils and groundwater. As a result, contamination of firing ranges is now proving to be a significant threat to drinking water sources such as those close to the Massachusetts Military Reservation. At present, there are no cost-effective processes to contain RDX or remediate large areas of contaminated vegetated land on training ranges. The objective of this project is to engineer perennial grass species for the phytoremediation of RDX from soil leachate to prevent contamination of groundwater on military training ranges. To achieve this goal, this work is investigating the expression in perennial grasses of microbial explosives degrading enzymes.

Creeping bentgrass (*Agrostis stolonifera*) was used as a model perennial grass system. The 2,4,6-trinitrotoluene (TNT) transforming nitroreductase *nfsI* and the RDX degrading cytochrome P450 system *XplA/B* were transformed into creeping grass with a biolistic co-transformation method. From 8 dishes of transformed embryogenic calli that were induced from nodes of a single creeping bentgrass strain, 84 hygromycin resistant callus lines were obtained. The integration and expression of the *nfsI* and *XplA* genes were confirmed by PCR assays and western blot analysis, respectively. Results of TNT and RDX stress tests with culture medium supplemented with TNT or RDX indicated that 12 transgenic lines showed clear TNT toxicity tolerance at 0.15 mM TNT level and 7 transgenic lines showed increased growth using RDX as the sole nitrogen source at 165 ppm. Transgenic creeping bentgrass lines expressing *XplA* were observed to efficiently remove RDX from hydroponic culture and contaminated soil. Three robust species of wheatgrass were subsequently selected for potential use in the field, western (*Agropyron smithii*), slender (*A. trachycaulum*) and Siberian (*A. fragile*), two of which are native. The wheatgrasses have broad applicability in a wide geographic range that includes 42 military facilities in the Intermountain West, they are not invasive, and they have been shown to germinate and establish rapidly. Western wheatgrass is a rhizomatous and relatively low growing native plant that is less likely to carry a fire and is also more resilient to training activities. Progress has been made towards engineering western wheatgrass. An optimal induction and propagation system of embryogenic callus has been developed and the subsequent regeneration of transgenic western wheatgrass lines from callus cultures has now been firmly established.

This work is funded under SERDP Project ER-1498.
DETOXIFICATION OF THE EXPLOSIVE TNT BY ENDOGENOUS ENZYMES IN
ARABIDOPSIS

NEIL C. BRUCE
University of York
Centre for Novel Agricultural Products
York, YO10 5YW UNITED KINGDOM
+44 1904 328777
ncb5@york.ac.uk

CO-PERFORMERS: Elizabeth L. Rylott, Emily Beynon, Fernando Gandia-Herrero,
Helen Sparrow, and Astrid Lorenz (University of York)

There is a great deal of work documenting the global contamination, general toxicity, and
microbial metabolism of the explosive compound 2,4,6-trinitrotoluene (TNT) in the
environment; however, relatively little is currently known about the enzymes mediating the
detoxification of TNT in plants. Additionally, phyto remediation is being increasingly proposed
as a viable alternative to conventional remediation technologies. Developing this potential
alternative also requires an understanding of the innate enzymology of TNT detoxification in
plants.

This project characterized the involvement of enzyme families in the classic activation and
conjugation phases of xenobiotic detoxification in the model species Arabidopsis thaliana. The
Old Yellow Enzyme plant homologues, oxophytodienoate reductases (OPRs), were upregulated
in response to TNT and it was shown that purified forms of the three predominantly expressed
OPR OPR1, 2, and 3 are able to activate TNT to yield nitro-reduced TNT derivatives, with
OPR1 additionally producing the aromatic ring-reduced products hydride and dihydride
Meisenheimer complexes. Specific uridine diphosphate glycosyltransferases (UGT) are also
upregulated in response to TNT. Following activation, these purified UGT conjugated the TNT-
transformation products, 2- and 4- hydroxylaminodinitrotoluene, exhibiting individual bias for
either the 2- or 4-isomer. For both 2- and 4- hydroxylaminodinitrotoluene substrates, two mono-
glucose conjugate products, confirmed by HPLC-MS-MS, were observed. Further analysis
indicated that these were conjugated by either an O- or C-glucosidic bond. The other major
compounds in TNT metabolism, aminodinitrotoluenes, were also conjugated by the UGT, but to
a lesser extent.

Arabidopsis lines over expressing specific OPR and UGT exhibited significantly enhanced
tolerance to TNT, and this project’s results show that these enzymes play an integral role in the
biochemical mechanism of TNT detoxification by plants.

This work is funded under SERDP projects ER-1498 and ER-1318.
REAL WORLD MUNITIONS CONSTITUENTS RESULTS FOR YOUR RESEARCH CONSIDERATION

MRS. DEBORAH WALKER
U.S. Army Engineering Support Center Huntsville
CEHNC-CX-MM
P.O. Box 1600
Huntsville, AL 35807
(256) 895-1796
deborah.d.walker@usace.army.mil

Since 2005, the U.S. Army Corps of Engineers (USACE) has been conducting a programmatic Site Inspection (SI) effort under the Military Munitions Response Program (MMRP) for Formerly Used Defense Sites (FUDS) on behalf of the U.S. Army. As of the fourth quarter of fiscal year 2009, approximately 785 SIs have been funded and are underway throughout the United States and its territories. This work will show the results of munitions constituents (MC) sampling efforts for the program for energetics, metals, and perchlorate. Approximately 472 sites had been completed as of July 27, 2009, 414 of which included MC sampling. More than 6000 samples have been collected to date. Approximately 60 of these sites have been sampled using the incremental sampling technique in the Southwest, Hawaii, and Idaho. This yields quite a data set for consideration for future research and development for further characterization and cleanup on FUDS.
MILITARY ranges in different parts of the world are contaminated with propellants and explosive residues. Explosives such as RDX pose a significant risk to human health and the environment due to their ability to move through soil into bodies of water. Other RDX-contaminated areas can be found at manufacturing, storage and disposal facilities including areas not related to military exercises like mining, construction and snow avalanche management.

Solving soil and water pollution arising from the use of RDX has become a priority due to the toxic nature of its residues, and a number of chemical and physical techniques have been tried in the past without the right levels of success. Mainly driven by the U.S. (SERDP) and the Canadian military, new genomic research aimed at identifying genes and processes involved in the degradation of RDX is being used to develop tools to monitor and improve the biodegradation of RDX and other nitramine explosives.

As with other recent genomic technologies, this emerging know-how may be technically promising, however, social acceptability and adoption are as yet untested.

Several of the social and policy implications of RDX contamination in North America were investigated in this project. This research will also identify some of the public perceptions and concerns about RDX pollution and about genomic bioremediation technologies when used by the military.

As part of this research, key individuals, institutions, and issues were identified and mapped in order to facilitate the development of appropriate products and policies that are better accepted by stakeholders and the public.

The adoption of genomic technologies for RDX remediation may face an uphill battle if the right communication and consultation processes are not implemented.
VERIFICATION OF METHODS FOR ASSESSING THE SUSTAINABILITY OF MONITORED NATURAL ATTENUATION (MNA)

MS. CARMEN LEBRÓN
Naval Facilities Engineering Command-Engineering Service Center
EV411
1100 23rd Avenue
Port Hueneme, CA 93043
(805) 982-1616
carmen.lebron@navy.mil

CO-PERFORMERS: Dr. Francis H. Chapelle (U.S. Geological Survey); Dr. Jack C. Parker (University of Tennessee); Drs. Mark A. Widdowson and John T. Novak (Virginia Tech)

When MNA becomes part of a long-term remediation strategy, it is assumed that natural attenuation processes will continue over the system’s operational lifetime. The objective of this project is to validate an integrated methodology for assessing the long-term sustainability of MNA at chlorinated ethene sites. The methodology uses the comprehensive solute transport code SEAM3D, Sequential Electron Acceptor Model 3D, to assess sustainability by integrating effects of DNAPL source depletion, advection, dilution, dispersion, volatilization, abiotic reactions, and microbial transformations. At chlorinated solvent sites where only indigenous carbon is present, sustainable reductive dechlorination is controlled by fluxes of electron acceptors and donors from recharge and dissolution of solid phase organic carbon within the aquifer. Long-term MNA sustainability requires a flux of bioavailable organic carbon (BOC) over time sufficient to consume dissolved oxygen and to maintain conditions favorable for reductive dechlorination over the project life cycle. This approach utilizes a simple but novel method to quantify BOC and a field-scale source-zone depletion (SZD) function to estimate contaminant fluxes and remediation time-frame. The project’s aim is to validate the BOC method by demonstrating correlations with the rate and extent of reductive dechlorination at 12 sites representing a wide range of geochemical conditions and source characteristics. Initial results suggest a positive correlation between BOC concentrations and amino acid concentrations derived from aquifer sediment samples. Because amino acids are known to be relatively biodegradable, this finding suggests that the procedure used to measure BOC—a much simpler procedure than measuring concentrations of compounds such as amino acids—is a useful indicator of bioavailable carbon in soils and aquifer sediments. Using contaminant monitoring data from the study sites, a positive correlation was also observed between BOC concentrations and the rate and extent of reductive dechlorination. Validation of the SZD function and demonstration of the overall MNA sustainability framework will be performed on a subset of project sites. Preliminary results on synthetic data sets indicate that DNAPL source model calibration to near-source concentrations or fluxes alone yields estimates of future mass discharge rates that are subject to large uncertainty. Prediction accuracy improves and uncertainty decreases by calibrating to whole plume data with longer time series and with source flux measurements, especially if available for multiple depths. More complex models (e.g., calibrating multiple source functions, spatially variable decay, source coordinates, release dates, etc.) generally reduced prediction uncertainty provided the inverse solution remained stable and well-posed. This work is funded under ESTCP Project ER-0824.
IMPROVING EFFECTIVENESS OF BIOREMEDIATION AT DNAPL SOURCE ZONE SITES BY APPLYING PARTITIONING ELECTRON DONORS (PEDS)

MS. CARMEN LEBRÓN
Naval Facilities Engineering Command-Engineering Service Center
EV411
1100 23rd Avenue
Port Hueneme, CA 93043
(805) 982-1616
carmen.lebron@navy.mil

CO-PERFORMERS: Dr. David Major, Michaye McMaster, and Cory Repta (Geosyntec Consultants); Dr. Frank E. Löeffler, Dr. Kurt D. Pennell, and Natalie Cápiro (Georgia Institute of Technology); Michael Pound (NAVFAC SW)

Partitioning electron donors (PEDs) are water soluble substrates that can partition strongly into a dense non-aqueous phase liquid (DNAPL). This project’s objective is to DEM/VAL the application of a PED and improve the biologically enhanced dissolution rate of DNAPLs. The project involves both laboratory and field components.

Batch and column studies were conducted to evaluate mass transfer of n-butyl acetate (nBA) and n-hexanol into non-aqueous phase liquids (NAPLs), using both pure trichloroethene (TCE) DNAPL and a surrogate NAPL consisting of TCE and 1,1,1-TCA, in hexadecane. These experiments suggested that nBA partitions strongly into the NAPL (n-hexanol less strongly). Column studies evaluating the dechlorination with soil from OU-11 at North Island Naval Air Station (Site) were inconclusive. Batch tests are being completed to assess potential secondary effects (e.g., other volatile organic compounds [VOCs], geochemical incompatibility) of the Site soil prior to proceeding with a pilot scale application.

Two single-well push-pull tests were performed at the Site to obtain site-specific information for the pilot scale demonstration. Two 4-inch wells were installed adjacent to two delineation locations from site characterization work. The push-pull tests were designed to help develop the field approach for nBA handling and amendment, and the two separate locations were selected to compare nBA performance between areas with and without residual NAPL. Two injection procedures were evaluated. Once in place the nBA solution was allowed to remain in the ground for four days prior to initiating groundwater extraction (the ‘pull’ phase). Groundwater was then extracted at a rate of 1 to 1.5 gallons per minute (gpm) until approximately 20 percent (%) more fluid was extracted than was initially amended. Samples of the extracted groundwater were collected after every 200 gallons and analyzed for VOCs, nBA and bromide tracer. Approximately 90% of the added bromide was recovered, indicating that most of the amended water was subsequently extracted. About 60% of the nBA mass was recovered, mostly in its original form, but with some formation of the hydrolysis product, n-butanol; about 20% of the nBA mass recovered was as n-butanol. This test showed that the nBA could be successfully delivered as an aqueous amendment and that the breakdown of the nBA via hydrolysis occurred at an acceptable rate, suggesting that field implementation for the DEM/VAL could be properly planned. This work is funded under ESTCP Project ER-0716.
STANDARDIZED PROCEDURES FOR USE OF NUCLEIC ACID-BASED TOOLS FOR MICROBIAL MONITORING

MS. CARMEN LEBRÓN
Naval Facilities Engineering Command – Engineering Service Center
EV411
1100 23rd Avenue
Port Hueneme, CA 93043
(805) 982-1616
carmen.lebron@navy.mil

CO-PERFORMERS: David Major, Natasha Barros, and Elizabeth Ney (Geosyntec Consultants); Janet Hatt, Frank Löeffler, and Kirsti Ritalahti (Georgia Institute of Technology); Winnie Chan, Melanie Duhamel, Elizabeth Edwards, and Helen Vrionis (University of Toronto); Greg Davis and Dora Ogles (Microbial Insights); Philip Dennis and Jennifer Wilkinson (SiREM); Chris Yeager (Savannah River National Laboratory)

SERDP Project ER-1561 is focused on developing the foundation for standardized methods for quantitative polymerase chain reaction (qPCR) analysis with the goal of understanding and minimizing method and sample variability. Progress on the project goals of internal standards development and Dehalococcoides (Dhc) reference culture and method optimization were made in the past year. A primary step in method optimization was to establish the baseline variability of current Dhc qPCR methods using inter-laboratory “round robins” performed between five commercial and research laboratories. The labs quantified the Dhc 16S rRNA gene using a variety of DNA extraction and qPCR methods. The round robins included plasmid DNA and whole Dhc cells to differentiate DNA extraction-based and qPCR-based variability. The round robins indicated that statistically significant differences in Dhc enumeration were obtained between some labs. Additional experiments to uncover the sources of this variability were performed including assessment of different DNA extraction kits, duration of bead-beating, PCR primers, PCR chemistries with the goal of reducing inter-lab variability. The impact of storage temperature and aerobicity of samples was also assessed. These experiments provided insights into factors affecting sample storage, extraction and analysis which could inform standard method development. Microbial internal controls are whole cells used in spike and recovery protocols to assess matrix effects and losses in extraction and analysis. Two microbial internal controls have been explored in preliminary tests, a modified E. coli strain carrying a cloned 16S rRNA gene identical to a Dhc except for an introduced mutation, and Prochlorococcus, a photosynthetic, marine bacterium not native to freshwater aquifers. Comparing the properties of these microbes relative to Dhc and the application of these internal standards to detect and quantify qPCR inhibition will determine which is used in downstream field sample focused experiments. A pure Dhc culture was enumerated by multiple techniques for use as a reference culture in calibration and assessment of qPCR methods. Quantification of Dhc cells via total DNA measurements, microscopic counts and phospholipid fatty acid analysis (PLFA) indicated that median cell counts were within approximately half an order of magnitude between non-PCR and qPCR based methods. This finding indicated that qPCR enumeration of 16S rRNA genes provides an accurate measure of Dhc cell numbers.
DIAGNOSTIC TOOLS FOR PERFORMANCE EVALUATION OF INNOVATIVE IN-SITU REMEDIATION TECHNOLOGIES AT CHLORINATED SOLVENT CONTAMINATED SITES

DR. MICHAEL KAVANAUGH
Malcolm Pirnie, Inc.
2000 Powell Street, Suite 1180
Emeryville, CA  94608
(510) 735-3010
mkavanaugh@pirnie.com

CO-PERFORMERS: Dr. Rula Deeb, Daria Navon, and Kenneth Goldstein (Malcolm Pirnie, Inc.); Dr. Beth Parker (University of Guelph); Dr. John Cherry (University of Waterloo); Dr. Kent Sorenson (CDM); Dr. Tamzen Macbeth (North Wind, Inc.); Dr. Lisa Alvarez-Cohen (University of California, Berkeley); Dr. Douglas Mackay (University of California, Davis); Murray Einarson (Einarson and Associates); Dr. Mark Goltz (Air Force Institute of Technology); Dr. Michael Annable and Dr. Kirk Hatfield (University of Florida)

The performance of remediation systems at chlorinated solvent contaminated sites has been historically evaluated using point measurements of dissolved contaminant concentrations in aquifers. Such an approach has significant limitations that may greatly impact the evaluation of technology effectiveness at contaminated sites. First, detailed monitoring of contaminant plumes in granular geologic media conducted has shown that the distribution of dissolved contaminants is often spatially complex due to several factors including spatial variability of contaminant distribution in the subsurface source zone, variability of groundwater flow rate and direction, and variation in water level. This means that it may often be difficult to impossible for typical groundwater monitoring efforts, especially those relying on sparse networks of long-screened wells, to determine where the majority of the contaminant mass is migrating and therefore whether remediation systems are effective in reducing contaminant migration. Second, at sites with complex geologies such as fractured rock sites, the evaluation of in-situ technology performance is even more complicated by contaminant migration through discrete fractures. To better evaluate the success of these systems, a set of diagnostic tools has been used at three hydrogeologically distinct sites employing in-situ chemical and biological treatment technologies over the past several years. These diagnostic tools include technology- and geology-specific tools, as well as those that can be used widely irrespective of the type of technology or site conditions. Mass flux measurement was used as a technology-wide metric of overall system performance since it has the potential to clearly demonstrate a reduction in the rate of contaminant mass release from the treated zone. Innovative technology-specific tools and geology-specific tools were tested for a real-time diagnosis of remedial technology success. Technology- and geology-specific tools evaluated in this study included rock core sampling, isotopic fractionation, molecular tools and integrated conventional techniques. This poster presentation will provide an overview of the diagnostic tools evaluated during this study, as well as a synthesis of the results from the three sites as they pertain to comparability across different geologies. Results from a comparative evaluation of various methods for measuring mass flux will be presented. This work is funded under ESTCP Project ER-0318.
APPLICATION OF MOLECULAR AND ANALYTIC TOOLS TO TRACK ENRICHMENT OF REDUCTIVE DECHLORINATION CULTURES FROM A TCE CONTAMINATED GROUNDWATER SITE

MS. YUJIE MEN
University of California, Berkeley
209 O’Brien Hall
Berkeley, CA 94720
(510) 643-3055
menyj@berkeley.edu

CO-PERFORMERS: Dr. Katie Harding, Dr. Shan Yi, Dr. Weiqin Zhuang, Dr. Helene Feil, and Prof. Lisa Alvarez-Cohen (University of California, Berkeley); Dr. Gary L. Andersen (Lawrence Berkeley National Laboratory); Professor Stephen H. Zinder (Cornell University)

Groundwater samples from 9 different wells at a TCE contaminated field site were enriched in batch serum bottles using defined mineral salts medium amended with different concentrations of vitamin B12, ~22 µmol TCE, 20 mM lactate and N2/CO2 headspace. TCE dechlorination activity was detected in only one out of nine enrichments, which contained the highest concentration of vitamin B12 (100 µg/L) and generated both hydrogen and methane. This enrichment (denoted “GW2”) completely dechlorinated TCE to VC and ethene after 52 days of incubation. After cell density was increased by re-amending with TCE and lactate, GW2 was sub-cultured under the same conditions. Elimination of methanogenesis in a subculture of GW2 (denoted “GW2_mdf”) was achieved by increasing the amended TCE to ~70 µmol. Both GW2 and GW2_mdf had similar TCE dechlorination activities, suggesting that the methanogens were not competing at an inhibitory level with the Dehalococcoides strains in GW2. Subcultures of both GW2 and GW2_mdf grown in vitamin B12-free media (denoted “GW2 NB12” and “GW2_mdf NB12” respectively) were also capable of reductive dechlorination of TCE to VC and ethene. Quantitative PCR (qPCR) results showed that the Dehalococcoides 16S rRNA gene and the functional tceA gene were present in the 4 enrichments at approximately a 1:1 ratio, while bvcA and vcrA were not detected. Since vitamin B12 is required during reductive dechlorination processes, the dechlorination activities in the two B12-free enrichments indicated the presence of certain microbial populations providing vitamin B12 to Dehalococcoides sp. To identify organisms that might be involved in interspecies vitamin B12 transfer in the enrichments, 16S rRNA gene clone libraries were constructed to compare the diversity and composition of different microbial populations in GW2 and GW2 NB12. Preliminary results showed that the majority of the clones identified in both of the enrichments showed high sequence similarity to the bacteria affiliated with the phyla of Firmicutes and Proteobacteria. Clones associated with Dehalococcoides represented 8% and 4%, respectively, of the clones from the vitamin B12-amended and vitamin B12-free enrichments, albeit both enrichments showed similar TCE dechlorination activities. The comparison of phylogenetic distribution between GW2 and GW2 NB12 also indicated that the enrichment without vitamin B12 produced more clones associated with species in class of Clostridia, such as Pelosinus sp. and Clostridium propionicum, than the enrichment with the presence of vitamin B12, indicating that these Clostridia species might be involved in supplying vitamin B12 to Dehalococcoides.
DEEP-RESOLVED MOLECULAR BIOLOGICAL ANALYSIS OF GROUNDWATER CONTAMINANT PLUMES: ADVANTAGES OF CRYOGENIC CORE COLLECTION

DR. RICK JOHNSON
Oregon Health and Science University
20000 NW Walker Road
Beaverton, OR  97006
(503) 748-1193
rjohnson@ebs.ogi.edu

CO-PERFORMERS: Christina N. Brow, Reid O’Brien Johnson, and Holly M. Simon (Oregon Health and Science University)

Monitoring of subsurface bioremediation should ideally identify zones within the contaminant plume in which biodegradation is dominantly occurring. Strategies in which sampling efforts focus mainly on groundwater samples from fixed depths from the presumed centerline of the plume may prove inadequate for several reasons. Firstly, contaminant transformations may be confined to discrete areas of the plume in which oxidation and/or reduction conditions are suitable for the microorganisms capable of degradation. For example, degradation may be confined to the fringes of the contaminant plume where overlapping counter-gradients of electron donors and acceptors exist, (the so-called “plume fringe concept”). Even multilevel groundwater sampling may not be adequate to characterize such zones because the resolution of sampling is typically on the scale of meters. Secondly, physical heterogeneities, and temporal variations in hydrologic conditions can contribute to spatial variability of the plume. Finally, many studies suggest that the majority of bacteria involved in contaminant degradation are sediment-attached as opposed to free-living in the groundwater, and that the rates of dechlorination of chlorinated hydrocarbons, biodegradation of aromatic hydrocarbons, and other cellular activities, are higher for soil bound bacteria. The effectiveness of a cryogenic core sampler to collect intact frozen cores has previously been demonstrated. Biomolecules of interest to remediation (DNA, RNA, and protein) also have been preserved during freezing and subsequent storage of up to several months. In the work presented here, the ability to characterize a subsurface contaminant plume to a vertical resolution of ~2 centimeters using cryogenically-collected core samples is demonstrated. A TCE/toluene plume was developed within a large-scale model aquifer. Concurrent with chemical composition analysis, molecular biological tools were used to characterize the microbial communities across the plume. Functional genes for aerobic and anaerobic toluene degradation were examined using quantitative PCR. Additionally, PCR-Single Strand Conformation Polymorphism was used to determine how the microbial community changes across plume interfaces. Results obtained from the cryogenically-collected core samples were also compared to those obtained at the same location from discrete-depth horizontally-collected water and sediment samples. The results of this work have important implications for the monitoring of subsurface remediation in regards to selecting an appropriate sampling approach. This work is funded under ESTCP Project ER-1559.
Bench-Scale Fracture Network Experiments: Evaluating DNAPL Dissolution Rates as a Function of DNAPL-Water Interfacial Area and DNAPL Dissolution Kinetics During Chemical Oxidation

Kaneen Christensen
Colorado School of Mines
1500 Illinois Street
Golden, CO 80401
(303) 619-4846
kachrist@mines.edu

CO-PERFORMERS: Dr. Peggy Altman and Dr. John McCray (Colorado School of Mines); Dr. Charles Schaefer (Shaw Environmental, Inc.)

Dense non-aqueous phase liquid (DNAPL) present in fractured bedrock settings introduces remediation challenges that are dramatically different from porous media. Yet, the kinetics of DNAPL dissolution fractured-aquifer systems have not been studied in detail. This research is the first to investigate aqueous DNAPL dissolution during ambient groundwater conditions as well as DNAPL dissolution during chemical oxidation in a three-dimensional (3-D) fractured sandstone network experiment. Prior to chemical oxidation experiments, two types of aqueous-only dissolution experiments were performed, complete dissolution followed by steady-state dissolution. Effluent concentrations of aqueous phase tetrachloroethylene (PCE) are monitored during the experiment and are used to quantify the dissolution mass-transfer rates. Initial results indicate that dead-end fractures greatly influence contaminant transport processes with low-flow fractures serving as regions of contaminant storage and slow release of solutes that mimic a dual-domain transport.

A comparison of dissolution mass transfer rates from the aqueous fracture network experiments to a comparable discrete fracture experiment by Schaefer et al., 2009, found similar dissolution mass transfer rates, 0.04 min\(^{-1}\) in network experiment and 0.02 min\(^{-1}\) in discrete experiment, even though velocity is greater in the discrete fracture experiments. However, based on the literature, dissolution rates in fracture systems are considerably smaller than in porous media. For example, Cho et al., 2005, measured mass transfer rates in the porous media that were at least two orders of magnitude greater than those for this project’s fracture-network or discrete-fracture experiments for similar experimental velocities. Preparations are currently underway for dissolution experiments using chemical oxidation in the experimental fracture network. The dissolution mass transfer rates will be compared to the discrete fracture study, in addition to comparable porous media experiments utilizing chemical oxidation. All experimentally derived mass transfer rates will be evaluated against system properties to determine the primary factors controlling dissolution: interfacial area, Reynolds number (lumped parameter that includes velocity and liquid properties), and other measures of the fracture network characteristics, to develop a constitutive, empirical, or phenomenological model that will yield predictive methods for contaminant-source longevity with DNAPL dissolution in groundwater, as well as during chemical oxidation.
INJECTION OF NANO ZERO-VALENT IRON FOR SUBSURFACE REMEDIATION: A FIELD SCALE TEST OF MATERIALS, METHODS, AND MODELS

PAUL G. TRATNYEK
Oregon Health and Science University
20000 NW Walker Road
Beaverton, OR  97006
(503) 748-1023
tratnyek@ebs.ogi.edu

CO-PERFORMERS: Richard L. Johnson, James T. Nurmi, and Peter Langren (OHSU); Gregory V. Lowry and Tanapon Phenrat (Carnegie Mellon University); Abdullah Cihan and Tissa Illangasekare (Colorado School of Mines); Yuxin Wu and Kenneth H. Williams (LBNL)

Among emerging technologies for in situ remediation of subsurface contamination, injection of nano-sized zero-valent iron (nZVI) stands out for the sudden growth in interest it has attracted. Field scale applications of this technology exist for a variety of types of sites, and most of these projects have been described as being successful. None of these sites have been extensively characterized, however, and there is not yet a critical mass of field data on which to make generalizations about the performance of nZVI-based remediation technologies. Furthermore, some aspects of the reported field results are not easily reconciled with results of laboratory and modeling studies of nZVI properties and behavior. Clearly, a more thorough and rigorous understanding of this system is needed to ensure that applications of this technology are successful. As a step toward achieving this goal, SERDP has funded an 18 month extension for Project ER-1485 in order to address three critical issues: (i) identify and validate characterization methods that can be used to detect breakthrough of nZVI and nZVI impacted groundwater, preferably in situ; (ii) calibrate and validate models of nZVI transport in porous media for use with real environmental materials and injection apparatus at field scales; and (iii) systematically evaluate the results of different injection regimes for emplacement of nZVI into realistic porous media. For methods to characterize the transport of nZVI and the impacted fluids, this work is pursuing a complementary suite of tools with emphasis on those that can be applied in situ and/or in real time. Electrical geophysical methods (e.g., complex conductivity) are one such tool, and preliminary results indicate that while bulk conductivity reflects the injectate volume, phase changes are sensitive to nZVI particles and possibly even its subsequent oxidation. For numerical modeling of nZVI transport during and after emplacement, this project is developing a tool that couples semi-empirical correlations to predict aggregate size and aggregate deposition with a numerical simulation of the flow field in the porous medium.

Physical modeling will be done of OHSU’s very large (ca. 1000 m³) 3-dimensional model aquifers, which is being prepared for controlled injections of nZVI. The conditions of injection (type and concentration of nZVI and stabilizers, injection velocity, etc.) will be derived from the results of objective (ii) and the results of the test injections (distribution of nZVI, dissolved iron, hydrogen, etc.) will be characterized using the suite of methods developed under objective (i).
USE OF MOBILE INJECTION TRAILERS TO COMPLETE LARGE-SCALE PERMANGANATE INJECTION

MS. AMANDA STRUSE
CH2M Hill
12377 Merit Drive, Suite 1000
Dallas, TX 75251
(972) 663-2350
amanda.struse@ch2m.com

CO-PERFORMERS: Sharon Schultz (CH2M Hill); Timothy Clendenin (United States Air Force Aeronautical Systems Center)

A significant trichloroethylene (TCE) release occurred at U.S. Air Force Plant 6, in Marietta, Georgia. Groundwater contamination in saprolite, partially weathered rock (PWR), and bedrock formations resulted from migration of TCE downward through 150 to 200 feet to the underlying bedrock. Historically, TCE concentrations in groundwater, at the source area, have been as high as 244,000 µg/L, suggesting the presence of dense non-aqueous phase liquid (DNAPL). A plume with TCE concentrations of greater than 5,000 µg/L extends more than 1,800 feet downgradient of the release zone in the PWR. CH2M HILL employed in situ chemical oxidation (ISCO) using potassium permanganate to reduce residual TCE mass in the source area. Pilot studies in the saprolite and PWR zones demonstrated injections were economically feasible within the PWR, while bench testing prior to the pilot phase indicated extremely low oxidant demand.

A 10,000 gallon batch-mix area and three mobile trailers were constructed to transport permanganate solution to the injection wells. The injected permanganate concentration varied between 30 and 50 g/L. CH2M HILL completed the full-scale application within the PWR with 32 wells placed on approximately 80-foot centers. The injection wells were screened over the entire PWR; screens varied between 20 feet and 95 feet in length. Between September 2 and November 13, 2008, CH2M HILL injected over 570,000 gallons of permanganate solution into the target treatment area.

Groundwater sampling conducted in February 2009 indicates significant permanganate persistence. Permanganate has migrated approximately 200 feet downgradient from the injection area and high permanganate concentrations (greater than 20 g/L) were measured in the source area. Permanganate appears to have also reached the underlying bedrock; however, lateral distribution and persistence was not as substantial as observed in the PWR. Prior to completing the full-scale injection, TCE was measured in PWR groundwater at 92,900 µg/L. Where permanganate is present, the TCE is considered non-detect. To date, the permanganate has spread to nearly 5 acres, with reduction of more than 750 pounds of TCE.

This poster will describe the chemical handling and mixing procedures, as well as the means of completing the chemical transport and injections, and the resulting treatment attained.
ENHANCING ISCO OF DNAPL USING ENCAPSULATED PERMANGANATE: SELECTIVE OXIDATION AND CONTROLLED RELEASE STUDIES

PAMELA DUGAN
Carus Corporation
315 5th Street
Peru, IL 61354
(815) 224-6870
pamela.dugan@caruscorporation.com

CO-PERFORMERS: Beth Vlastnik (Carus Corporation); Lindsay Swearingen and Jason Swearingen (Specialty Earth Sciences)

Controlled release techniques have been utilized extensively in diverse fields such as pharmaceutical and agrochemical technologies. However, controlled release of an oxidant during in situ chemical oxidation (ISCO) is an emerging concept that is extremely relevant to the field of environmental remediation, yet to-date has received little attention. ISCO using the oxidants permanganate, persulfate, and catalyzed hydrogen peroxide has shown great promise for remediation of many recalcitrant organic contaminants of concern (COC). Because the oxidant also reacts with natural organic matter, inorganic soil constituents, and other reduced compounds, the presence of a protective barrier that controls oxidant release—as well as a coating that has an affinity for, and dissolves rapidly in hydrocarbons—may enhance the efficiency of ISCO. To this end, micro-encapsulated potassium permanganate (MEPP) was developed and characterized. Paraffin wax was used as the environmentally benign matrix material for encapsulating the sub-micron size, permanganate particles. The following physical characteristics were desired in order to serve as an effective matrix material: (1) solid phase at room temperature; (2) substantially water-insoluble (i.e., hydrophobic); (3) soluble in dense nonaqueous phase liquids (DNAPLs) (i.e., oleophilic); (4) biodegradable; and (5) resistant to permanganate oxidation. The paraffin matrix protects the solid potassium permanganate particles from fast dissolution. In addition, it could potentially sequester the permanganate from undesirable nonproductive reactions, and facilitate selective-release of permanganate in the presence of dissolved phase and DNAPL chlorinated solvents.

Batch studies were conducted to evaluate the partitioning behavior of dissolved phase tetrachloroethene (PCE) in paraffin alone, the release properties of MEPP in the presence of DNAPL as compared to water alone, and the degradation of PCE DNAPL using MEPP. Reactive solids can be used to create reactive barriers that passively degrade contaminants in situ. Raw permanganate is too soluble to form a persistent reactive barrier; however, the controlled-release properties of the microencapsulated permanganate may allow for the creation of an oxidative barrier and establishment of a reactive zone that could have viable applications to the field of remediation. To evaluate this, a column experiment was conducted to assess the use of MEPPs for permeable reactive barrier applications. Promising experimental results reveal that the encapsulated oxidant technology may enhance traditional ISCO through the formation of controlled-release micro-encapsulated permanganate capable of selective-release in the presence of DNAPL.
OPTIMIZING FLUID FORMULATIONS AND DESIGN SIMULATIONS FOR IMPLEMENTING POLYMER-AMENDED PERMANGANATE TREATMENT AT THE FIELD-SCALE

JEFF A. K. SILVA
Colorado School of Mines
1500 Illinois Street
Golden, CO 80401
(303) 579-1275
jsilva@mines.edu

CO-PERFORMERS: Dr. Michelle L. Crimi (Clarkson University); Thomas A. Palaia (CH2M Hill); Saebom Ko (EPA)

Two challenges with any in situ remediation technology are (1) treatment amendment delivery limitations due to site heterogeneities, and (2) minimizing unfavorable impacts of technology implementation. With respect to permanganate in situ chemical oxidation (ISCO), these challenges specifically relate to (1) the ability to deliver into low permeability media (LPM) (vs. preferential flow and bypassing of the LPM), and (2) deposition of oxidation reaction byproduct manganese dioxide (MnO₂) particles, preventing effective distribution and contact with contaminants. Poor amendment sweep efficiencies are typically the result of the injection process whereby the injected amendments are delivered into preferential flow paths within zones of higher permeability. This leads to the treatment amendment bypassing LPM and rebounding contaminant concentrations within a groundwater aquifer following treatment. In addition to difficulties due to naturally existing site heterogeneities, MnO₂ particles, a product of the reaction of permanganate with organic materials, can create secondary site heterogeneities that may provide an added hindrance to the technology’s effectiveness. MnO₂ particles may deposit in the subsurface and impact flow, thereby preventing effective oxidant distribution and contact with contaminants. Methods to mitigate the potential for preferential flow and bypassing effects would increase remediation effectiveness and reduce costs of environmental restoration efforts through reduced occurrence of rebound. SERDP-funded laboratory investigations into methods of mitigating MnO₂ particle precipitation and improving the sweep efficiencies during permanganate ISCO applications have been recently completed. Both methods involve the addition of water-soluble polymers. SERDP Project ER-1484 demonstrated that additions of the polymer sodium hexametaphosphate (HMP) inhibits MnO₂ deposition, improving flow through areas of high contaminant mass density. SERDP Project ER-1486 demonstrated that the addition of Xanthan gum biopolymer formed a stable viscous solution with permanganate that can be used to improve permanganate sweep-efficiencies in heterogeneous strata via mobility control mechanisms. Both technologies have been selected by ESTCP for a field-scale demonstration as a cooperative demonstration that is scheduled for the Summer of 2010. This presentation will focus on the results of laboratory treatability study and site characterization activities that are currently underway to support field-scale evaluation. Specifically, the optimization of polymer/permanganate fluid formulations under flow in porous media and the results of 3-D simulations for implementation design will be presented.
A SPREADSHEET TOOL FOR DESIGNING ISCO SYSTEMS WITH PERMANGANATE

MR. KI YOUNG CHA
North Carolina State University
Campus Box 7908
Raleigh, NC 27695
(919) 515-1625
kycha@ncsu.edu

CO-PERFORMERS: Robert Borden (North Carolina State University); Tom Simpkin (CH2M Hill)

In situ chemical oxidation (ISCO) can provide a lower cost, less intrusive, and more rapid method for remediating contaminated soil and groundwater. However, effective treatment requires effective distribution of permanganate (MnO₄⁻) throughout the target treatment zone. Reagent distribution depends on the physical characteristics of the site (treatment zone dimensions, total NOD, rate of NOD consumption, contaminant concentrations, aquifer permeability distribution, background hydraulic gradient) and design parameters that can be adjusted to optimize remediation system performance (injection volume and flowrate, reagent concentration, well spacing, reinjection frequency). Unfortunately, changes in design parameters that improve performance (e.g., reducing well spacing) often result in higher initial costs. As a result, injection system designs are often a trade-off between remediation performance and cost.

A spreadsheet design tool (CDISCO – Conceptual Design for ISCO) has been developed to assist designers in identifying lower cost, more effective systems for distributing MnO₄. CDISCO was developed with support from ESTCP under Projects ER-0625 and ER-0623 and consists of two major components: (1) a numerical model for simulating the one-dimensional radial transport and consumption of MnO₄ following injection into a single well or direct-push probe. This model allows users to easily evaluate the effect of aquifer parameters (effective thickness, permeability, and natural oxidant demand) and injection conditions (MnO₄ concentration, injection flow rate, and duration) on the effective radius of influence (ROI) of an individual injection point. Injection well spacing equals 2*ROI*OF where OF is the Overlap Factor; and (2) a procedure to quickly evaluate the effect of different design alternatives on capital costs. Major inputs to this calculation include unit costs for well installation, injection labor, and reagents.

The Overlap Factor (OF) specifies the extent of overlap between MnO₄ impacted zones generated by adjoining wells. Unfortunately, there is essentially no information on what value of OF is required for effective treatment. Higher values of OF will probably result in increased contact efficiency but will also result in higher costs. A series of numerical simulations were generated using MODFLOW and RT3D to examine the effect of design variables on remediation system performance. Simulations were run for both 2D homogeneous conditions and 3D heterogeneous conditions to evaluate the effects of aquifer heterogeneity. Simulation results showed that the OF was a good predictor of remediation system performance and can be used to guide remediation system design.
MULTIFUNCTIONAL NANOCOLLOIDS FOR ENVIRONMENTAL REMEDIATION OF CHLORINATED HYDROCARBONS

DR. VIJAY JOHN
Tulane University
300 Lindy Boggs Building
New Orleans, LA  70118
(504) 865-5883
vj@tulane.edu

CO-PERFORMERS: Jingjing Zhan, Bhanu Sunkara, Tonghua Zheng, Gerhard Piringer, Gary McPherson, Yunfeng Lu, and Jeffrey Wickliffe (Tulane University)

The widespread occurrence of dense non-aqueous phase liquids (DNAPLs) in groundwater and in soil is of serious environmental concern. Nanoscale zerovalent iron particles (NZVI) are a preferred option for reductive dehalogenation of trichloroethylene (TCE) due to their environmentally benign nature, high efficiency, and low cost. However, it is difficult to transport these particles to the source of contamination due to aggregation. This study describes a novel approach to the preparation of ZVI nanoparticles that are efficient and effectively transported to contaminant sites and serve as targeted delivery agents for remediation. This project describes the synthesis of carbon supported submicron spherical particles imbedded with zerovalent iron nanoparticles. These materials have multiple functionalities: (1) they are extremely reactive and efficient with reductive dehalogenation; (2) they are highly adsorptive, thereby bringing the chlorinated compound to the proximity of the reactive sites and also serving as adsorption materials for decontamination; (3) they are of the optimal size for transport through sediments; and (4) they have amphiphilic chemical functionalities that help stabilize them when they reach the DNAPL target zones. These multiple functionalities can be designed at low cost. The detailed characterization of these multifunctional colloids through cryo-electron microscopy and their reactive, adsorptive, and transport properties will be described.
A LOW COST PASSIVE APPROACH FOR LARGE-SCALE SOURCE AREA BIOAUGMENTATION

MR. JOEY TROTSKY
Naval Facilities Engineering Command-Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043
(805) 982-1258
joey.trotsky@navy.mil

CO-PERFORMERS: Kent S. Sorenson, Ryan A. Wymore, Mike Lamar, and Tamzen W. Macbeth (CDM)

Bioaugmentation is a promising technology for overcoming the “DCE stall” that occurs at many sites where bioremediation of TCE DNAPL source areas is implemented. However, bioaugmentation has been rigorously demonstrated only at the pilot scale. A primary issue is that these pilot scale tests have primarily used an active recirculation approach for distributing bacteria. While successful at the pilot scale, logistical and regulatory problems might exist for applying recirculation for full-scale applications of hundreds of feet.

An ESTCP project is underway at Naval Weapons Station Seal Beach, Site 70 to compare a low-cost, passive approach for bioaugmentation to the more common recirculation approaches for full-scale DNAPL source area application. Site 70 has groundwater contaminated with TCE as high as 190 mg/L and sulfate concentrations upwards of 9,000 mg/L. The water table occurs at 5-12 ft below ground surface (bgs), and the shallow aquifer zone, which is the focus of this study, extends to 40 ft bgs. The scale-up area is centered within the source area and is approximately 400 ft long by 150 ft wide, which dwarfs currently rigorously documented bioaugmentation studies. The active recirculation cell continuously extracts and reinjects groundwater continuously. Electron donor (1% to 3% sodium lactate) is being pulsed into the reinjection line approximately once per week. For the passive treatment cell, sodium lactate is being injected into each of three injection wells once per month. After several months of “pre-conditioning,” the treatment cells were bioaugmented using a commercially available culture.

Performance is being assessed through monthly monitoring of contaminants and daughter products, redox-sensitive parameters, water quality parameters, biological activity indicators, compound-specific stable carbon isotope analysis, and quantitative polymerase chain reaction (qPCR) for Dehalococcoides species and functional genes. Results through six months of post-bioaugmentation operations show strongly reducing conditions and moderate to high concentrations of electron donor throughout most of both the active and passive treatment cells. In addition, dechlorination to VC with significant production of ethene has been observed in the upgradient half of the active treatment cell, and at monitoring wells near two of the three passive cell injection locations. Also, high cell concentrations of Dehalococcoides bacteria have been observed at distances of more than 35 ft from injection wells in the active cell, and at distances of 15-20 ft from injection points in the passive cell. Results through 9 months of this demonstration will be discussed. This work is funded under ESTCP Project ER-0513.
POST ERH BIOAUGMENTATION AT AIR FORCE PLANT 4

MR. RICHARD WICE
Shaw Environmental, Inc.
2790 Moss Side Blvd.
Monroeville, PA 15146
(412) 858-3309
richard.wice@shawgrp.com

CO-PERFORMERS: Mr. George Walters (U.S. Air Force);
Mr. Randall McDaniel (Shaw Environmental, Inc.)

In situ bioaugmentation was applied in a limited area at a former trichloroethene (TCE) DNAPL source area as a remedial technology follow-up to an Electric Resistance Heating (ERH) application. The ERH removed a significant mass of TCE. The bioaugmentation performance monitoring indicates that TCE groundwater concentrations were reduced to levels well below the cleanup goals.

At Air Force Plant No. 4 (AFP4) in Fort Worth, Texas, past spills and a 1991 vapor degreaser tank failure at the Chemical Process Facility released several thousand gallons of TCE into the vadose zone and the Terrace Alluvium groundwater beneath Chemical Process Building 181 (B181). In accordance with the AFP4 Record of Decision (ROD), the Air Force implemented a sequence of remedial technologies at B181. The initial remedial technology was soil-vapor extraction (SVE). After expanding the SVE system twice, ERH was selected as the most appropriate technology to enhance the SVE to meet the ROD-required cleanup objectives for both soil and groundwater. Except for a small recalcitrant area, the ERH application has remediated the soil and groundwater beneath B181 to below the ROD-required cleanup levels.

A post-remedial action mass-flux investigation by Arizona State University and the Battelle Institute under an Environmental Security Technology Certification Program (ESTCP) project, along with an evaluation of groundwater analytical data, confirmed the success of the ERH application. Based on technology screening and bench scale testing, bioaugmentation was selected to address the small area with TCE groundwater concentrations above the 10,000 micrograms per liter (µg/L) ROD cleanup level.

Utilizing nine new borings and two existing wells, 13,000 gallons of emulsified oil substrate (EOS) was injected into the saturated zone basal sands, gravel, and weathered bedrock surface at a depth of 25 to 35 feet below ground surface (bgs). Once reducing conditions developed in the saturated zone, 20 gallons of SDC-9™ culture were injected. Performance monitoring groundwater samples were collected two, five, and nine months after SDC-9™ injection. TCE and TCE daughter product concentrations in groundwater samples were on downward trends with corresponding increases in ethene.
DEMONSTRATION OF ENHANCED MASS TRANSFER DURING BIOREMEDIATION OF TCE DNAPL

DR. KENT S. SORENSON, JR.
CDM
555 17th Street, Suite 1100
Denver, CO 80202
(303) 383-2430
SorensonKS@cdm.com

CO-PERFORMERS: Tamzen W. Macbeth (CDM); Kira Lynch (U.S. EPA)

Bioremediation has the potential to reduce capital costs compared to other technologies for chlorinated solvent source area cleanup. However, conventional wisdom suggests that bioremediation is limited by the rate at which nonaqueous contaminants dissolve or diffuse to where bacteria can degrade them. Recent advances have shown however, that mass transfer rates of chlorinated solvents from the nonaqueous phase to the aqueous phase can be substantially increased during bioremediation. The overall objective of this demonstration was to show that facilitating enhanced mass transfer allows bioremediation to be applied cost-effectively to chlorinated solvent source areas in groundwater. A phased approach ensured experimental control was sufficient to measure with confidence the effects of different whey injection concentrations on mass transfer. This demonstration represents the first time the phenomenon of enhanced mass transfer in chlorinated solvent source areas as a function of whey injection concentration has been thoroughly documented at the field scale. The results demonstrate significant potential impact of enhanced mass transfer not only on source areas, but also on downgradient plumes. Two hydraulically isolated treatment cells, each consisting of a network of monitoring wells, an injection well, and an extraction well, were installed at the site. Two injection strategies were applied to each treatment cell to compare the effects of high concentration (10%) and low concentration (1%) whey powder injections. The factor of increase in aqueous chloroethene concentrations from baseline to 10% whey injections ranged from 1.8 to 4.2, with only one sampling location showing an increase less than a factor of 2.4. These increases greatly exceeded those during the 1% whey injections, even though the extent of dechlorination was equivalent. Three statistical comparisons demonstrated that contaminant molar concentrations were increased at the 95% confidence level as a function of electron donor concentration. A row of flux monitoring wells installed downgradient of the treatment cells revealed the impact of high-concentration whey injections on downgradient contaminant flux. Chloroethene concentrations downgradient of high concentration whey injections increased by a factor of 3 to 16, while total chloroethene concentrations downgradient of low concentration injections changed only by a factor of 0.8 to 1.3. Furthermore, in seven of the eight downgradient wells, downgradient mass flux based on total chloroethenes concentrations decreased by 94 to 99% three months after the end of whey injections. The costs of the demonstration were carefully tracked in order to provide a realistic estimate of the cost of implementing the technology for chlorinated solvent source area cleanup. Based on these data, costs of full-scale application at this Fort Lewis source were compared to estimated costs for thermal remediation and pump and treat. The net present value cost for full-scale implementation of bioremediation was roughly half that of the other technologies even though the operational timeframe was significantly longer than that for thermal remediation.
Permeable Reactive Barriers (PRB) have been installed to intercept and treat contaminated groundwater at polluted sites throughout the country for many years, and iron material PRB are now widely accepted as a conventional treatment technology. However, advances in the PRB field have continued with the evolution of new reactive materials, such as nano-scale zero-valent iron, emulsified zero-valent iron, organic substrates, and other non-iron reactive media. Proper usage of these newer reactive materials in PRB can result in time and cost savings as well as add another technology to the environmental remediation arsenal. The ITRC PRB: Technology Update Team is currently developing a technical and regulatory guidance document as it relates to these advances in PRB. This document will focus on PRB that may be used to treat chlorinated aliphatic hydrocarbons (chlorinated solvents), oxidizers (perchlorate and chlorate), explosive and ordnance compounds (RDX, TNT), dissolved metals (hexavalent chromium), nitrates, and sulfates.

The goal of the ITRC team is to discuss advances in these technologies and to help the regulatory community become more familiar with the treatment applicability, installation, performance, and mechanisms of reactive materials. An additional goal is to provide guidance to regulators and environmental practitioners to help them evaluate and implement plans for reactive materials technology at appropriate sites resulting in time and cost savings.

The ITRC PRB: Technology Update team includes members from five state regulatory agencies, industry, federal agencies, academia, and citizen stakeholders.
NONLINEAR RELATIONSHIP BETWEEN KOBS AND nZVI DOSE FOR PCE DECHLORINATION IN BATCH AND FLOW THROUGH COLUMNS AT REALISTIC SEEPAGE VELOCITY IN POROUS MEDIA

MS. HYE-JIN KIM
Carnegie Mellon University
5000 Forbes Ave Civil and Environmental Engineering
Pittsburgh, PA 15213
(412) 334-7352
hyejink@andrew.cmu.edu

CO-PERFORMERS: Tanapon Phenrat, Robert D. Tilton, and Gregory V. Lowry (Carnegie Mellon University); Fritjof Fagerlund (Uppsala University); Menka Mittal, Sidika Pinar Turkbey Cihan, and Tissa Illangasekare (Colorado School of Mines)

To meet remediation goals using nZVI (nano scale zero valent iron) requires knowledge of the contaminant reaction rate and the life time of nZVI. The reactivity of poly (maleic acid-co-olefin) (MW=12K) coated nZVI (MRNIP2) was examined in batch and column reactors to determine the effect of particle dose and seepage velocity on PCE dechlorination rate, pathways and the hydrogen evolution rate which control the effectiveness and the longevity of the treatment. In batch, the PCE dechlorination rate constants at practical MRNIP2 application concentrations (1, 2, 5, 10, 15 and 20 g/L) ranged from 2 ~ 4 × 10^{-4} Lh^{-1}m^{-2}. A nonlinear relationship between the pseudo first order reaction rate constant (kobs) and nZVI mass loading was observed below a 5 g/L dose. Increasing mass loading of nZVI from 1 g/L to 20 g/L also increased pH and decreased oxidation reduction potential (ORP) of the system. The PCE dechlorination rate increased proportionally with increasing pH. However, the nZVI mass loading showed the opposite result for the hydrogen evolution rate. The surface area normalized hydrogen evolution rate was higher at low particle dose and showed a constant rate above 10g/L mass loading. These results suggest that PCE dechlorination and hydrogen evolution involve different reduction pathways, therefore, varying pH and ORP will affect the PCE dechlorination rate and hydrogen evolution rate independently. The effect of the seepage velocity on the PCE dechlorination rate was examined in column experiments at various linear pore-water velocities (7 ~ 113.5 cm/day) in sand (an average grain size of 300 μm) columns packed with 10 g/L of MRNIP2. For linear pore-water velocities of 14.1 cm/d, 53.6 cm/d and 113.5 cm/day, the PCE dechlorination rates were 4.29 ± 0.15 × 10^{-4} (Lh^{-1}m^{-2}), 8.45 ± 0.47 × 10^{-4} (Lh^{-1}m^{-2}) and 1.14 ± 0.07 × 10^{-3} (Lh^{-1}m^{-2}) respectively. By increasing the velocity from 14.1 cm/day to 113.5 cm/day reaction rates increased 2.65 times which indicates mass transfer limitations occur at low flow velocities. However, hydrogen evolution under flow gradually decreased and stopped even though the nZVI remained reactive for PCE dechlorination. This also implies that the sites for hydrogen evolution and reductive dechlorination on nZVI are different. This study implies that an nZVI mass loading of less than 5 g/L is less effective than higher particle dosages both for PCE reduction and for the reactive life time of nZVI. Reactivity is lower at low pore-water velocity, but the effect was less than a factor of ~3. Dechlorination rates were found to depend on both site hydrogeochemistry and injected nZVI mass.
FACTORS AFFECTING THE SUCCESS OF BIOAUGMENTATION APPLICATIONS

DR. ROBERT J. STEFFAN
Shaw Environmental, Inc.
17 Princess Road
Lawrenceville, PA 08648
(609) 895-5350
Rob.steffan@shawgrp.com

CO-PERFORMERS: Simon Vainberg, David Lippincott, and
Dr. Charles Schaefer (Shaw Environmental, Inc.)

Bioaugmentation has become an accepted and widely used technology for treating chlorinated solvent-contaminated aquifers that do not have an adequate indigenous microbial population able to effectively degrade the target pollutants. Several bacterial cultures containing strains of *Dehalococcoides* sp. that are able to completely degrade chlorinated ethenes via reductive dehalogenation are now commercially available. The cultures are commonly applied with an exogenous carbon substrate that ultimately serves as an electron donating substrate to support reductive dechlorination by the added culture. During ESTCP-funded project ER-0515, several factors have been evaluated that can affect the performance of the bioaugmentation cultures, including geochemistry, cell dosage, methods of culture application, and electron donor concentration. Specifically, experiments were performed to evaluate the affect of high contaminant concentrations, reducing agents, fluorescent tracer dye, chromium co-contamination, ethanol concentrations, high total dissolved solids (TDS), sulfate concentration, temperature, and pH on dehalogenation by *Dehalococcoides*-containing bioaugmentation cultures. For example, to evaluate the affect of mixing electron donor substrates with bacterial cultures so that both can be applied in a single injection, this project evaluated the affect of high concentrations of 5 commercially available electron donor substrates on tetrachloroethene (PCE) dehalogenation by the SDC-9 bioaugmentation culture. Each product was prepared according to manufactures’ recommendations and then mixed with anaerobic groundwater to a final concentration of 9% (weight for weight [w/w]) as organic carbon. SDC-9 was then added to the solution and the cells were incubated for 16-17 hours at 13°C. The cell suspensions were then centrifuged to collect the cells, and the cells were washed and suspended in reduced anaerobic mineral medium (RAMM). Sodium lactate and PCE were then added, and the cells were incubated to assess dehalogenating activity relative to cells that had not been incubated with the electron donor. All of the electron donor substrates resulted in significant loss of dehalogenation activity in SDC-9, suggesting that adding bioaugmentation cultures to electron donor solutions before injecting them into the subsurface could have a deleterious affect on remediation performance. The mechanisms of the observed inhibition are under investigation. The results of these studies will allow remediation practitioners to evaluate the potential for successful bioaugmentation applications in aquifers under a wide range of hydro/geochemical conditions.
ENHANCING ABIOTIC REACTION RATES USING ERH AS A SUSTAINABLE REMEDIATION SOLUTION AT TWO DoD SITES

MR. MARK KLUGER
Dajak, LLC
7 Red Oak Road
Wilmington, DE 19806
(302) 655-6651
mkluger@dajak.com

CO-PERFORMER: Tim Warner (TRS Group, Inc.)

The primary mass removal mechanism of Electrical Resistance Heating (ERH) is soil vapor extraction subsequent to the conversion of volatile liquid phase contaminants to the gas phase. At sites where ERH has been implemented, it has been unexpectedly observed that heat enhanced chemical, biological, and physical processes provide a significant amount of remediation activity.

Hydrolysis, which is quite slow under normal groundwater temperatures (the half life of the reaction is normally measured in decades), becomes very rapid (less than a day) under temperatures that can easily be achieved using ERH. Heat-enhanced hydrolysis has been used to remediate halogenated alkanes from soils and groundwater at various sites, including DoD sites in California and Maryland.

Furthermore, ERH provides the appropriate conditions for accelerated biological activity for dissolved phase contaminant treatment. ERH increases dissolved organic carbon content by more than an order of magnitude, providing terminal electron donors for the biodegradation of chlorinated solvents. Bioactivity has been shown to increase during and after ERH.

For the treatment of oil and coal tar residues from manufactured gas plants, a process called steam bubble floatation physically moves the long-chain hydrocarbons to the top of the water table. Conventional multi-phase extraction equipment removes the contaminants. The ERH-enhanced steam bubble floatation process can significantly reduce (>85% concentration reduction) coal and oil tar constituents with boiling points of less than 300°C. Left behind are immobile, insoluble, and non-volatile oil and coal tar fractions resulting in negligible impact to groundwater and greatly reduced risk from vapor intrusion.

Thus, chemical, biological, and physical processes are increasing the applicability of ERH in environmental restoration projects, treating a wider variety of compounds than previously considered. Further, these mechanisms lower costs by reducing the amount of energy used.

Two DoD project examples will be detailed, highlighting the hydrolysis reactions during the ERH remediation process, the effect on energy use, and the resulting cost savings.
THE TRUTH IS OUT THERE: UNRAVELING THE MYSTERY OF THE MISSING DCE, VINYL CHLORIDE & ETHENE

MR. EVAN COX
Geosyntec Consultants
130 Research Lane, Suite 2
Guelph, ON N1G 5G3 CANADA
(519) 822-2230, Ext. 237
ecox@geosyntec.com

CO-PERFORMERS: Dr. Jim Gossett (Cornell University); Dr. Jim Spain (Georgia Institute of Technology); Dr. Elizabeth Edwards and Dr. Barbara Sherwood Lollar (University of Toronto)

It is generally accepted that cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC) can further degrade through a variety of mechanisms. However, it has proven difficult to confidently and reliably quantify several of the degradation processes (mainly the oxidation and abiotic reactions) at field scale using common investigation techniques, and as such, monitored natural attenuation (MNA) and enhanced in situ bioremediation (EISB) cases invoking these reactions as explanations for apparent cDCE and VC mass loss often appear speculative. Research is in progress to better understand and quantify the frequency of occurrence, relative contribution, and overall environmental relevance of the various cDCE and VC degradation processes in field settings. The objectives of the research program are to:

• Confirm the existence of, and isolate if possible, microorganisms capable of anaerobic oxidation of cDCE and VC, and determine the degradation mechanism and pathway;
• Determine the actual aerobic oxidation pathway(s) and enzymology for cDCE oxidation;
• Verify potential mechanisms for ethene mass loss under reducing conditions; and
• Develop and field validate DNA-based molecular biological tools (MBTs) and compound specific isotope analyses (CSIA) for the aforementioned microorganisms and mechanisms.

This presentation will unveil groundbreaking new results for each of these areas. Specifically:
• Anaerobic oxidation linked to iron and manganese reduction remains elusive despite extensive testing. Aerobic oxidation at extremely low oxygen levels, under apparent anaerobic conditions, may provide an alternate explanation for some sites;
• Discovery of multiple distinct pathways of cDCE oxidation, including epoxidation, reduction to 1,2-DCA with subsequent transformation, or transformation via glutathione transferase;
• Confirmation of ethene transformation using CSIA, via reduction to ethane and possibly methane, providing proof and diagnostic tools to explain poor ethene mass balance at MNA and EISB sites.

Using the new information and MBT and CSIA tools produced through this project, remediation practitioners will be better able to understand and potentially quantify the relative roles of the various cDCE and VC degradation mechanisms at field scale, improving the quality of MNA and EISB projects.
ENZYME ACTIVITY PROBES (EAP) FOR ESTIMATING TCE DEGRADATION RATES

M. HOPE LEE
Idaho National Laboratory
P.O. Box 1675
MS2203
Idaho Falls, ID 83415
(208) 526-8212
hope.lee@inl.gov

CO-PERFORMERS: Dana Swift (North Wind, Inc.); Vinton King (Tinker Air Force Base); Crispin Wanyolke (AECOM)

Estimating a link between microbiological activity and contaminant degradation rates are often high priorities for evaluating the potential of selecting monitored natural attenuation (MNA) as a remedy at field sites. Molecular biological tools (MBTs) can contribute significantly in directly estimating or documenting the extent and rate of microbial degradation. A demonstration to develop the relationship between enzyme activity probes (EAP) for aerobic cometabolic enzymes, and TCE degradation rates is presently underway at several contaminant plumes. The primary objectives of this demonstration are to validate methods for (a) directly assessing the activity and contribution of targeted enzymes for cometabolism, and (b) determining TCE degradation rates for aerobic chlorinated solvent plumes. Secondary objectives include (a) determining the relationship between EAPs and other MBTs such as qPCR and fluorescent in situ hybridization (FISH) and (b) to determine the importance of sampling media. Tinker Air Force Base, Building 3001 is the site of a chlorinated solvent plume. Contaminant trend data suggest that the contaminants present in situ are attenuating and regions of the plume are aerobic. Analyses of groundwater from the site revealed there was a significant response with EAPs, and other indicators of aerobic metabolism. A microcosm study was performed on four distinct groundwater samples. The in situ microbial population showed significant activity with EAPs and other MBTs evaluated; more importantly the microcosms showed degradation of the contaminant. Follow-on studies currently being conducted include a second microcosm at the site, the incubation and sampling of biotrap samplers in the same wells sampled for the lab microcosm, and site core analysis. A comparison of total biomass, activity, and potential will be completed for all three sampling media. IRP Site 2 in El Toro, California also showed significant activity with the EAPs. Historical groundwater geochemical conditions suggest the aquifer is aerobic. Microcosm studies from this site are showing degradation of the contaminants and EAP activity. Interestingly, it appears that the cometabolic potential is found primarily within the contaminant plume, likely based on availability of carbon, whereas in most other investigations the potential for and activity of the oxygenase gene is wide spread. Together these data provide evidence that the EAPs provide an accurate and direct measurement of activity for the targeted oxygenases. More importantly, these studies are providing a more detailed description of the distribution, potential, activity, and even sustainability of aerobic processes and their importance in degrading chlorinated solvents. This work is funded under ESTCP Project ER-0708.
A NEW CORE SAMPLER FOR CRYOGENIC COLLECTION OF COMPLETE SUBSURFACE SAMPLES FOR MOLECULAR BIOLOGICAL TOOLS ANALYSIS

DR. RICK JOHNSON
Oregon Health and Science University
20000 NW Walker Road
Beaverton, OR 97006
(503) 748-1193
rjohnson@ebs.ogi.edu

CO-PERFORMERS: Reid O’Brien Johnson (Oregon Health and Science University); Tom Christy (Geoprobe Systems, Inc.)

Molecular biological tools (MBT) are an increasingly important approach for evaluating subsurface bioremediation performance. Currently, most MBT analyses are performed on water samples collected from wells. While water samples can be used to identify the presence of particular organisms in the subsurface, it is generally accepted that most organisms are associated with aquifer solids and that community structures on those solids are likely to be different than those in an associated water sample. However, collection of high-quality subsurface solids for MBT analysis is difficult because of possible contamination, incomplete solids recovery and redistribution of fluids during sample collection. To overcome these difficulties, we have developed a core sampler that freezes samples in situ and allows them to remain frozen during transport to the laboratory.

The current version of the cryogenic sampler is specifically designed to work with the Geoprobe “Dual Tube” sampler, but it can easily be adapted to work with any drilling method. To freeze the sample, liquid nitrogen (LN) is delivered to the core barrel and vented out the drill rod string. The core barrel contains internal channels that allow the LN to circulate within the barrel, while remaining isolated from the sample and the subsurface. Freezing of the core takes ~3 minutes, after which the core can be removed from the subsurface through the outer drill casing. Samples can then be packed in dry ice, shipped to the lab and stored until they are processed.

Once at the laboratory, cores can be rapidly sectioned by: (1) cutting the sleeve containing the core into cylindrical sections with a tubing cutter; (2) cleaving the frozen core with a sterile chisel (this can be accomplished on core sections as thin as 1 cm); and (3) sub-coring the cylindrical section with a sterile diamond-tipped hole saw to eliminate any contamination present on the outside surface of the core. Frozen samples can then be transferred directly to media for extraction of the desired biomolecule. It has previously been demonstrated that DNA, RNA and proteins are all preserved during whole-sample freezing, storage for periods of months and extraction of frozen core sections.

This work is funded under SERDP Project ER-1559.
COMPARISON OF PCR AND FISH FOR DETECTION OF BACTERIA IN DECHLORINATING SAMPLES

DR. NATUSCHKA M. LEE
Technical University of Munich, Department of Microbiology
Am Hochanger 4
Freising/Munich D85354 GERMANY
+491799414338
nlee@microbial-systems-ecology.de

CO-PERFORMERS: D. B. Meisinger and H. Schmidt (Technical University of Munich); Kirsti M. Ritalahti and Frank E. Löeffler (Georgia Institute of Technology); Carmen A. Lebrón (Naval Facilities Engineering Service Center)

Microscopy tools combined with specific gene probes and fluorescence in situ hybridization (FISH) complement nucleic acid-based tools, like traditional or quantitative PCR, in several useful ways. Not only do microscopy-based tools provide crucial information on morphology and growth characteristics, they also reveal the distribution and dynamics of different species simultaneously; thus, they allow the exploration of synergistic relationships with greater detail. Unfortunately, data interpretation of FISH results obtained for contaminated aquifers, sediments, and soil has proven to be difficult due to factors such as low cell counts, slow activity measurements, low activities, and confounding background “noise” caused by undefined particles. The aim of this research is to optimize and develop novel FISH tools to visualize not only metabolic reductively dechlorinating bacteria, but also relevant associated community members such as methanogens and sulphate-reducing bacteria in chloroorganic contaminated environmental systems. This project approached these goals using five subtasks: (i) development of hierarchical probe sets targeting different types of genes for all known dechlorinating species, which will also enable the identification of novel affiliated species; (ii) systematic evaluation of different types of sampling preparation and FISH protocols; (iii) application of different FISH tools on different types of samples from pure cultures of reductively dechlorinating strains, defined dechlorinating consortia cultivated under lab under different conditions, and groundwater samples collected from different tetrachlorethene (TCE)-contaminated sites; (iv) comparison of different FISH protocols with other analytical tools such as PCR and degradation kinetic studies; and (v) intergrated lab and field studies employing optimized FISH approaches for detailed characterization of the microbial ecology of dechlorinating species. This project will systematically compare results obtained by FISH and different molecular biological tools (subtask iii) on different chloro-organic solvent contaminated field samples in Germany as well as in the United States. Significant discrepancies were occasionally observed between results obtained using different analytical tools (e.g., degradation patterns, nucleic acid-based studies such as PCR, electron microscopy and FISH). These details have been explored in order to develop a confirmation protocol that serves to explain the known biases of each tool and discusses suggestions for how these biases can be minimized in order to enable advanced, holistic insight into the true presence, function, and activities of reductively dechlorinating organisms in lab cultures and field samples.

This work is funded under SERDP Projects ER-1561 and ER-1586.
Microarrays for Reductive Dechlorination Biomarker Identification and Dehalococcoides Monitoring

DR. FRANK LÖEFFLER
Georgia Institute of Technology
Environmental Engineering
311 Ferst Drive
Atlanta, GA 30332
(404) 894-0279
frank.loeffler@ce.gatech.edu

CO-PERFORMERS: Dr. Kirsti Ritalahti and Elizabeth Padilla (Georgia Institute of Technology); Laura Hug and Dr. Elizabeth Edwards (University of Toronto)

Microbiologically-mediated anaerobic reductive dechlorination is an important process for bioremediation of sites contaminated with chlorinated solvents. Members of the Dehalococcoides group catalyze dechlorination of chlorinated ethenes and other chlorinated contaminants to environmentally benign products, and have thus become relevant in bioremediation. All known Dehalococcoides organisms contain multiple, distinct reductive dehalogenase (rdh) genes. Little is understood about Dehalococcoides biology, in particular the evolution and functional importance of the rdh gene complement present within each Dehalococcoides genome. Distinct rdh gene complements give Dehalococcoides strains unique substrate specificities; however, only few reductive dehalogenases (RDases) have been biochemically characterized, and the function of the majority of rdh genes has not been determined. To distinguish Dehalococcoides sharing identical 16S rRNA gene sequences, assign function to rdh genes, correlate rdh gene expression with dechlorination activity, and determine the dechlorination potential (i.e., the presence of rdh genes) at contaminated sites, this project designed and tested two different microarray platforms. The rdh microarray is a spotted oligoarray with 1,690 probes that target all known rdh, hydrogenase, and dechlorinator 16S rRNA genes, as well as several other Dehalococcoides genes of interest. The rdh array aims to assign function to Dehalococcoides rdh genes responsible for specific dechlorination reactions. Microarray performance was systematically evaluated, revealing that rdh gene transcription is a dynamic process and that multiple RDase genes respond to a single chlorinated substrate, suggesting functional redundancy or unspecific induction of rdh gene transcription.

A second microarray is based on the Agilent 60-mer array platform and consists of probes targeting all genes identified on the five available Dehalococcoides genomes and includes a ‘pan-genome’ array. The integrated application of these microarray platforms to samples from laboratory cultures and contaminated field sites will provide new insights into rdh gene diversity, identify new process-specific biomarkers, validate the pan-genome array approach to comprehensively capture Dehalococcoides genes, generate new understanding of Dehalococcoides metabolic networks and monitor Dehalococcoides gene expression and activity.

This work is funded under SERDP Project ER-1586.
ELUCIDATING THE ROLE OF HORIZONTAL GENE TRANSFER IN VINYL CHLORIDE RESPIRATION OF DEHALOCOCCOIDES THROUGH COMPARATIVE GENOMICS

PAUL J. MCMURDIE
Stanford University
318 Campus Drive - BioX
E250, Spormann Lab
Stanford, CA 94305
(650) 868-1899
mcmurdie@stanford.edu

CO-PERFORMERS: Professor Alfred Spormann (Stanford University); Professor Frank Löeffler (Georgia Institute of Technology)

Respiration of vinyl chloride is both unique to certain members of the Dehalococcoides group and key to complete reductive dehalogenation of chloroethenes to non-toxic ethene. We analyzed and compared the genome sequences of Dehalococcoides (Dhc) strains VS, BAV1, GT and KB1-VC, all Dhc strains capable of vinyl chloride (VC) respiration. In all strains, the VC reductase operon is embedded within a genomic island (GEI), with clear signatures for recent acquisition. Furthermore, strains VS, GT, and KB1-VC have a nearly identical vcrABC-operon in a distinct GEI that has integrated at the same position in each genome. The site-specific integration appears to depend on a recognition of the terminal (3’) 30 bps of the highly conserved, single copy ssrA gene. Repeated fragments of this 30 bps stretch of ssrA are found downstream demarcating the boundaries of the vcrABC island as well as other rdhA-containing GEIs in these Dhc strains. This suggests that site-specific integration at ssrA is a common mechanism for dissemination of rdhA among Dhc in general, and not specific to only horizontal acquisition of vcrABC. The nearly identical sequence of the vcrABC operons in these strains, as well as their position immediately flanking ssrA, suggests that vcrA is among the most recently acquired rdhA in these Dhc strains. Molecular tools were designed to specifically target ssrA and other key recognition sites for acquisition of novel rdh genes in Dhc. These tools have been applied to various Dhc-containing cultures to explore the recent evolution of reductive dehalogenation in Dehalococcoides. The results suggest that acquisition of a VC reductase operon is sufficient to confer Dhc with the ability to respire VC.

This work is funded under SERDP Project ER-1588.
TRANSCRIPTOME ANALYSES OF UNSEQUENCED DEHALOCOCCOIDES STRAINS IN DECHLORINATING ENRICHMENT CULTURES USING A GENUS-WIDE MICROARRAY

MS. KIMBERLEE A. WEST
University of California, Berkeley
Department of Civil and Environmental Engineering
Berkeley, CA 94720-1170
(510) 643-9714
kimberleew@gmail.com

CO-PERFORMERS: Dr. Ping Hu, Dr. Todd Z. DeSantis, Dr. Eoin L. Brodie, and Dr. Gary L. Andersen (Lawrence Berkeley National Laboratory); Dr. Patrick K. H. Lee and Dr. Lisa Alvarez-Cohen (University of California, Berkeley); Dr. Stephen H. Zinder (Cornell University)

Bacteria in genus *Dehalococcoides* could completely reductively dechlorinate chlorinated ethenes to the nontoxic end product, ethene. This unique metabolic activity has rendered *Dehalococcoides*-based in situ bioremediation emerging as an effective treatment option for chlorinated ethenes. *Dehalococcoides* spp. must depend on supporting organisms to survive in the environment, since they are strictly dependent on hydrogen and cobalamin for dechlorination, but cannot generate either de novo. However, to date, the effects of community structure on the performance of *Dehalococcoides* in a dechlorinating microbial community are still indeterminate. In order to determine the interactive responses of *Dehalococcoides* spp. to the changes of microbial community, this work developed a new *Dehalococcoides* genus-wide microarray which allows us to query a more comprehensive view of all the *Dehalococcoides* genes and their transcripts. The microarray was developed based upon the publicly available annotated genomes of the four *Dehalococcoides* strains (195, CBDB1, BAV1, and VS). A total of 4739 probe sets for the correspondent candidate genes were designed on the array, including the unique coding genes belonging to each annotated strain, as well as the common coding genes shared among all the annotated strains. This project applied this new genus-wide microarray to a *Dehalococcoides*-organism-containing microbial consortium (referred to as ANAS) that was enriched from contaminated soil. DNA from ANAS was hybridized to the microarray to characterize the genomic content of the ANAS enrichment. The microarray results revealed a high degree of gene conservation between ANAS and strain 195, some similarity of ANAS to VS, and little gene conservation between ANAS and either BAV1 or CBDB1. These results suggest that the *Dehalococcoides* strain(s) present in ANAS represent a unique collection of functional genes. Additionally, RNA was collected from ANAS at 3 time-points throughout the growth cycle of the culture and was applied to the microarray to investigate differential gene expression within ANAS across temporal and growth phase variations. Analysis indicates that about 1/3 of the ANAS genes detected by the microarray were differentially expressed between time-points. These insights into the transcriptomes of *Dehalococcoides* under different environmental parameters will improve our understanding of the physiology of these bacteria in the environment, which is essential in developing effective strategies for in situ bioremediation of chlorinated ethenes in the environment. This work is funded under SERDP Project ER-1587.
A continuous-flow column study was conducted to analyze the reductive dehalogenation of trichloroethene (TCE) in a soil representative of that found on contaminated sites. The column was packed in aquifer material containing a high iron concentration and was bioaugmented with the Point Mugu (PM) culture, which is capable of completely transforming TCE to ethene. A comparison was made to determine whether lactate, formate, or propionate fermentation resulted in more effective dehalogenation. The combined microbial processes of reductive dehalogenation, fermentation, sulfate, and iron and manganese reduction were all exhibited within the column. Different pseudo-steady-states of dehalogenation were achieved based on the concentration of substrates added, with very effective transformation to ethene obtained when ample electron equivalents were provided. Most of the electron donors were channeled to sulfate, iron, and manganese reduction. When similar electron equivalents were added, the most effective dehalogenation was achieved with formate, 14% of the electron equivalents going towards dehalogenation reactions, compared to 6.5% for lactate and 9.6% for propionate. Effective dehalogenation was maintained over 1000 days of column operation. Over 90% of electron equivalents added were accounted for, with 50% associated with soluble and precipitated iron and manganese reduction. More iron and manganese reduction was associated with lactate addition than formate addition. Sulfate reduction was a competing electron acceptor reaction with all three electron donors. DNA was extracted from solid samples obtained during the course of the experiment and analyzed using 16S rRNA gene clone libraries, quantitative PCR, and hydrogenase gene DNA microarrays. Lactate addition resulted in an increase in Geobacter, Spirochaetes, and Desulfitobacterium phylotype population relative to Dehalococcoides compared to formate addition. Molecular results support chemical observations that a greater percentage of the electron donor addition was channeled to iron reduction when lactate was added compared to formate, and formate was more effective than lactate in supporting dehalogenation. The results demonstrate the importance of electron donor selection and side reactions in the design of reductive dehalogenation remediation technologies.

This work is funded under SERDP Project ER-1588.
COMPARISON OF FISH VERSUS PCR-BASED QUANTIFICATION OF DEHALOCOCCOIDES CELLS IN PCE/TCE-CONTAMINATED GROUNDWATER

DR. MICHAEL LEPUIL
Tetra Tech, Inc.
800 Oak Ridge Turnpike, Suite A-500
Oak Ridge, TN 37830
(703) 885-5448
michael.lepuil@tetratech.com

CO-PERFORMERS: Dr. John Biggerstaff, Ph.D. and Dr. Steven Minkin, Ph.D. (University of Tennessee); Dr. Frank Löffler, Ph.D. (Georgia Institute of Technology); Dr. Ronnie Britto, Ph.D., P.E., Steve Muffler, P.G., C.G.W.P., and Dr. Rick Arnseth, Ph.D., P.G. (Tetra Tech, Inc.); Mike Kovacich, P.G. and Dr. Dan Burnell, Ph.D., P.G. (GeoTrans, Inc.)

Chlorinated solvent (e.g., PCE, TCE) releases have resulted in contamination of aquifers and groundwater reservoirs used for drinking water production, hence causing serious public health issues. In addition, site closures under the Base Realignment and Closure (BRAC) program and property transfers are often delayed when contaminants in soil and groundwater prevent these facilities and associated land from being redeveloped. Due to cost concerns and increased environmental awareness, bioremediation and (enhanced) monitored natural attenuation are increasingly used for treating such contamination. These processes rely on degradation of the contaminants by native or augmented microbial populations. Paramount to the technology is detoxification and production of non-toxic products. While several organisms have been found to transform PCE and TCE to less chlorinated ethenes through the reductive dehalogenation process, the only organisms known detoxify dichloroethenes and vinyl chloride to innocuous ethene (i.e., complete dehalogenation) are members of the recently discovered *Dehalococcoides* group. The most commonly used method to detect and quantify these bacteria is the quantitative real-time Polymerase Chain Reaction (qPCR) assay. qPCR relies on extracting the DNA from the sample (thus destroying the cells), amplifying *Dehalococcoides*-specific target genes with specific primers (SYBR Green assay) and probes (TaqMan assay) and correlating target gene copies to cell numbers. This study discusses the comparison of qPCR with an alternative technique known as Fluorescence In-Situ Hybridization (FISH), at two distinct PCE/TCE contaminated sites, for the direct quantification of the *Dehalococcoides* cells in groundwater. FISH involves specific fluorescently-labeled oligonucleotide probes similar to TaqMan probes, but FISH does not rely on DNA extraction and PCR amplification. Attachment of the probe to its target (i.e., hybridization) is carried out directly within the cell, whose morphology and integrity are preserved thanks to a fixation step with paraformaldehyde. With FISH, quantification is carried out by taking a series of fluorescence microphotographs of the sample, separating the signals of the fluorescent label/probe combinations in different channels, and quantifying the fluorescence conferred by each probe in each channel. Cell density is obtained by dividing the total fluorescence in each channel by the fluorescence emitted by a known number of visually identifiable and separable organisms in that channel. While offering unique advantages (e.g., imaging and in-situ approach) unavailable with qPCR, this study shows, through side-by-side comparison, that FISH constitutes a suitable technique for direct and true quantification of the *Dehalococcoides* cells in groundwater and complements qPCR for monitoring of bioremediation and MNA at TCE/PCE-contaminated sites.
DESIGNING MONITORING LOCATIONS IN FRACTURED ROCK FOR REMEDIATION OF CHLOROETHENE CONTAMINATED GROUNDWATER

DR. ALLEN SHAPIRO
U.S. Geological Survey
12201 Sunrise Valley Drive
Mail Stop 431
Reston, VA 20192
(703) 648-5884
ashapiro@usgs.gov


The U.S. Geological Survey, with the support of SERDP, is undertaking a field-based investigation of the fate of chloroethene-contaminated groundwater in fractured sedimentary rock. Field techniques and interpretive methods are being developed to evaluate the remediation of groundwater contaminated by trichloroethene (TCE) and its daughter products by pumping, natural attenuation, and bioaugmentation. The investigation is being conducted at the former Naval Air Warfare Center (NAWC), West Trenton, NJ, where TCE was released at land surface and migrated into the underlying fractured mudstones of the Newark Basin.

As part of this investigation, an in situ bioaugmentation experiment was conducted at the NAWC by injecting an electron donor material, along with a consortium of bacteria known to degrade TCE and its daughter products. The bioaugmentation experiment showed significant reduction of TCE concentrations at the injection borehole, but no perceptible change at a nearby abstraction well that is part of the pump-and-treat operation at the site. Results from the injection borehole point to the successful application of bioaugmentation amendments, whereas results from the abstraction borehole indicate the bioaugmentation was ineffective.

In highly heterogeneous groundwater flow regimes, such as fractured rock, it is challenging to evaluate the effectiveness of remediation based on concentrations from a sparse number of monitoring boreholes. Monitoring of remediation in boreholes where amendments have been added provides a biased interpretation, because residuals may remain from the injection of the amendments. At points of groundwater withdrawals, evaluating the effectiveness of remediation requires detailed knowledge of the groundwater flow regime. At the NAWC, careful characterization of groundwater flow using a combination of hydraulic and chemical tracing experiments showed that water withdrawn from the pumped borehole was primarily drawn from areas of the aquifer other than that treated with the bioaugmentation amendments. To accurately assess the degradation of TCE from the bioaugmentation experiment at the NAWC, monitoring wells were installed along flow paths between the injection and pumping boreholes to monitor the biogeochemical evolution of the groundwater.

This work is funded under ESTCP Project ER-1555.
MONITORING MICROBIAL COMMUNITY STRUCTURE BEFORE AND DURING BIOAUGMENTATION AT THE FORMER NAVAL AIR WARFARE CENTER (NAWC) SITE

MS. JULIE KIRSHTEIN
U.S. Geological Survey
12201 Sunrise Valley Drive, MS430
Reston, VA 20192
(703) 648-5493
jkirshte@usgs.gov

CO-PERFORMERS: Mary Voytek, Allen Shapiro, Tom Imbrigiotta, Dan Goode, and Claire Tiedeman (U.S. Geological Survey)

The Naval Air Warfare Center (NAWC) was a U.S. Navy jet engine testing facility from the mid 1950’s until the late 1990’s. Activities at the facility caused trichloroethlylene (TCE) and jet fuel to leak into the underlying fractured-rock aquifer. Research supported by SERDP (under Project ER-1555), the U.S. Navy, and the U.S. Geological Survey at the NAWC is evaluating the mass removal capacity of Pump-and-Treat, monitored Natural Attenuation, and Enhanced Bioaugmentation in fractured rock aquifers. This research is focused on an area referred to as the In Situ Test Facility (ISTF) at NAWC where concentrations of TCE are as high as 100,000 µg/L. A transect from an injection borehole (36BR) to a pumping borehole (15BR) was established and characterized before beginning a bioaugmentation experiment. This experiment was conducted by adding KB1™, a consortium of anaerobic dechlorinating bacteria, and EOS™ electron donor material, on October 15, 2008. As part of the bioaugmentation experiment, quantitative PCR was used to characterize specific populations of the microbial community for six months prior to the start of the experiment and after its inception. Microbial communities under investigation included dechlorinators (organisms containing vinyl chloride reductase and Dehalococcoides), sulfate reducers, Geobacter (an iron reducer), and methanogens. The data provide a baseline by which the biodegradation potential of the natural community could be evaluated and progress of the bioaugmentation experiment monitored. Groundwater samples from 11 ISTF monitoring locations were collected 4 times between March and August 2008 before the bioaugmentation commenced, and 6 times after the start of the experiment between October 2008 and May 2009. Microorganisms capable of dechlorinating TCE were present at some sites within the ISTF prior to injection of the bioaugmentation amendments but not at concentrations deemed necessary for effective TCE degradation. The effect of bioaugmentation could be seen by decreases in chlorinated parent compounds and several order of magnitude increases of dechlorinators at the injection borehole and other monitoring boreholes within the ISTF. Changes in abundances of sulfate reducers, Geobacter, and methanogens also were observed at the injection site and several nearby monitoring locations. A weak correlation between dechlorinator abundances and geochemical evidence of dechlorination was observed. Quarterly monitoring is ongoing and the analyses should provide better tools for evaluating and monitoring the succession of microbial communities during bioaugmentation and the effectiveness of the bioaugmentation in fractured rock aquifers.
SIMULATION OF THE REACTIVE TRANSPORT AND MASS REMOVAL OF CHLOROETHENES IN A FRACTURED ROCK AQUIFER

GARY P. CURTIS
U.S. Geological Survey
345 Middlefield Road, MS 409
Menlo Park, CA  94306
(650) 329-4553
gpcurtis@usgs.gov

CO-PERFORMERS: Paul A. Hsieh, Thomas E. Imbrigiotta, Claire R. Tiedeman, and Allen M. Shapiro (U.S. Geological Survey); Mary F. DeFlaun (Geosyntec)

Remediation of fractured-rock aquifers contaminated with chlorinated solvents is challenging because of the complexity of groundwater flow and contaminant reactive processes in the aquifer. The U.S. Geological Survey and Geosyntec Consultants, with the support of the SERDP-funded project ER-1555 and the U.S. Navy, have been evaluating the mass removal of dissolved chloroethenes by pumping, monitored natural attenuation, and bioaugmentation in a trichloroethene (TCE) contaminated fractured-rock aquifer at the former Naval Air Warfare Center (NAWC), West Trenton, New Jersey. High chloroethene concentrations have persisted at the site even though pump-and-treat remediation has been ongoing since 1995. Natural reductive dechlorination has partially transformed TCE to cis-1,2-dichloroethene (cisDCE), vinyl chloride (VC), and ethane, but the process is too slow to efficiently remove the chloroethenes from the aquifer. An in situ bioaugmentation experiment was initiated in 2008 by co-injection of an electron donor (EOS™) and a microbial consortium containing Dehalococcoides ethenogenes (DHC) to test this method for accelerating chloroethene removal. After the injection, TCE concentrations decreased while cisDCE, VC and ethene concentrations increased in the injection well and in two downgradient monitoring wells. Sulfate concentrations decreased while Fe(II) and methane concentrations increased, indicating that multiple electron acceptors compete for the electron donor.

Reactive transport simulations are being conducted to understand the processes that control the observed chloroethene concentrations under background and bioaugmentation conditions. Natural attenuation and pump and treat were simulated using a simple conceptual model that considered heterogeneous transmissivity, matrix diffusion, and first-order decay. Model parameters were constrained by results from aquifer tests, nonreactive tracer tests, field-based estimates of TCE diffusion rates in the primary porosity, and historical concentrations. Simulations of the bioaugmentation experiment included fermentation of EOS™ to form acetate and H2. The H2 is used by native and injected DHC to transform TCE to cisDCE, VC and ethene and to synthesize DHC biomass. In addition, the simulations include the competitive consumption of H2 and acetate by iron-reducing, sulfate-reducing and methanogenic bacteria. These competitive reactive processes were incorporated in a reactive transport model to quantify the degradation rates and reaction pathways occurring in the subsurface. A preliminary analysis suggests that approximately one third of the electron donor is coupled to reductive dechlorination, while the remaining electron donor is consumed by background concentrations of other electron acceptors. The reactive transport model will be used to quantify and compare the mass removal of the chloroethenes by natural attenuation, pump and treat, and bioaugmentation.
SOLID POTASSIUM PERMANGANATE EMLACEMENT USING HYDRAULIC FRACTURING

CORINNE MARKS, P.E.
URS Corporation
2870 Gateway Oaks Drive, Suite 150
Sacramento, CA  95833
(916) 679-2343
corinne_marks@urscorp.com

CO-PERFORMER: Maurice Benson (Defense Enterprise Support San Joaquin)

A potassium permanganate (KMnO₄) pilot study was conducted at the Defense Distribution Depot San Joaquin California, Sharpe Site (DDJC-Sharpe) in Lathrop, California. The pilot study involved emplacing solid KMnO₄ using hydraulic fracturing, then evaluating its distribution and effectiveness in reducing trichloroethene (TCE) groundwater concentrations greater than 1,000 micrograms per liter (µg/L) in clay, silt, and sand layers of the saturated zone between 40 and 75 feet below ground surface (bgs).

The pilot study consisted of: (1) establishing baseline conditions by sampling groundwater within the pilot study area using the HydroPunch method and installing and sampling monitoring wells outside of the fracture area; (2) emplacing 8,000 pounds of solid KMnO₄ as a KMnO₄ solids-gel slurry using hydraulic fracturing at several depths (47, 53, 59, 65, and 71 feet bgs) in two fracture initiation boreholes (FIB); and (3) conducting performance monitoring by advancing soil borings after fracturing to verify physical fracture extent (i.e., radius of fracture) and by advancing soil borings 6 and 12 months after fracturing to evaluate KMnO₄ diffusion. Performance monitoring also included sampling groundwater using the HydroPunch method within the pilot study area and monitoring wells outside of the fracture area. Samples were analyzed for volatile organic compounds (VOCs) and metals.

The objectives of this pilot study were to evaluate the effectiveness of emplacing KMnO₄ into fine-grained (low-permeability), saturated-zone layers using hydraulic fracturing to (1) increase subsurface distribution of the oxidant over other injection methods and (2) destroy VOCs through oxidation. Based on the pilot study results, the following can be concluded:

1. KMnO₄ distribution in low-permeability layers is increased by use of fracturing and diffusion. The distance of fracture in fine-grained lithology from the FIB averaged 10 feet. The KMnO₄ vertical diffusion rate in fine-grained lithology averaged approximately 10 inches per month. However, fracturing was not predictable or uniform at DDJC-Sharpe.

2. KMnO₄ effectively oxidizes TCE in the fracture area to concentrations less than 5 µg/L. However, since KMnO₄ was not evenly distributed within the entire soil matrix, rebound may occur after KMnO₄ dissipates.
SODIUM PERSULFATE ACTIVATED WITH MODIFIED FENTON’S REAGENT FOR THE TREATMENT OF CARBON TETRACHLORIDE

JAMES F. FEIN
ECC
1600 Falmouth Road, Unit 40
Centerville, MA 02632
(508) 771-1636
jfein@ecc.net

CO-PERFORMERS: Prasad Kakarla and William Caldicott (ISOTEC, Inc.);
David Glass (Malcolm-Pirnie, Inc.)

Previous operations at a former fire station in an active Department of Defense (DoD) facility resulted in groundwater volatile organic compound (VOC) contamination. Dissolved phase VOCs detected at the site include carbon tetrachloride (CCl₄), trichloroethylene (TCE), and chloroform. The primary contaminant of concern at the site is CCl₄; non-aqueous phase liquids have not been previously detected. The geology at the site consists of fine grained sediments - a silty sand/ clayey sand, and a silt/sandy silt matrix. A clay confining unit is located at a depth of approximately 35-feet below ground surface (bgs). An average hydraulic conductivity of 7.63 × 10⁻⁴ cm/sec was determined for the shallow water bearing unit, along with an estimated porosity of approximately 0.20. Groundwater elevations at the site range from 4.5 to 12 feet bgs and the hydraulic gradient is estimated at 0.18 feet/foot. Groundwater flow direction is towards the north-northeast. The chosen oxidizer, sodium persulfate (activated with modified Fenton’s Reagent), was injected at the top of the confining clay layer with the objective of targeting dissolved VOC contamination in the vicinity of the confining unit. A vertical treatment interval of 15- to 35-feet bgs was designed for the site.

One treatment application was performed at the site via direct-push techniques. A total of 31 injection points were advanced to the vicinity of the confining unit. Each injection point was divided into a lower treatment zone (27.5-35 feet bgs) and an upper treatment zone (20-27.5 feet bgs). The treatment typically consisted of the injection of sodium persulfate first, followed by the modified Fenton’s Reagent. Catalysts were also injected at each injection point.

A total of six or more side-gradient and down-gradient monitoring wells were sampled prior to the injection event and during four subsequent sampling events. This work will discuss the treatment effect of the sodium persulfate/modified Fenton’s Reagent on the dissolved phase VOCs. Performance monitoring to date indicates that CCl₄ concentrations at the source area well have decreased from 500 µg/L to 80 µg/L with reduction of other VOCs to nearly below detection limits. A Remedy-In-Place designation was achieved for the site in September 2008.
SODIUM PERMANGANATE FOR THE TREATMENT OF TRICHLOROETHYLENE

JAMES F. FEIN
ECC
1600 Falmouth Road, Unit 40
Centerville, MA 02632
(508) 771-1636
jfein@ecc.net

CO-PERFORMERS: Prasad Kakarla and William Caldicott (ISOTEC, Inc.);
David Glass (Malcolm-Pirnie, Inc.)

Historic operations at a maintenance building in an active Department of Defense (DoD) facility resulted in groundwater volatile organic compound (VOC) contamination. Various vehicular and facility maintenance operations were conducted for an unspecified number of years. Waste liquids (petroleum products, paints, and solvents) dripped onto floor surfaces and subsequently drained to a leaching drywell adjacent to the building, contaminating groundwater. Dissolved phase VOC detected at the site include trichloroethylene (TCE), tetrachloroethylene (PCE), and cis-1,2-dichloroethene (DCE). Records indicate that impacted filter media and soil may still exist at the former source area. The primary contaminant of concern at the site is TCE. Non-aqueous phase liquids have not been previously detected. The geology at the site largely consists of a fine to medium silty and clayey sand matrix. A sandy clay semi-confining unit is located at a depth of approximately 35-feet below ground surface (bgs). An average hydraulic conductivity of $1.02 \times 10^{-2}$ cm/sec was determined for the shallow water bearing unit along with an estimated porosity of approximately 0.25. The hydraulic conductivity of clayey sand lenses was estimated at $7.5 \times 10^{-4}$ to $9.68 \times 10^{-4}$ cm/sec. Groundwater elevations at the site range from 15 to 20 feet bgs and the hydraulic gradient is estimated at 0.0107 feet/foot. Groundwater flow direction is towards the east and site surfaces are impervious (paved or covered with buildings).

One treatment application of sodium permanganate was performed at the site via direct-push techniques. A total of 24 injection points were advanced to the top of the semi-confining unit to target dissolved VOC contamination. A vertical treatment interval of 15 to 35 feet bgs was targeted during the application of sodium permanganate. Each injection point was divided into a lower treatment zone (25-35 feet bgs) and an upper treatment zone (15-25 feet bgs). Injections were performed by first targeting the lower treatment zone and then the upper treatment zone.

A total of four or more side-gradient and down-gradient monitoring wells were sampled prior to the injection event and during four subsequent sampling events. This work will discuss the treatment effect of sodium permanganate on the dissolved phase VOC. Performance monitoring to date indicates that TCE concentrations at the source area well have decreased from 326 µg/L to below detection limits, with the reduction of other VOC to nearly below detection limits. A Remedy-In-Place designation was achieved for the site in September 2008.
LOADING RATES AND IMPACTS OF SUBSTRATE DELIVERY FOR ENHANCED IN SITU ANAEROBIC BIOREMEDIATION

BRUCE M. HENRY
Parsons
1700 Broadway, Suite 900
Denver, CO 80290
(303) 831-8100
bruce.henry@parsons.com

CO-PERFORMERS: Dr. Ross Miller (Parsons); Ms. Erica Becvar (Air Force Center for Engineering and the Environment-Environmental Restoration Division)

Effective application of enhanced in situ bioremediation of chlorinated solvents in groundwater depends on the delivery of appropriate levels of substrate amendments in the subsurface and the development of optimal geochemical conditions for anaerobic degradation processes to occur. An inadequate substrate loading rate (i.e., the volume, concentration, and frequency of injection) may result in reducing conditions that are insufficient to support complete dechlorination of chlorinated solvents, thereby increasing the potential for accumulation of regulated intermediate dechlorination products. Conversely, excessive levels of organic substrate may lead to inefficient utilization of substrate and the potential for adverse impacts to secondary groundwater quality. Therefore, determining an appropriate substrate loading rate and delivery method are critical design and operational objectives for successful implementation of enhanced anaerobic bioremediation.

A study has been conducted and funded under ESTCP Project ER-0627 with the objectives to: (1) better understand the effects that substrate loading rates have on substrate distribution and persistence; (2) determine how control of loading rates affects development of optimal geochemical conditions; (3) identify loading rates that have adverse impacts on secondary water quality; (4) evaluate the effect that loading rates have on hydraulic conductivity; and (5) develop practical guidelines for designing and optimizing substrate loading rates for differing substrate types and for differing geochemical and hydrogeologic conditions.

Fifteen case studies were selected for a comparative review of the methods used to determine substrate loading rates. In general, there is a significant degree of uncertainty in determining the amount of substrate that will meet a site-specific electron-acceptor demand. A combination of evaluating the distribution and magnitude of native and anthropogenic electron acceptors at a site, along with comparing the substrate requirement to past applications at similar sites, provides the best method to determine an appropriate substrate loading rate.

Practical screening criteria are provided to avoid the most common issues that impact enhanced bioremediation performance. For example, evaluating the potential for the aquifer to buffer changes in pH is recommended to avoid undesirable pH excursions and costly modifications to add pH modifiers post-injection. Results of this study are used to develop guidance for designing appropriate substrate loading rates and implementing effective amendment strategies, with recommendations for the appropriate use of calculations and site-specific design factors.
CHALLENGES TO ENHANCED IN SITU BIOREMEDIATION OF CHLORINATED SOLVENTS IN A COLD TEMPERATURE ENVIRONMENT

BRUCE M. HENRY, PG
Parsons
1700 Broadway, Suite 900
Denver, CO 80290
(303) 831-8100
bruce.henry@parsons.com

CO-PERFORMERS: Ms. Melissa Markell and Ms. Donna Baumler (Elmendorf Air Force Base)

Two enhanced in situ bioremediation treatability studies using a combination of emulsified vegetable oil and sodium lactate have been conducted by the Air Force at the DP98 Site and the Kenney Avenue Plume at Elmendorf Air Force Base (AFB) in Anchorage, Alaska. Monitoring data showed near molar conversion of trichloroethene (TCE) to cis-1,2-dichloroethene (cis-DCE), with dechlorination of cis-DCE to vinyl chloride (VC) only being observed at the DP98 Site. Evidence of dechlorination to ethene was not observed, and cis-DCE and VC continue to persist at elevated concentrations at the DP98 site. These results may be due to a failure to achieve a groundwater redox state that is thermodynamically favorable for the transformation of cis-DCE to VC, or to a lack/slow growth of Dehalococcoides species.

Data collected under ESTCP Project ER-0627 indicates that the growth of native Dehalococcoides species was limited, if it occurred at all, under ambient groundwater temperatures of 7 to 8 degrees Celsius (°C) at the two sites. Select groundwater samples were submitted for quantification of Dehalococcoides species and reductase enzymes. Results for the DP98 Site indicate that Dehalococcoides species exist only at very low concentrations in groundwater. A single sample had a detectable concentration of Dehalococcoides—1.73E-01 cells per milliliter. All other results for Dehalococcoides and the functional genes for TCE, BAV1 VC, and VC reductase enzymes were below method detection limits. Results for the Kenney Avenue Plume were similarly below detection. The conversion of TCE to cis-DCE at both sites occurred with the onset of methanogenesis, and it is possible that the dechlorination of TCE to cis-DCE is carried out by non-Dehalococcoides species. A microcosm study performed under the Kenney Avenue Plume Study further showed that the growth of a Dehalococcoides mixed bioaugmentation culture (KB-1®) could not be sustained using native soil and groundwater at a laboratory controlled temperature of 10°C.

These studies demonstrate that dechlorination of TCE to cis-DCE and VC may be stimulated in a cold water environment. However, the ability to stimulate the growth of Dehalococcoides species to dechlorinate cis-DCE and VC to ethene appears to be a significant limitation. Alternative in situ treatment technologies may be considered, but the impacts of low temperatures on biological and chemical reactions should be carefully reviewed for sites with groundwater temperatures below 10°C.
NOVEL CHITOSAN-BASED PROCESSES FOR TOXIC METAL ION REMOVAL FROM ACIDIC ENVIRONMENTS

MR. PRASHANT JHA
Stony Brook University
K2164 ay Chapin Apartment
700 Health Science Drive
Stony Brook, NY 11790
(631) 365-9344
prashant.jha@gmail.com

CO-PERFORMER: Dr. Gary Halada (Stony Brook University)

Both the presence of groundwater plumes containing mobile toxic metal contaminants, as well as surface cleaning and decontamination methods, can result in formation of acidic solutions requiring volume reduction and long term stabilization. Chitosan, a safe and common organic macromolecule, is a well known chelator for metallic ions. It remains insoluble in water at neutral and alkaline pH, but is soluble if pH is acidic. This work investigates polymerization of chitosan with change in pH by various spectroscopic techniques (ultraviolet-visible spectroscopy [UV-Vis], fourier transform infrared spectroscopy [FTIR], and Raman Spectroscopy). Chitosan powder, chemically polymerized chitosan, electrochemically polymerized chitosan, and chemically modified chitosan using dimercaptosuccinic acid (DMSA) and tyrosine were investigated for their efficiency in contaminant removal. The contaminants tested were uranium(VI), mercury, and chromium(VI). Modified chitosan was found to be an excellent remediation agent. The process developed for remediation consists of three steps: (1) injecting chitosan solution at pH5 into contaminated solution and letting complexation take place; (2) inducing polymerization of chitosan either by increasing the pH or by using tyrosine solution; and (3) recovery of precipitated chitosan polymer containing contaminants. Complexes were analyzed at each stage of the process.

Effects of change in various parameters to optimize the process, including temperature, pH, deposition voltage and amount of modifiers, are also discussed. In addition, selectivity of the material in presence of competing ions is being investigated and will be discussed.
A DECISION FRAMEWORK FOR APPLYING ATTENUATION PROCESSES TO METALS AND RADIONUCLIDES

MR. CARL SPRENG
Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South
Denver, CO  80246
(303) 692-3358
carl.spreng@state.co.us

CO-PERFORMER: Dr. Dib Goswami (Washington State Department of Ecology)

Many sites across the United States have groundwater contaminated with metals or radionuclides – often at low levels, but above standards.

Most potential engineered remedies are too costly or otherwise impracticable. In contrast, attenuation-based remedies rely on natural processes to sequester the contaminants of concern and are therefore less aggressive, less invasive, and less costly. While attenuation of organic contaminants is being increasingly accepted as a remedy, attenuation of metals and radionuclides involves more complicated or interdependent sets of processes and has rarely been applied. Because technical guidance specifically addressing the use of attenuation-based remedies for metals and radionuclides has only recently been available, the application of attenuation remedies for metals and radionuclides has been inconsistent.

In order to facilitate the acceptance of attenuation-based remedies for metals and radionuclides, the Interstate Technology and Regulatory Council (ITRC) has developed a technical and regulatory guidance document, which builds upon the EPA’s new Technical Framework Documents and emerging policy directive. To determine the specific approach of this document, ITRC conducted a web-based survey of state regulators and stakeholders to determine the existing state of knowledge and acceptance regarding the application of attenuation processes as a remedy. The document addresses issues identified in the survey and provides paths forward for resolving them. The guidance also includes recommendations for evaluating and documenting attenuation-based remedies in a consistent and technically defensible manner. A decision framework flowchart guides users through a stepwise series of decisions that help determine if relying on attenuation processes is feasible and can lead to successful implementation.

ITRC’s document is intended for anyone involved with investigating, managing, or overseeing a site with metal and/or radionuclide contaminants. This audience includes public stakeholders, site owners, commercial operators, regulators, site managers, and investigators at all levels, including state and federal agencies.
VALIDATION OF AN IN VITRO BIOACCESSIBILITY TEST METHOD FOR ESTIMATION OF THE BIOAVAILABILITY OF ARSENIC FROM SOIL

MS. YVETTE WIEDER LOWNEY
Exponent, Inc.
4141 Arapahoe Avenue
Suite 101
Boulder, CO  80303
(303) 245-7070
Lowneyy@exponent.com

CO-PERFORMERS: Dr. Susan Griffin (EPA Region VIII); Dr. William Brattin, Gary Diamond, and Penelope Hunter (Syracuse Research Corporation); Dr. John Drexler (University of Colorado)

The objective of this effort is to develop an in vitro (i.e., bench-top) bioaccessibility assay that is predictive of the relative oral bioavailability of arsenic from soils and sediments, and that can be used to support bioavailability adjustments in human health risk assessment. At present, a broad database has established that the bioavailability of arsenic from soil can be significantly less than the assumed default of 100%, and that the controls on bioavailability from soil vary with site-specific factors. Regulatory guidance allows for adjustment to account for such reduced bioavailability, with appropriate supporting data. To date, for arsenic, acceptance of such adjustments has generally required conduct of in vivo (i.e., animal) studies using site-specific soil/sediment samples. Although in vitro methods have been developed to predict the relative oral bioavailability of arsenic from soil, none have yet been fully validated against data from animal studies for a broad diversity of soil types or contaminant sources. This research is using existing in vivo data on the relative oral bioavailability of arsenic in soil from 41 different arsenic-containing test materials from mining, smelting, pesticide, and chemical plant sites across the U.S. that have been tested previously for bioavailability in either cynomolgus monkeys or juvenile swine. These soils will form the basis for in vitro method development and validation. The project will include statistical evaluation of the relation between in vitro and in vivo results, as well as an assessment of the inter-lab reproducibility of the in vitro assay. A fully validated in vitro method will provide a mechanism for efficient and inexpensive evaluation of the relative bioavailability of arsenic in soil that could be used to evaluate and/or support alternatives to the default assumption of 100% absorption of arsenic from soils.

This work is funded under ESTCP Project ER-0916.
ASSessing SPECiation: BENEFICIAL REuse of PHosphATE and THERMAL Treated SEDiments and the POTENTIAL FOR Metal LEACHING INTO GROUNDWATER

Dr. Lisa Axe
New Jersey Institute of Technology
Department Civil and Environmental Engineering
University Heights
Newark, NJ 07102
(973) 596-2477
axe@adm.njit.edu

Co-Performer: Dr. Peter Ndiba (University of Nairobi)

Treatment and reuse of dredged harbor sediments in construction as an alternative to disposal reduces costs and conserves resources. This research focused on leachability of metal contaminants subsequent to phosphate addition and thermal treatment at 700ºC. X-ray absorption spectroscopy (XAS) in combination with principal component analysis, target transformation, and linear combination revealed that in the untreated sediments zinc (Zn) precipitated as the relatively soluble smithsonite (ZnCO₃) (67%) and adsorbed to hydrous iron oxides (15%) and hydrous manganese oxides (18%). Phosphate addition and calcination resulted in sparingly soluble phases, hopeite (Zn₃(PO₄)₂•4H₂O) (22%), and spinels, gahnite (ZnAl₂O₄) (44%) and franklinite (ZnFe₂O₄) (34%). Sequential extraction revealed similar shifts in metal forms from labile to recalcitrant residuals for Ni, Cu (spinels), Mn (crystalline oxides), Pb (phosphate mineral), Cd (alumino-silicate), and Co (adsorption to cryptomelane). The EPA toxicity characteristic leaching procedure (TCLP) confirmed both phosphate addition and calcination reduced leachability of metals with the combined treatment achieving up to an 89% reduction. In beneficial reuse, the synthetic precipitation leaching procedure (SPLP) revealed that impact to groundwater criteria can be achieved in the treated sediments but will be dependent on the applied dilution attenuation factor (DAF). These standard leaching tests, however, may not adequately address potential leaching when considering kinetics as well as pH changes. Overall, this research demonstrates the importance of evaluating speciation alongside leaching behavior in developing accurate prediction and assessment of risks posed by waste materials.
The objective of this project is to assess the utility of geophysical methods for monitoring the installation of sand fractures with Hydrogen Release Compound (HRC®) via hydraulic fracturing for biostimulation and the cost-effectiveness of using geophysical method to improve the conceptual model of amendments delivery and distribution. The project includes several key components, including: (1) lab experiments to explore the geophysical signatures (radar, seismic, complex electrical) of amendments; (2) development of petrophysical relationships that link the geophysical responses with remediation-induced processes; (3) pilot tests to document the utility of time-lapse geophysical datasets for developing a conceptual model of in-situ amendment delivery; and (4) evaluation of the cost-efficiency of a remedial design based on a conceptual model developed using geophysically-obtained information relative to that based on soil boring information alone. To date, this project has focused on conducting the laboratory experiments and planning for the field-based pilot test experiment. Laboratory experiments have been conducted to document the geophysical signatures of the replacement of groundwater-saturated formation with proppant/guar and HRC as well as the replacement of proppant/guar with HRC. These studies suggest that electrical methods should respond to each treatment step, that seismic should respond to the treatment steps that involve proppant/guar, and that radar velocity (dielectric constant) is most sensitive to the treatment steps that involve HRC. Field tests have also been performed at the F.E. Warren AFB Site in Wyoming to test the signal-to-noise ratio of different geophysical methods at the site. These studies suggested that the crosswell high frequency seismic data displayed excellent quality with frequency content up to 4000 Hz, and that seismic tomographic methods should be useful for imaging wellbore separations up to ~15m. The field test demonstrated the first successful first field test of a one-of-a-kind environmental cross borehole orbital vibrator, which yields both seismic P and SH wave signal transmission at frequencies up to 700 Hz over distances of up to ~25m between holes. The crosshole electrical data were considered to be of good quality while the radar data propagation was limited, likely due to the presence of conductive lithology and groundwater. The laboratory and field test results are being used to guide the design of the field-based pilot experiment, which will in turn be used to assess the utility and cost-effectiveness for using geophysics to develop a conceptual model of amendment delivery and distribution.
ULTRAFAST PARTICLE CHARACTERIZATION: MEASURING THE PREVIOUSLY IMMEASURABLE IN ENVIRONMENTAL SAMPLES USING NEW AUTOMATED TECHNOLOGIES

DR. HERMAN LEMMENS
FEI
5350 NE Dawson Creek Drive
Hillsboro, OR 97124
(503) 705-2081
herman.lemmens@fei.com

CO-PERFORMERS: Pieter W.S.K. Botha and Dr. Alan R. Butcher (FEI)

Automated Mineralogy is a new technology that addresses the need for reliable sample analysis and high throughput results in intractable environmental problems. Automated Mineralogy is an ultra-fast method of obtaining repeatable and statistically robust quantitative data pertaining to site characterization, risk assessment, remediation, long-term monitoring, and restoration/reclamation efforts at potential and known contamination sites.

The automation and integration of electron beam technology (Scanning Electron Microscope) with Energy Dispersive X-ray analysis (EDX), has proven to be an invaluable tool for high-throughput particle characterization in mineral processing applications in the mining industry.

This poster reports on how the same principles of particle analysis can be applied to the mineralogical and textural analysis of natural soil (such as silicates, oxides and carbonates), man-made materials (including brick, cement, concrete, fly ash), radioactive materials (natural and man-made uranium phases, naturally occurring radiogenic minerals), and fugitive dust (particles less than 10 microns in diameter).

It is now possible to routinely sample and analyze environmentally important materials and fully characterize their mineralogy and textures, including mineral associations, particle size, particle shape, grain size and shape, porosity, and degree of aggregation. These data are collected on a particle-by-particle basis through revolutionary image analysis software which allows the analyst to quantify environmentally important parameters—and plot these in the form of images, graphs, and tables—which can be used to provide information that was previously immeasurable.

Examples will be presented where Automated Mineralogy has been used to characterize hazardous waste materials, such as heavy metal-containing minerals and phases, to determine the bioavailability of the pollutants (arsenic speciation). These data are crucial in identifying, planning, and executing appropriate clean up procedures.
IN SITU SEDIMENT COLUMN MICRO COSMS FOR STUDYING BIOREMEDIATION

TOMASZ KALINOWSKI
The Biodesign Institute at Arizona State University
1001 S. McAllister Avenue
P.O. Box 875701
Tempe, AZ 85287-5701
(480) 727-0698
tkalinow@asu.edu

CO-PERFORMERS: Dr. Kristin McClellan and Dr. Rolf Halden (Arizona State University)

Flow-through microcosms constructed from sediment columns are a proven laboratory technology for studying groundwater processes, including chemical sorption, contaminant retardation, and biotransformation. The in situ microcosm array (ISMA), technology was developed to enable the execution of multiple sediment column studies in parallel in a groundwater monitoring well (i.e., in situ). There are good reasons for conducting microcosm studies in situ rather than in the laboratory. These include the fact that many microorganisms do not survive the transfer from their native environment to the laboratory setting and the chemistry of groundwater is known to change when water samples are brought to the ground surface, shipped to research facilities, and stored for extended periods of time for use in long-term laboratory studies. ESTCP Project ER-0914 was launched in 2009 to study the utility of in situ sediment microcosms. Conducting multiple column studies in a self-contained device in a groundwater monitoring well offers opportunities for generating data that cannot be obtained in laboratory flow-through and batch experiments. In this project, the concept of in situ column studies were introduced, and illustrate the utility of the approach by showcasing a matrix of experiments that can potentially be run in the field using the ISMA technology. An overview is presented of remedial design parameters and of statistical information that can be generated using in situ flow-through microcosms. To highlight the advantages and disadvantages of laboratory and field studies, data output is compared to that of industry-standard batch microcosms and to small-scale field tests. Some advantages of in situ column microcosms include: use of authentic groundwater conditions and microbial consortia; the determination of biotransformation rates under in situ conditions; the ability to run multiple experiments unattended and remotely in the same monitoring well; testing of mutually exclusive treatment technologies simultaneously using the same groundwater input; and, in contrast to small-scale field tests, leaving unaffected from testing, the physical, chemical and biological characteristics of the monitoring well and aquifer in which the tests are conducted.

This work is funded under ESTCP Project ER-0914.
FINAL CONCLUSIONS FROM DEMONSTRATIONS OF THE SNAP SAMPLER
PASSIVE GROUND WATER SAMPLING DEVICE

MS. LOUISE PARKER
U.S. Army ERDC-CRREL
72 Lyme Road
Hanover, NH 03755-1290
(603) 646-4393
Louise.V.Parker@usace.army.mil

CO-PERFORMERS: William Major (NAVFAC-ESC); Richard Willey (EPA Region 1); Thomas Imbrigiotta and Dr. Jacob Gibbs (NJ USGS); Donald Gronstal (AFRPA)

Passive ground water sampling techniques are gaining acceptance in the scientific community for many ground water sampling applications. Where use of this technology is appropriate, these methods can provide quality data and cost savings over conventional low-flow purging and sampling methods. The objectives of this project were to demonstrate that passive sampling—especially the Snap Sampler—can provide technically defensible analytical data for a wide spectrum of analytes, and can provide utility and potential cost savings.

This project included laboratory studies and two field demonstrations. In the field, samples were collected using (a) the Snap Sampler, (b) low-flow purging and sampling following EPA guidelines, and (c) dialysis (or regenerated cellulose membrane) passive diffusion samplers. The two field studies were conducted at the former Pease Air Force Base (AFB) at Portsmouth, NH, and the former McClellan AFB in Sacramento, CA. Analytes tested included: volatile organic compounds (VOC), non-metal anions, transition metals, alkaline earth metals, alkali metals, and metalloids. For the metals, samples were analyzed for both total and filtered concentrations. Using the dialysis membrane samplers allowed us to compare in-situ concentrations of filtered metals with both the field-filtered and unfiltered samples that were collected using the other sampling methods.

For each of the test sites, statistical analyses were performed on an analyte-by-analyte basis. Standard statistical tests were conducted on the analyte concentrations to determine whether there were significant differences between the sampling methods (i.e., whether there was a consistent bias that could be associated with any sampling method). Regression analyses were used to determine whether there was a linear relationship between any two of the sampling methods and if so, whether that relationship was one of equality.

This poster will present a summary of findings including a discussion of the outliers and possible reasons for differences when they occurred. This discussion also will include the effects of well construction methods and materials (including corrosion of stainless steel wells), well development, and possible experimental biases (e.g., agitation of the well during deployment of the equipment). The precision of the sampling methods and cost comparison analyses of the three sampling methods will also be presented.

This work is funded under ESTCP Project ER-0630.
METALLIC RESIDUES ON MILITARY TRAINING RANGES:
METHOD DEVELOPMENT

MR. ALAN D. HEWITT
U.S. Army ERDC-CRREL
72 Lyme Road
Hanover, NH 03755
(603) 646-4388
Alan.D.Hewitt@erdc.usace.army.mil

CO-PERFORMERS: Susan R. Bigl and Jay Clausen (ERDC-CRREL);
Anthony Bednar (ERDC-EL); Charles A. Ramsey (EnviroStat, Inc.);
Tom Georgian, Anita Meyer, and Terry Walker (CEHNC-CX-ES);
Brian Jordan (CESPA-EC-G)

The Environmental Security Technology Certification Program (ESTCP) has sponsored an
evaluation/demonstration (Project ER-0918) of the collection and processing of soils from
military training ranges for the characterization of metals. Metals may accumulate at firing
points, on the earthen backstops of small arms ranges, on demolition and hand grenade ranges,
around direct-line-of-sight targets, and elsewhere. Site inspections (SI) at munitions response
sites often require quantification of metals in the <2mm fraction of surface and near surface soils.
When remedial investigations (RI) are performed on these sites, the size fraction of greatest
concern for risk assessment/management may range from >2mm to <0.25mm, depending on the
nature of the receptors. For the quantification of metals in the <2mm soil fraction, EPA Method
3050B and 3051A (strong acid digestions) are typically used to prepare subsamples for analysis
by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) (e.g., Method
6010C) or Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (e.g., Method 6020A).

Similar to the protocols that evolved for characterizing energetic residues in training range soils
(Method 8330B), this program will assess the MULTI INCREMENT® (MI) sampling strategy
for metals and determine the protocols for sample processing that are necessary to obtain
representative (unbiased and precise) estimates of the mean concentrations in areas of concern
(decision units) for both SI and RI. Once developed and demonstrated, the approach will be
documented (e.g., as a published method) and promoted to various government agencies.

This effort was formulated on the premise that metallic debris generated as a consequence of
military training activities is heterogeneously distributed over military training ranges as
particles of various sizes, shapes and compositions. Moreover, within the <2mm faction, metal
particles will confound efforts to obtain reproducible results when subsamples collected for
digestion and analysis are equal to or less than 10g.

The presentation will summarize the results of some initial studies that used MI sampling and
laboratory sample processing strategies to quantify metal concentrations, highlight problems
encountered, and discuss potential solutions.
STATISTICAL METRICS FOR THE IDENTIFICATION OF INTERDEPENDENT ANALYTES

DR. TIFFANY DOWNEY
Tetra Tech, Inc.
7717 S. 71st Avenue
Phoenix, AZ  85339
(623) 243-3994
tiffany.downey@tetrattech.com

CO-PERFORMERS: Brian Caldwell, Dr. Ronnie Brito, Melissa Geraghty, and Rick Arnseth (Tetra Tech, Inc.)

Complex interactions between chemicals of concern (COC) and geochemical species become critically important when evaluating the success of in-situ remediation techniques. However, these interactions are rarely obvious due to the multi-species correlations resulting from changes in pH or oxidation-reduction potential (ORP). Site investigations often rely on a broad suite of analyses to detect and characterize changes in groundwater quality as an indicator of remedial progress. Consequently, long-term remediation activities accumulate huge costs associated with monitoring activities, laboratory fees, and database maintenance. Many of the monitored analytes have little or nothing to do with the remedial activities and result in huge accumulated costs over the course of the project. Using well-established statistical analyses, such as Pearson’s linear relations and multi-variate Principal Components Analysis (PCA), the significance of each geochemical species can be evaluated to determine the overall contribution to site activities and the necessity of future monitoring.

In order to better understand the overall in-situ process and focus future sampling activities on relevant parameters, groundwater monitoring results were analyzed to determine if correlations exist between the site COC and other geochemical analytes. For the purposes of this investigation, initial significance thresholds were set at $\alpha = 0.05$ for all Pearson’s relations and eigenvalues greater than 1 for all PCA eigenvectors. Given uncertainties in temporal and spatial variability, more rigorous significance criteria were not deemed appropriate. Datasets were initially screened for completeness, and all incomplete datapoints (i.e., unmeasured analytes) were eliminated from further inclusion. PCA was computed using a commercially available statistical analysis software including the calculation of squared cosine values for each analyte and eigenvector. Primary eigenvectors with eigenvalues greater than 1 were selected and the eigenvector best described by each analyte (i.e., eigenvector for which cosine squared is largest) was determined. Analytes whose highest squared cosine values were correlated with a single primary eigenvector were labeled as correlated analytes, thus establishing a dependency. Any vector best described by a single analyte or any analyte best described by a minor eigenvector was labeled as independent. The process was then iterated, excluding the independent analytes from previous iterations until all remaining analytes were correlated (i.e., dependent) within the primary eigenvectors. Results were compared to the Pearson’s correlations to establish if any contradictions existed with simple uni-variate linear relationships. In concert, these statistical methods begin to highlight analytes that show evidence of interdependence.
OPTIMIZED ENHANCED BIOREMEDIATION THROUGH 4D GEOPHYSICAL MONITORING AND AUTONOMOUS DATA COLLECTION, PROCESSING, AND ANALYSIS

MR. WILLIAM R. MAJOR
Naval Facilities Engineering Command-Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043
(805) 982-1808
william.major@navy.mil

CO-PERFORMERS: Dr. Timothy C. Johnson and Dr. Roelof J. Versteeg (Idaho National Laboratory); Dr. Frederick D. Day-Lewis and Dr. John W. Lane, Jr. (USGS); Louise V. Parker (CRREL); Mike Rooney (Booz Allen Hamilton)

ESTCP Project ER-0717 is seeking to demonstrate/validate a Hydrogeophysical Performance Monitoring System (HPMS) at the Brandywine Defense Reutilization and Marketing Office (DRMO) site, Brandywine, Maryland that will provide timely, actionable information to site managers on the processes associated with enhanced bioremediation. The HPMS system allows for near real-time monitoring of injections of amendments through autonomous acquisition of hydrological and electrical geophysical datasets, which undergo QA/QC and are imported in a relational database. Web-accessible tools allow for automated data processing and delivery of results. Distributed software, chained together as workflows, allow for data retrieval, visualization, and validation. Although previous laboratory and pilot-scale field experiments suggested that common amendments have observable geophysical signatures, this is the first field-scale demonstration/validation using geophysical monitoring (electrical resistivity, induced polarization, spontaneous potential, and periodic crosshole radar monitoring) to understand field-scale amendment distribution and resulting geochemical changes.

The site underwent extensive biostimulation and bioaugmentation between February and July 2008 to remediate groundwater contaminated with volatile organic compounds including TCE, the primary groundwater contaminant. The commercially available amendment used at the site consists of a proprietary mixture of lactic esthers and a pH adjustment. The HPMS system was deployed on site in November and December 2007, in advance of the bioremediation effort, to monitor the progress and behavior of the amendment injected at two locations on March 10th and 14th, 2008. Our HPMS well network consists of 19 wells for electrical and induced-polarization tomography, crosshole radar, and multi-level sampling.

Time-lapse difference inversions of 4D electrical geophysical datasets show both the initial injections as well as subsequent behavior of the amendment over time. Time-lapse bulk conductivity estimates have been calibrated and validated based on subsets of geochemical data collected in sampling events. Calibrations were developed to first relate geophysically-estimated bulk conductivity to fluid conductivity, and then to relate estimated fluid conductivity to the total organic acid (TOA), which we use as a surrogate for the presence of the amendment.
LOCATION AND ACTIVITY SPECIFIC SITE-MANAGEMENT FOR MILITARY LOCATIONS

LINDA MARING
Deltares
P.O. Box 85467
3508 AL Utrecht NETHERLANDS
+31(0)6 20826140
linda.maring@deltares.nl

CO-PERFORMERS: Monique van Hulst and Denise Meuken (TNO Defense, Security and Safety)

Space is limited in the Netherlands and military activities, that may cause nuisance or environmental hazards, should therefore be considered and evaluated during the use of military locations. The last few years TNO and Deltares have worked on a research program on environmental effects due to military activities. One of the goals was to inventory the activities on all locations of the Ministry of Defense. The activities are stored in a database which is connected to a Geographical Information System (GIS) to link them with spatial information. This spatial information consists of geological information and the presence of possible receptors, such as water-supply-areas and nature preservation areas.

The aim of the database is to give an indication on the vulnerability of a site, based on the possibility that: (1) contaminations, based on military activities, are released into the environment; (2) contamination is likely to disperse in the environment, based on geological information; and (3) the dispersal of contamination may cause immediate problems due to the presence of receptors. The database can act as an “early warning system” and as a tool for site management.

An overview of potential attention-areas can be given with relatively low effort and information. Based on this, research activities for different locations can be prioritized. The methodology of linking activities to contamination in the environment is based on the intensive research of two military sites in the Netherlands. For the validation of the database, two other sites are being investigated.

Within the research program, activity-specific sampling strategies are also being developed. When military sites are abandoned and (usually) get another land use function, an aimed and cost-specific site characterization can be carried out. Another benefit of linking activities to possible vulnerability of a site is smart site-management in terms of preventive measures. This method can also be valuable by choosing future locations for military activities. This is a particularly interesting perspective for countries with lower pressure on available space.

Future research can be aimed at: (1) linking the activity database to additional information, such as ammunition databases; (2) cost-effective prevention and remediation actions; (3) redevelopment of military areas; and (4) smart storage of site information and data. The research gives insight in the remediation and management tasks that can occur, e.g., by abandoning sites and changes in land use function.
USING BIO-MEDIATED SORPTION PROCESSES TO IMPROVE FUNCTIONALITY OF RECYCLED CONCRETE MATERIALS USED FOR POLLUTANT MANAGEMENT IN BRACKISH COASTAL AREAS

JUNE WOLFE
Texas AgriLife Research/Blackland Research and Extension Center
720 East Blackland Road
Temple, TX 76502
(254) 774-6016
jwolfe@brc.tamus.edu

CO-PERFORMER: Dennis Hoffman (Texas AgriLife Research/Blackland Research and Extension Center)

Scientists at the Blackland Research and Extension Center are cooperating with Japanese scientists at Shimane University to improve the performance of recycled concrete materials (RCM) by using periphyton, the attached aquatic community consisting mainly of algae and bacteria. Periphyton communities are useful water quality indicators in natural systems and can be exploited for wastewater treatment in engineered systems. Periphyton is present in all aquatic environments and rapidly colonizes almost any substrate; however, its ability to maintain attachment and vigorous growth is dependent upon substrate surface characteristics. Scientists in the Department of Ecology and Environmental Science at Shimane University in Matsue, Japan have developed RCM with high sorption capacities for numerous dissolved pollutants. The local Lake Shinji, a shallow brackish lake, suffers from phosphorus-driven eutrophication. This work investigated the types and growth forms of periphyton which have an affinity for RCM with high phosphorus sorption capacity so its surface characteristics could be modified to encourage periphyton growth and improve RCM functionality. Understanding the role periphyton communities play in the regulation of phosphorus onto RCM is helpful to expanding RCM technology. Bio-mediated sorption coupled with RCM has the potential to provide an environmental remediation system addressing multiple problems on Department of Defense (DoD) lands. Obsolete concrete structures should be recycled to provide raw materials useful for water quality remediation rather than landfill material. The selection, preparation, and utilization of these materials and processes can be used to target pollutants of interest to DoD.
DETERMINING COSTS AND SUSTAINABILITY METRICS USING THE AFCEE SUSTAINABLE REMEDIATION TOOL (SRT) AND RACER

DR. CHARLES J. NEWELL
GSI Environmental, Inc.
2211 Norfolk, Suite 1000
Houston, TX 77098
(713) 522-6300
cjnewell@gsi-net.com

CO-PERFORMERS: Erica Becvar (U.S. Air Force Center for Engineering and the Environment); Doug Ruppel and David Woodward (AECOM); Tiffany N. Swann, Lila M. Beckley, and Dr. Ata U. Rahman (GSI Environmental, Inc.); Doug Downey, Paul Favara, and Brad Woodard (CH2M Hill)

The Air Force Center for Engineering and the Environment (AFCEE) has developed the Sustainable Remediation Tool (SRT) to evaluate and optimize remediation systems on the basis of sustainability metrics. This Microsoft Excel-based tool is intended to aid environmental professionals in remedy selection and in improving remedy effectiveness without increasing risks. To that end, the SRT provides an easy-to-use mechanism for remediation professionals to incorporate sustainability concepts into their decision-making, while avoiding time-consuming hand calculations. The SRT is designed to be used as both a planning tool for future implementation of remediation technologies at a particular site, and an evaluation tool to optimize remediation systems already in place. In the current version, the SRT allows users to estimate sustainability metrics for specific technologies. The technologies are: (1) Excavation; (2) In Situ Soil Vapor Extraction; (3) In Situ Thermal Desorption; (4) Pump and Treat; (5) Enhanced Bioremediation; (6) In Situ Chemical Oxidation; (7) Biowalls; and (8) Monitored Natural Attenuation and Long-Term Monitoring. The metrics estimated in the SRT are: (a) greenhouse gas emissions, including CO₂, NOₓ, SOₓ, and PM; (b) energy consumed; (c) technology cost; (d) safety/accident risk; and (e) natural resource service. In addition to estimating sustainability metrics, the SRT is able to take in technology costs directly from the Remedial Action Cost Engineering Requirements (RACERTM) model, a detailed budget estimation system used by many environmental remediation professionals. A case study will be presented to demonstrate the capabilities of this SRT-RACERTM interaction.
CSM DEVELOPMENT THROUGH FIELD INVESTIGATION AND ASSESSMENT: IMPLEMENTATION OF A STRATEGIC APPROACH FOR COMPLEX VI ASSESSMENT AT A LARGE MILITARY FACILITY

MS. EMILY H. MAJCHER
Geosyntec Consultants
10220 Old Columbia Road
Suite A
Columbia, MD 21046
(410) 381-4333
emajcher@geosyntec.com

CO-PERFORMERS: Paul Nicholson, David Himmelheber, Aron Krasnopolker, Todd McAlary, and Robert Ettinger (Geosyntec Consultants); Jennifer Harris (General Physics); John Wrobel (US Army USAG APG)

Vapor intrusion (VI) assessments are often conducted on a building-by-building basis, with regulatory guidance-specified spacing for sampling of various media (soil gas, sub-slab gas and indoor air) and analytical methods (typically only VOCs). At military installations, large numbers of buildings often comprise a site and more non-standard contaminants of potential concern (COPCs) may be present, including SVOCs, PCBs, pesticides, and chemical warfare agents. A blanket-type sampling and analysis plan (all chemicals in all media at every building) would be prohibitively expensive. This was an issue at the Canal Creek Study Area (CCSA), Aberdeen Proving Ground (APG), Maryland, which has about 300 buildings and where regulatory negotiations had been stalled for nearly a year. Geosyntec developed and negotiated a strategic approach to prioritize potential VI risks based on historic soil and groundwater data based on a CSM of the VI pathway.

We are currently implementing a phased approach to VI assessment, which will serve as a model for other study areas within APG, and we believe can also become a model for application more widely across hundreds of sites where VI assessments are pending for the DoD.

Key components of our services included: (1) A project-developed GIS and RDMS based on the knowledge of former chemical use and handling areas and secondary contamination in hydrostratigraphic units with varying depth below land surface; (2) Development of site-specific screening levels for the chemicals not normally included in VI assessments; (3) Spatial analysis of historic concentrations measured in soil and groundwater compared to the locations of occupied buildings to establish the first phase of field work, which was limited to a subset of 13 of the 312 buildings believed to pose the greatest risk for VI; (4) Several innovative tools, including PDMS samplers (VOCs) and absorbent tubes (non-VOCs) for indoor air, HPV sampling for sub-slab sampling for a very large building, and absorbent tubes for non-VOCs in the subsurface; and (5) Regulatory negotiation to secure approval of the prioritization strategy, using the GIS for visuals and our strong experience and reputation in this field to build confidence in the strategy.
RESULTS OF A TREATABILITY STUDY FOR SediMite™

DR. CHARLES MENZIE
Exponent, Inc.
1800 Diagonal Road, Suite 300
Alexandria, VA  22314
(571) 214-3648
camenzie@exponent.com

CO-PERFORMERS: Dr. Upal Ghosh (University of Maryland Baltimore County);
Dr. Cindy Gilmour (Smithsonian Environmental Research Center)

SediMite™ is a granular material that offers an alternative approach to in situ treatment of contaminated sediment. The material, which can be produced using a variety of sorbents, was designed to be easy to apply, minimally disruptive to the environment, and cost-effective. The approach employs granules that can be used to deliver treatment materials to sediments contaminated by organic chemicals and metals. SediMite™ was designed for broadcast application. The material can be applied at the water surface and is designed to sink to the bottom, where the granules mix into surface sediments and slowly release the treatment material.

The current study represents preliminary stages of a larger study that will test the efficacy of SediMite™ in mitigating mercury bioaccumulation from a contaminated estuarine sediment. The purpose of this preliminary study was to provide information on the effectiveness of SediMite™ at the study site, and to determine the optimal application rate for a field demonstration study. For this study, SediMite™ was formulated with activated carbon. Among a suite of treatment materials tested in preliminary trials, activated carbon yielded the highest reductions in methylmercury bioaccumulation by an aquatic oligochaete, Lumbriculus, per unit cost. To our knowledge, these trials have been the first demonstration of the efficacy of activated carbon in remediation of Hg-contaminated sediments.

In a 14-day sediment/water microcosm study, SediMite™ formulated with activated carbon was highly effective in reducing total and methylmercury concentrations in sediment porewaters, and in reducing methylmercury bioaccumulation by Lumbriculus. The study was carried out as a dose/response study, using SediMite™ amendments ranging from approximately 0.5 to 1.5 times the sediment’s native total organic carbon (TOC) content, plus un-amended controls. In addition to the standard measurement of total Hg concentrations in Lumbriculus after a 14 day exposure, the study also examined the components of the mercury cycle that contribute to its toxicity, mobility, and bioaccumulation, specifically: (1) net methylmercury production; (2) Hg and methylmercury partitioning between sediments and porewaters; and (3) bioaccumulation factors for total and methylmercury.

A SediMite™ dosing rate of roughly 1X the organic carbon content of the sediment reduced 14-day MeHg bioaccumulation by Lumbriculus by roughly 2/3 relative to un-amended controls. SediMite™ also enhanced partitioning of both Hg and MeHg to the solid phase, reducing MeHg concentrations in porewaters by more than 90%.

This work is funded under ESTCP Project ER-0835.
REACTIVE CAPPING MAT DEVELOPMENT AND EVALUATION FOR SEQUESTERING CONTAMINANTS IN SEDIMENT

MS. AMY HAWKINS
Naval Facilities Engineering Command-Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043
(805) 982-4890
amy.hawkins@navy.mil

CO-PERFORMERS: Dr. Gregory Tracey and Jesse Swanko (SAIC); Dr. Kevin Gardner, Dr. Jeffrey Melton, Scott Greenwood, Bhawana Sharma, and Rafael Prieto (University of New Hampshire)

The SAIC/UNH/NAVFAC team funded by SERDP is working to develop a reactive geotextile mat system as a chemically effective, mechanically stable and cost efficient technology for reducing ecological risks by sequestering contaminants in sediment, thereby avoiding the need for dredging and offsite placement. The mat system, if successful, would be deployed in a wide variety of environmental settings to prevent both metals and organic contaminants from entering overlying surface waters while simultaneously allowing both groundwater flux and surficial biological colonization. As part of the pilot study, various mixtures of reactive amendments to potentially absorb different classes of sediment contamination have been evaluated in a laboratory setting and the optimal combination (0.28 lb/sf activated carbon, 0.23 lb/sf apatite, 0.28 lb/sf organoclay) has been placed within prototype mats consisting of woven geotextile tops and a non woven geotextile backs to be positioned on top of sediments of concern. Cottonwood Bay in Grand Prairie, Texas was selected as the most suitable project test site based on a variety of chemical, physical, biological and logistical factors. A comprehensive geophysical investigation, including bathymetry, side scan sonar, sediment profile imaging and groundwater seep surveys, was conducted to characterize this site and identify a specific target area for mat placement featuring a substantial groundwater plume. Gradient ratio testing and finite element modeling experiments were conducted in a laboratory setting using both clean geotextiles delivered to the laboratory and field weathered small scale (6 ft × 6 ft) test mats retrieved to identify the non woven geotextile most resistant to biofouling (8 oz/sq. yd polypropylene with 80 apparent opening size) to be used for construction of a prototype mat system. A full scale mat system featuring four 25 ft × 25 ft test arrangements (bare single layer geotextile, single layer geotextile with sand cap, bare double layer geotextile, sand cap only) and an undisturbed control area was then deployed and following five months of soak time the geophysical properties of the mat system were evaluated with side scan sonar, sub bottom and sediment profile imaging surveys. The contaminant sequestering effectiveness of the various test arrangements within the system was also monitored by passive samplers (peepers, semi-permeable membrane devices, solid phase micro extraction fibers) allowed to soak in each treatment area for approximately 30 days, with results indicating that metals concentrations were generally greater in the natural porewater below the treatment compared to porewater within/above the treatment and the single layer geotextile mat with sand capping was most effective in reducing PAH exposure to benthic biota. Following one year of soak time, UltraseepTM groundwater seepage meters were used to quantify water flux through the mats from underlying sediments as well as to identify any changes in contaminant concentration.
IN SITU WETLAND REMEDIATION DEMONSTRATION

MS. AMY HAWKINS
Naval Facilities Engineering Command – Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA  93043
(805) 982-4890
amy.hawkins@navy.mil

CO-PERFORMERS: Dr. John Bleiler and Dr. Emese Hadnage (AECOM Environment);
Dr. Kevin Gardner (University of New Hampshire)

Wetlands owned by the Department of Defense (DoD) often act as sinks for contaminants, including persistent, bioaccumulative, and toxic (PBT) compounds (e.g., DDT and PCBs), as well as inorganic constituents (e.g., copper and lead). Remediation of contaminated palustrine wetlands traditionally has involved excavation of hydric soils and off-site transport of excavated materials for treatment and disposal. This type of remediation is both ecologically destructive and expensive, and restoration of ecological systems can be challenging. A newly funded ESTCP program investigates an alternative remedial approach that allows targeted in situ remediation of wetlands through the application of various sequestration agents, a technology that has the potential to reduce costs tremendously and minimize impacts on ecosystem components. Several sequestration agents have recently been evaluated at the laboratory scale to determine which material provides the most cost-effective and environmentally protective solution. All the chosen materials are known for having chemical properties that can limit bioavailability and mobility of organic contaminants and metals. Laboratory tests are underway to test the contaminant removal capacity of sequestration agents, including activated carbon, zero valent iron, and organoclays. Results of these experiments are summarized in a treatability study and guidance manual which will help inform the field demonstration phase of work. Field demonstrations at Canal Creek, at the Aberdeen Proving Ground (Maryland), will evaluate the efficacy of different application technologies, including dry broad-casting systems. The main goal of this program is risk reduction, not mass removal; therefore performance in the field application will be gauged through several measures of reduction of contaminant bioavailability (e.g., solid-phase microextraction, bioassays, bioaccumulation studies, instream impairment studies) following the addition of the sequestration agents. Further, a monitoring program designed to evaluate the health of hydrophytic vegetation following amendment application is being conducted as well.

This work is funded under ESTCP Project ER-0825.
PEPTIDE SEPARATOR ELECTROCHEMICAL SENSOR (PSES) FOR THE LONG-TERM MONITORING OF MUNITIONS CONSTITUENTS IN GROUND WATER

Lt. Col. ROBERT G. BOZIC
United States Military Academy
Department of Chemistry and Life Science
West Point, NY  10996
(845) 938-3918
robert.bozic@us.army.mil

CO-PERFORMERS: Dr. Anthony J. Bednar (USACE ERDC-EL); Dr. Scott A. Banta and
Dr. Alan C. West (Columbia University)

Long-term monitoring of waste disposal sites for munitions constituents (MC) using the Environmental Protection Agency Method 8330A high performance liquid chromatography, is a costly analytical technique for which there is not a current comparable alternative. This has inspired research and development of fast, low cost techniques to detect parts per billion concentrations of MC, such as 2,4,6-Trinitrotoluene (TNT). In collaboration with the U.S. Army Engineer Research and Development Center Environmental Laboratory in Vicksburg, Mississippi, Columbia University Department of Chemical Engineering, and the Department of Chemistry and Life Science at the United States Military Academy, West Point, New York, have on-going research efforts combining electrochemical engineering, microfluidics, and protein engineering with a goal of developing engineering fundamentals to enable in-situ detection of MC. Recent efforts included miniaturization of the working electrode to ensure portability. A gold rotating disc electrode surface endowed with an alkanethiol self-assembled monolayer and gold microwires treated the same way were tested during this study. The current research focus is on testing synthetic peptides engineered to separate and concentrate TNT. These peptides were selected from ones evolved using phage display techniques. While synthetic peptide experiments with TNT have been conducted, research on evolution of peptides that bind other MC is ongoing.
SHEAR STRESS MEASUREMENTS AND EROSION IMPLICATIONS FOR WAVE AND COMBINED WAVE-CURRENT GENERATED FLOWS

DR. JOSEPH GAILANI
U.S. Army Corps of Engineers
Engineer Research and Development Center
3909 Hall Ferry Road
Vicksburg, MS 39180-6199
(601) 634-4851
Joe.Z.Gailani@usace.army.mil

CO-PERFORMERS: Jesse D. Roberts, Richard A. Jepsen, and Sean P. Kearney (U.S. Army Corps of Engineers Engineer Research and Development Center)

Sediment transport in wave dominated environments is of great interest for contaminated sediments, habitat protection, offshore alternative energy projects, dredged material beneficial use, and other issues. The shear stress at the sediment-water interface during a wave event is an important parameter in determining erosion and transport for both experimental and model simulation applications. A team of scientists at Sandia National Laboratories and the U.S. Army Corps of Engineers have developed a laboratory and field device called the SEAWOLF flume in which Particle-Image Velocimetry (PIV) has been applied to investigate turbulent flow shear stresses for a variety of flow conditions. The results of the PIV analysis for a wave cycle demonstrate a fully developed turbulent flow, relaminarization, and an explosive transition back to turbulence. The determination of shear stress time history based on the detailed PIV analysis for oscillatory flows and the subsequent effects on erosion is very important for predicting sediment transport in wave-dominated environments. This work clearly demonstrates the effects of transient oscillatory flow on the resultant shear stress and subsequent erosion processes.

This work is funded under SERDP Project ER-1497.
DEMONSTRATION OF AN IN-SITU FRICTION-SOUND PROBE FOR MAPPING PARTICLE SIZE AT CONTAMINATED SEDIMENT SITES

DR. BART CHADWICK
SPAWAR Systems Center Pacific
53560 Hull Street
San Diego, CA 92152
(619) 553-5333
bart.chadwick@navy.mil

CO-PERFORMERS: Ernie Arias (SPAWAR Systems Center Pacific); John Radford (Zebra-Tech); Joe Germano (Germano & Associates)

A prototype commercial friction sound probe (SED-FSP) for in-situ measurement of sediment grain size was designed, manufactured and evaluated in the laboratory for verification of sensor performance. The SED-FSP was developed for integration with the Trident Probe system, used for rapid in-situ screening of contaminated sediment sites and groundwater-surface water interaction sites. Commercial specifications were developed, including probe configuration, materials, Trident Probe hardware and software interface, signal processing, and display. Testing of the prototype SED-FSP in the laboratory with a variety of field collected and commercially available coarse, medium, and fine grain sands, silts, and clays of known size distributions was conducted. Testing of sediment samples collected from a range of locations within the San Diego Bay was performed with the SED-FSP, and results compared with standard methods of grain size measurement. Results confirmed that the amplitude of the sound intensity can be correlated to median grain size and that the SED-FSP provides a sensitive measure of grain size. The effects of compaction of the sediment and probe penetration rate were also evaluated, including the ability of the SED-FSP to acquire a vertical profile of grain size. A pneumatically powered drive system was developed to drive the Trident Probe/SED-FSP into the test of sediment bed at a controlled and constant penetration rate.

This work is funded under ESTCP Project ER-0919.
USING A FEW PERFORMANCE REFERENCE COMPOUNDS IN POLYETHYLENE PASSIVE SAMPLERS TO DEDUCE SEDIMENT POREWATER CONCENTRATIONS FOR NUMEROUS TARGET CHEMICALS

PHILIP GSCHWEND
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 48-413
Cambridge, MA 02139
(617) 253-1638
pmgschwe@mit.edu

CO-PERFORMERS: Loretta Fernandez and Charles Harvey (Massachusetts Institute of Technology)

Polymeric passive samplers are useful for assessing hydrophobic organic contaminants in sediment beds. Here, an improved method is described for measuring concentrations of contaminants in porewater by using only a few performance reference compounds (PRC) to calibrate sampler/site-specific mass transfer behavior. The method employs a one-dimensional diffusion model of chemical exchange between a polymer sheet of finite thickness and an unmixed sediment bed. The model is parameterized by diffusivities and partition coefficients of the chemicals in both the sampler and sediment. By observing the loss of PRC from the sampler, the model is used to calibrate site-specific properties, and then the target compound presence in the sediment can be deduced using their sub-equilibrated build up in the sampler. This method was applied to estimate porewater concentrations for 17 PAH from polymeric samplers deployed for 3 to 10 days. The accuracy of the method was verified by comparing the passive sampler results to concentrations measured through liquid-liquid extraction of physically-separated porewaters, with corrections for sorption to colloidal organic carbon.

This work is funded under SERDP Project ER-1496.
INTEGRATED FORENSICS APPROACH TO FINGERPRINT SEDIMENT PCB SOURCES

DR. JAMES LEATHER
SPAWAR Systems Center Pacific
53475 Strothe Road
San Diego, CA 92152
(619) 553-6240
leather@spawar.navy.mil

CO-PERFORMERS: Greg Durell (Battelle); Dr. Glenn Johnson (University of Utah); Dr. Marc Mills (Environmental Protection Agency)

Determining the original source of contamination to a heterogeneous matrix, such as sediments, is a requirement for both clean-up and compliance programs. Understanding the source(s) of contaminants to sediments in industrial settings is a prerequisite to implementing proposed sediment remedial options. This is due to the fact that the sources must be controlled prior to remedial efforts to ensure that recontamination can be avoided. An additional reason for source identification includes ensuring that costs of any remedial efforts can be fairly allocated among multiple principle responsible parties (PRP). In some instances, elevated levels of polychlorinated biphenyls (PCBs) in sediments have led to impairment designations requiring the development of total maximum daily loads (TMDL) and subsequent waste load allocations under compliance programs. The need to develop these types of TMDL also requires the development and use of a forensics approach to fingerprint contaminant sources so that loads can be allocated. In recognition of these requirements, the approach described in this project includes the combined use of rapid screening technologies to map sediment contaminant plumes, and advanced chemical fingerprinting on a subset of samples to identify sources. This provides a cost-effective and technically advanced and defensible approach to characterizing the PCB contamination and its sources. The current alternative approach, without a forensics study, merely assumes the most visible landholder (often a military facility) closest to the sediment contamination is responsible.

This work is funded under ESTCP Project ER-0826.
HIGHLY REACTIVE SUBNANO-SIZED ZERO-VALENT IRON SYNTHESIZED ON SMECTITE CLAY TEMPLATES

DR. CHENG GU
Michigan State University
526 Plant and Soil Science Building
East Lansing, MI 48824
(517) 355-0271, Ext. 249
chenggu@msu.edu

CO-PERFORMERS: Dr. Hui Li, Dr. Brian J. Teppen, and Dr. Stephen A. Boyd (Michigan State University)

A novel method was developed for synthesizing subnano-sized zero-valent iron (ZVI) using smectite clay layers as templates. Exchangeable Fe(III) cations were used to compensate the structural negative charges originating from isomorphic substitution in the aluminosilicate layers of smectites. Reduction with NaBH4 resulted in the formation of ZVI on the external and internal surfaces of layered smectite clay assemblages. The unique structure of smectite clay, in which isolated exchangeable Fe(III) cations reside at or near the discrete sites of structural negative charges, prevents the agglomeration of ZVI and results in the formation of subnanoscale iron particles on the clay surfaces. X-ray photoelectron spectroscopy confirmed the formation of ZVI. The templated subnanoscale ZVI showed superior reactivity and efficiency compared to other previously reported forms of ZVI, as indicated by the reduction of nitrobenzene. Over 90% of nitrobenzene (0.65 mM) was degraded within one minute. Nitrosobenzene and phenylhydroxylamine were detected as transient intermediates, even at the first sampling time (1 minute). Aniline was the final product accounting for >60% of added nitrobenzene after 10 minutes, and ~94% at the end of the three-hour reaction. Smectite clays are widely distributed in the environment and inexpensive, hence offering the potential for in situ and ex situ remediation of many persistent contaminants in surface/subsurface soils and sediments utilizing smectite-templated ZVI in constructed reactive domains, such as reactive caps for contaminated sediments.
A NEW LOOK AT THE BIOAVAILABILITY AND METHYLATION POTENTIAL OF MERCURY SULFIDES IN SEDIMENTS

DR. HELEN HSU-KIM
Duke University
Department of Civil and Environmental Engineering
121 Hudson Hall
Box 90287
Durham, NC 27708
(919) 660-5109
hsukim@duke.edu

CO-PERFORMER: Dr. Marc Deshusses (Duke University)

This new project deals with the geochemical processes that control the bioavailability of mercury (Hg) in contaminated sediments. The production of methyl mercury (MeHg) by anaerobic bacteria and the bioavailability of inorganic Hg to these microbes are critical steps for MeHg bioaccumulation in benthic organisms. This project has initiated investigations that will determine the relationship between Hg speciation and microbial methylation potential in anaerobic sediments. The central hypothesis is that kinetically-limited mercury sulfide mineralization reactions, rather than equilibrium porewater chemistry, control the concentration of bioavailable mercury to sediment bacteria that convert it to MeHg. Current models utilize equilibrium Hg-sulfide (HgS) chemistry to predict bioavailable Hg concentration. Such models, however, are flawed because they incorrectly overestimate the solubility of HgS minerals and also ignore the ‘aging’ effects of mercury in sediments that reduce bioavailability over time. A known aging process for mercury in sediments is the precipitation of sulfide minerals (i.e., HgS metacinnabar). So far, this research has shown that nanoparticles of HgS can form as stable intermediates of slow precipitation reactions. These nanoparticles, especially amorphous phases, are inherently more soluble than bulk minerals and can be more bioavailable than larger particles. Thus, a major thrust will be placed towards quantifying the microbial methylation potential of nanoparticulate HgS in relation to bulk scale HgS and dissolved Hg-sulfide species.

This work is funded under SERDP Project ER-1744.
DEMONSTRATION AND VALIDATION OF ENHANCED MONITORED NATURAL RECOVERY AT DoD SITES

DR. BART CHADWICK
SPAWAR Systems Center Pacific
53560 Hull Street
San Diego, CA  92152
(619) 553-5333
bart.chadwick@navy.mil

CO-PERFORMERS: Ms. Victoria Kirtay (U.S. Navy); Dr. Victor Magar and Dr. Jason M. Conder (ENVIRON); Dr. Marc Greenberg (EPA); Dr. Gui Lotufo (U.S. Army Engineer Research and Development Center); Dr. Joe Germano (Germano & Associates, Inc.)

Successful remediation of contaminated sediment sites relies on well defined remediation goals and performance criteria, realized via long-term monitoring following remedy implementation. This paper presents a remedy-specific monitoring approach designed to evaluate the performance of Enhanced Monitored Natural Recovery (EMNR) at DoD sediment sites. The approach is based on a broad case study review and will be validated through site-specific demonstration at the Quantico Embayment site (Quantico Marine Corps Base, Virginia).

Quantico Embayment is an inlet of the Potomac River where elevated DDT in the sediment was identified as a risk driver for piscivorous birds. EMNR and habitat enhancement capping was the preferred alternative, involving the placement of a thin layer (6-9 inches) of clean sediment within the remedial footprint delineation. As the clean sediment layer mixes with underlying sediments, recovery extends to deeper layers and ultimately results in ecosystem recovery at higher trophic levels.

Baseline sampling strategies are presented, as well as a discussion of the proposed post-remedy monitoring plan to evaluate the performance and goals of the EMNR remedy, focusing on the following questions: (1) What is the physical stability of TLCs?; (2) At what rate and to what extent is the TLC material mixed into the sediment bed?; (3) What is the extent and rate of recovery of the benthic community following TLC application?; (4) What is the effect of EMNR in reducing surface Contaminant of Concern (COC) concentrations?; and (5) What is the effect of EMNR in reducing toxicity and bioaccumulation?

The presentation details the various monitoring approaches to address these focus questions, providing the experimental design and monitoring tools that will be used. The paper also presents a review of EMNR case studies, focusing on three principal sites that represent locations in which EMNR has been implemented as a component of a mature site remedy, and for which the success of implementation can be assessed through available placement and post-placement monitoring data. EMNR was selected for those portions of each site in which stated goals were to reduce chemical concentrations in the sediment biologically active zone to enhance the sediment ecology, while not causing widespread disturbance to the existing habitat. This work is funded under ESTCP Project ER-0827.
ITRC’S TECHNICAL AND REGULATORY GUIDANCE FOR INCORPORATING BIOAVAILABILITY CONSIDERATIONS IN THE EVALUATION AND REMEDIATION OF CONTAMINATED SEDIMENTS

MR. JOHN CARGILL
Delaware Department of Natural Resources and Environmental Control/ITRC
391 Lukens Drive
New Castle, DE  19720
(302) 395-2622
john.cargill@state.de.us

CO-PERFORMERS: Kimberly Ward (New Jersey Department of Environmental Protection/ITRC); Steve R. Hill (RegTech, Inc./ITRC)

In 2008, the Interstate Technology and Regulatory Council (ITRC) established a Team focused on Contaminated Sediments. Since that time the team has been developing a Web-based Technical and Regulatory Guidance on the concepts, process and use of bioavailability in a risk decision-making framework at a contaminated sediment site. This Web-based Technical and Regulatory Guidance provides a common resource for state regulators and practitioners to determine the appropriate application of bioavailability concepts and processes within an exposure pathway. “Bioavailability processes,” as defined by the National Research Council (NRC 2003), are the “individual physical, chemical, and biological interactions that determine the exposure of plants and animals to chemicals associated with soils and sediments.” Bioavailability assessment tools aid in the assessment of human and ecological exposure and can help develop site specific remedial objectives. This guidance identifies where bioavailability considerations may be pertinent in the human health and ecological exposure assessment process. The guidance also provides a description of available tools used for the evaluation of bioavailability in the context of evaluating exposure pathways of benthic invertebrates, fish and aquatic invertebrates, wildlife, plants and human health. Case studies, referenced throughout the document, help to demonstrate the practical application of bioavailability measures. Also, it assists state regulators and practitioners in understanding and incorporating fundamental concepts of bioavailability in contaminated sediment management by: (1) outlining how bioavailability considerations within a prospective exposure pathway can be incorporated into the conceptual site model (CSM); (2) identifying and describing available tools (biological, chemical, and physical) and models that are used to measure and characterize the fate and transport and potential bioavailability of contaminants; (3) modifying remedial goals based on application of bioavailability concepts in evaluating potential risk and taking advantage of bioavailability concepts in designing remedies and managing risk; and (4) communicating these bioavailability-based conclusions, especially to the public. The web-based operation of the guidance offers streamlined access to items that are the most important to the user. There are options where a pop-up screen will display tables that relate to the narrative within the section. Flow diagrams in each section of the guidance contain interactive links to specific discussion points within the narrative. Completion date for this guidance is February 2011. A free ITRC internet training will be offered during 2011–2013 on the proper use of the Guidance.
MEASUREMENT AND MODELING OF ECOSYSTEM RISK AND RECOVERY FOR IN-SITU TREATMENT OF CONTAMINATED SEDIMENTS

RICHARD LUTHY
Stanford University
473 Via Ortega, Y2E2 Building
Stanford, CA 94305
(650) 723-3921
luthy@stanford.edu

CO-PERFORMERS: Elisabeth Janssen and Dr. Yeo-Myoung Cho (Stanford University); Dr. Samuel Luoma and Dr. Janet Thompson (U.S. Geological Survey); Dr. Amy Oen (Norwegian Geotechnical Institute)

A biodynamic modeling approach was developed to predict the uptake of PCBs for benthic organisms with different feeding strategies. A polychaete showed a high accumulation of PCBs in their tissue and a distinct response of 95% lower tissue concentrations after sorbent-amendment. Reduced uptake in organisms at the base of the food web further supports that sorbent-amendments can reduce trophic transfer of PCBs and diminish risk. Such deposit-feeders are among the most suitable biological indicators for sediment risk assessment because the food uptake mainly comprises sediment ingestion. Rapid assessment tools to measure PCB sediment pore water concentrations are being tested to correlate aqueous concentrations of PCBs with reduced bioavailability. Polyethylene sampling devices (PEDs) and thin polyoxymethylene (POM) sampling devices are being tested in the laboratory and validated in the field using performance reference compounds (PRCs). To overcome uncertainties about pore water movement and exchange with the overlying water, a new method of measuring temperature profiles in the field and modeling heat transfer to assess pore water movement is being developed. A mass transfer model to estimate PCB uptake by activated carbon could then incorporate sediment pore water movement and heterogeneous activated carbon distribution. Field deployments of polychaetes showed less reduction in PCB uptake in AC-amended sediment than passive samplers or laboratory bioassays. It was concluded that (a) physiochemical measurements alone may not solely represent in-situ effects in biota, and (b) field deployments in small vessels may deliver confounding results because of the influence by surrounding areas of non-treated, contaminated field sediment. Benthic surveys were conducted and community data was collected from more than 50 sampling stations in the San Francisco Bay. The statistical power from such data is used to reduce uncertainties about whether natural factors confound differences between the Hunters Point benthic community and the recruitment areas. Subsurface deposit-feeders and subsurface carnivores showed significantly lower abundance at Hunters Point compared to the Central Bay. With such insights, an ecosystem recovery conceptual model is being developed to explain the benefits of AC-amendment by correlating reduced PCB availability with species abundance. Establishing correlations among physiochemical measurement tools (passive sampling) and bioaccumulation processes and models in the field will allow users to confidently use the rapid, inexpensive tools to assess the status of a contaminated sediment site after treatment or during a monitored natural recovery. This work is funded under SERDP Project ER-1552.
SEQUESTRATION OF METALS IN ACTIVE CAP MATERIALS: A LABORATORY AND NUMERICAL EVALUATION

MR. KENNETH L. DIXON
Savannah River National Laboratory
Building 773-42A
Aiken, SC 29841
(803) 725-5205
kenneth.dixon@srnl.doe.gov

CO-PERFORMER: Dr. Anna S. Knox (Savannah River National Laboratory)

Breakthrough column studies were conducted to evaluate the effectiveness of selected active amendments in the sequestration of various metals. Two columns have been tested under saturated conditions; one packed with sand and one packed with apatite. A spike solution containing 10 µg L⁻¹ of As, Cd, Co, Se, Cr, Cu, Ni, Pb, and Zn was injected into the sand column at a flow rate of 0.2 ml/min⁻¹. A spike solution containing 2 µg L⁻¹ of As, Cd, Co, Se, Cr, Cu, Ni, Pb, and Zn was injected into the apatite column at a flow rate of 0.5 ml/min⁻¹. A non-reactive tracer was used to determine breakthrough of the advective front and to estimate the pore volume of both the sand and apatite columns. Approximately 3 to 4 pore volumes of solution were pumped through the sand column over a period of approximately 24 hrs and breakthrough of all metals was observed during this period. As expected, breakthrough of the metals was similar in timing to breakthrough of the non-reactive tracer. Approximately 1,800 pore volumes of solution were pumped through the apatite column over a period of 135 days. Relative to the non-reactive tracer, the breakthrough of each metal was significantly delayed by the apatite.

A one-dimensional numerical model was used to qualitatively assess the transport and retention of the metals through both the sand and apatite columns. Good agreement was noted between the predicted and observed contaminant breakthrough for the sand column. However, for the apatite column, breakthrough was observed somewhat earlier in the laboratory studies than predicted by the numerical model. The numerical model was also used to simulate metals movement through the active amendment organoclay. Breakthrough curves were prepared for selected metals and compared to the sand and apatite simulations.

The results of this study demonstrate that caps composed of active amendments can significantly delay contaminant breakthrough compared with caps composed with passive amendments. The results of this study also illustrate the usefulness of numerical models in designing active caps, in that they can be used to estimate the required cap thickness to delay contaminant breakthrough for a specified time period given specific field conditions.

This research work is funded under SERDP Project ER-1501.
GEOCHEMICAL AND BIOLOGICAL FACTORS INFLUENCING METAL ACCUMULATION IN BENTHIC ANIMALS

ZOFIA TUREK
Stony Brook University
Endeavour Hall
Stony Brook, NY 11794-5000
(631) 632-8700
zosia@ravenblond.com

CO-PERFORMERS: Nicholas S. Fisher and Gregory A. Cutter (Old Dominion University)

Sediments in harbors and estuaries are greatly enriched in particle-reactive chemical contaminants and may serve as a significant source of these contaminants for benthic organisms and possibly pelagic organisms in overlying waters. This work addresses the extent to which sediments can introduce contaminant metals and metalloids into benthic food chains by examining the bioavailability of Cd, Cr, and As in the ubiquitous deposit-feeding polychaete, *Nereis succinea*. Contaminated sediments from the Chesapeake Bay (Norfolk and Baltimore Harbors) and from Mare Island in San Francisco Bay have been compared. This study assesses both the geochemical factors in the sediments that influence this bioavailability—specifically the chemical speciation of the metals in the sediments—and the biological factors that influence the bioaccumulation of these metals. Recent studies have underscored the importance of diet as a source of metals for many aquatic animals, and have quantified the proportion of metal uptake from aqueous and dietary sources by relying on a biokinetic (or biodynamic) model which in turn relies on quantitative estimates of uptake from water and food, and biological loss following each exposure pathway. This approach was extended to evaluate the relative importance of pore water and diet as sources of metals for polychaetes by measuring the assimilation efficiencies of these metals from whole sediments and different sediment components in laboratory radiotracer experiments, as well as assessing the uptake of metal from pore water. This study determined the efflux rates of these metals from the polychaetes, and consistently showed that diet plays a major role in delivering metals into these worms (>90%), and that assessments which rely solely on aqueous exposure to evaluate bioaccumulation and attendant risk are inappropriate. The bioavailability of metal was related to the speciation of the metals in the sediments (and how this varies over time)—determined with an improved sequential chemical leaching scheme—and to the release of metals from specific components of sediments into the gut fluid within the worm’s gut. This project found that release of As from whole sediments or specific geochemical components of sediments into gut fluid somewhat exceeded As assimilation efficiencies (AE), but more closely matched AE than did metal release into water or simulated gut fluid.

This work is funded under SERDP Project ER-1494.
OBJECTIVE IDENTIFICATION OF STRUCTURAL PROPERTIES ASSOCIATED WITH POLYCHLORINATED BIPHENYL DECHLORINATION PROCESSES

A. S. HUGHES
Carnegie Mellon University
5000 Forbes Avenue
129 Baker Hall
Pittsburgh, PA 15213
(215) 421-4564
ahughes@cmu.edu


Polychlorinated biphenyl (PCB) molecules can be biologically degraded through sequential losses of a chlorine atom, following 840 pathways from higher-chlorinated to lesser-chlorinated congeners and biphenyl. Eight recurring sets of pathways, called dechlorination processes, have been identified through the analysis of shifts in congener masses in field and laboratory studies. Dechlorination processes were originally described in terms of explicitly reported pathways. From these, dechlorination process generalizations were qualitatively extrapolated based on limited attributes of the congeners.

Dechlorination process generalizations are valuable because they allow comparisons of dechlorination patterns across laboratory experiments and contaminated sites. However, due to analytical limitations and a paucity of studies, the explicitly reported pathways in dechlorination processes likely do not represent all of the pathways that may be observed at contaminated sites. Further, it has been suggested that possible dechlorination pathways in sediment are affected by a variety of biogeochemical conditions. Consequently, the pathways within dechlorination process generalizations may have been limited by the small number of evaluated studies.

A novel application of classification trees is an alternative, quantitative and replicable approach to the identification of candidate pathways for inclusion in dechlorination process generalizations. It is not intended to replace traditional laboratory techniques, but rather to supplement them. The classification tree method expands on the accepted structure-based premise that was originally taken to identify dechlorination process generalizations while providing a basis for exploring the implications of including or excluding alternative pathways in a given dechlorination process. Alternative trees can then be compared in terms of critical congener attributes for classification. The dechlorination process classification trees performed very well, with correct classification rates ranging from 0.90 to 0.99. The classification trees predicted the inclusion of 486 pathways in addition to the 108 explicitly reported pathways. While many of the attributes used in the original generalizations were also selected as predictors for dechlorination process inclusion by the classification trees, the trees suggest that the small number of attributes used to identify the original generalizations were not able to fully capture the microbial specificity represented by dechlorination processes.

This work is funded under SERDP Project ER-1495.
CONTINUOUS TIME HIDDEN MARKOV MODEL TO DETERMINE
DECHLORINATION PATHWAY LIKELIHOODS OF POLYCHLORINATED
BIPHENYL CONGENERS

AMANDA HUGHES
Carnegie Mellon University
5000 Forbes Avenue
Baker Hall 129
Pittsburgh, PA 15213
(215) 542-7591
ahughes@cmu.edu

CO-PERFORMERS: J. Gonzalez, M. J. VanBriesen, and M. J. Small
(Carnegie Mellon University)

The biotransformation of polychlorinated biphenyl (PCB) congeners in sediment continues to be a widely studied and incompletely understood problem. Biotransformations from higher-chlorinated to lesser-chlorinated congeners and biphenyl occur according to 840 dechlorination pathways. These pathways describe the loss of a single chlorine atom from each of the 209 congeners. Laboratory studies investigate dechlorination pathways, as they may lead to changes in specific congeners that alter the human health risk associated with contaminated sediments. However, pathway occurrence is extrapolated from observed changes in congener masses. Such extrapolations are complicated by (1) individual quantification of fewer than the full 209 congeners due to co-elution, (2) stochastic and static uncertainties, (3) the presence of multiple pathways to reach congener end points, and (4) a simultaneous increase and decrease in congener mass during multi-step transformations. Therefore, extrapolations have necessarily relied on the knowledge and experience of the researcher. Consequently, they are often not reproducible and may be inaccurate.

In order to address these concerns, a continuous time hidden Markov model has been developed to predict the likelihoods of the 840 dechlorination pathways across the course of controlled laboratory experiments. Application of this model to a laboratory setting enables it to be constrained such that total PCB mass is conserved. Model inputs are the uncertainty associated with congener measurements and the initial congener concentrations and the changes in congener concentrations over time as ascertained though sampling. Using this construction, it is not necessary for all 209 congeners to be quantified, as the model is capable of handling missing data. Uncertainty is incorporated through a Bayesian approach and application of the Monte Carlo method according to the Metropolis Hastings sampling algorithm. Therefore, additional updates to the model, in the form of congener-specific samples, will result in more certain findings. Primary outputs are the likelihoods of each of the 840 dechlorination pathways and their associated uncertainties for time periods between samples and across the entire experiment. These pathway likelihoods, or changes in them, can then be readily correlated to congener concentrations, microbial populations, sediment conditions and risk in both past and future experiments. This model will aid in the effort to learn all that we can from costly and time consuming experiments while providing a better understanding for the drivers of biotransformation of PCBs in sediments. This work is funded under SERDP Project ER-1495.
PRELIMINARY ASSESSMENT OF RISK DRIVERS AT SEDIMENT DOĐ SITES

DR. KATHERINE VON STACKELBERG
Environmental Risk Sciences, LLP
12 Holton Street
Allston, MA  02134
(508) 596-4209
kvon@erisksciences.com

CO-PERFORMERS: Tim Thompson (Science and Engineering for the Environment, LLC);
Cara Patton (HydroGeologic, Inc.)

The U.S. Department of Defense (DoD) has numerous sediment sites at various stages of the assessment and potential clean-up process. DoD therefore has an interest in understanding which contaminant-receptor-pathways are driving predicted human health and ecological risks posed by contaminants in sediments. Understanding the basis for decision making at sites for which Records of Decision (ROD) have been issued is useful for evaluating uncertainty and identifying focus areas where further research might be warranted, particularly with respect to bioavailability, which is often not quantitatively considered in the risk assessment process. To evaluate the basis for decision making at sediment DoD sites, this work developed a database that extracted summary information across a set of ROD published by EPA, including contaminant, pathway, receptor (ecological or human), and clean-up goal. A summary of statistics and observations from preliminary analysis will be presented to assist in identifying trends across sites where information and data might be leveraged for future analyses. The goal is to understand and ultimately reduce uncertainty in human health and ecological risk assessments used to support environmental decision-making at DoD sites.
PCB ANALYTICAL METHOD UNCERTAINTY AND EVALUATION OF PCB TRANSFORMATIONS IN NATURAL SYSTEMS

DR. JEANNE VANBRIESEN
Carnegie Mellon University
5000 Forbes Avenue
Porter Hall
Pittsburgh, PA 15213
(412) 268-4603
jeanne@cmu.edu

CO-PERFORMERS: Amanda Mitchell, Amanda Hughes, Dr. Sandra Karcher, and Dr. M. J. Small (Carnegie Mellon University)

Analytical methods for the analysis and quantification of polychlorinated biphenyls (PCBs) have developed from simple measures of organic chlorine to full congener analysis. However, most analyses used for environmental and human sampling involve some grouping of congeners or some bulk measurement. These methods, therefore, introduce uncertainty with respect to concentrations of specific congeners and with respect to total mass of PCBs. Understanding the movement and fate of PCBs in the environment and making decisions regarding PCB risk and remediation should be based on quantification of individual congeners because different congeners have significantly different effects on human health (e.g., toxicity, carcinogenicity); further, they exhibit different partitioning in the environment and different bioavailability to PCB-degrading organisms and organisms at the base of the food chain. When full congener-specific analysis is not possible, uncertainty introduced into model predictions and regulatory decisions due to less specific data should be evaluated. The present work quantifies the uncertainty introduced into PCB analyses using the standard gas chromatography/electron capture detector (GC/ECD) method for analysis. The effect of this uncertainty on the determination of total PCBs and an evaluation of the effect on in situ biodegradation potential is discussed.

This work is funded under SERDP Project ER-1495.
EVALUATION OF REDUCTIVE DECHLORINATION OF POLYCHLORINATED BIPHENYLS (PCBs) IN SEDIMENT CORE SAMPLES USING TRACKER PAIRS

DR. JEANNE M. VANBRIESEN
Carnegie Mellon University
5000 Forbes Avenue
Porter Hall 119
Pittsburgh, PA 15213
(412) 268-4603
jeanne@andrew.cmu.edu

CO-PERFORMERS: Dr. Mitchell J. Small and Dr. Sandra C. Karcher
(Carnegie Mellon University)

Using published Aroclor congener distribution data and statistical methods, we identified 95 correlated PCB congeners. These 95 congeners, when analyzed in pairs and transformed into log space, display a linear relationship in 276 combinations. We refer to these 276 correlated congeners as tracker pairs.

In a previous study on sediment samples collected from the Hudson River, it was found that many of the 276 tracker pairs showed a statistically significant shift away from their Aroclor correlation relationships; they were no longer, “Aroclor-like.” In many cases, the congeners that remained in the sediments in higher proportions than in Aroclors were congeners identified in published laboratory studies as being resistant to microbial mediated reductive dechlorination.

A similar trend has been found in samples collected from the Grasse River. Furthermore, when applying the tracker pair method to sections of an intact core, many of the correlated congeners move further from their Aroclor-like relationship in the deeper sediments. This trend is evident in Grasse and Hudson River sediments, suggesting that the Aroclors in the deeper sediments continued to dechlorinate years after their initial deposition.

This work was funded by the Packard Foundation Interdisciplinary Science Program and under SERDP Project ER-1495.
COMBINING DEEP-SEQUENCING AND ULTRA-DENSE MICROARRAYS TO DEFINE METAL EXPOSURE IN THE KILLIFISH, FUNDULUS HETEROCLITUS

JOSEPH R. SHAW  
The School of Public and Environmental Affairs  
Indiana University  
1315 East Tenth Street  
Bloomington, IN 47405  
(812) 855-1392  
joeshaw@indiana.edu

CO-PERFORMERS: Jeong-Hyeon Choi and John K. Colbourne (Indiana University); Bruce A. Stanton (Dartmouth Medical School); Celia Y. Chen (Dartmouth College)

The overarching goal of this work is to develop a set of robust genomic signatures (i.e., expanded biomarkers) in the killifish that are predictive of the site-specific risks posed by contaminated sediments. In support of this objective, the project used next-generation sequencing techniques (454, Roche) to sequence the killifish transcriptome illuminated by 72 different conditions, including sex, tissue, salinity, developmental stage, and metal exposure. Approximately 1,500,000 expressed sequence tags (EST) were generated, totaling 275,000,000 bp. Assembly of the EST yielded 39,000 contiguous fragments (i.e., gene/gene fragments) stretching 17,000,000 bp with a mean sequence depth of 10.5X. All filtered and analyzed sequences were directly fed into a pipeline for microarray design to determine appropriate oligonucleotide sets. A microarray (KF_V2.0) was constructed on the NimbleGen 12-plex platform that consists of 12 sub-arrays per slide with each sub-array containing 137,000 oligonucleotide probes (~70mers). All of the 29,245 assembled contigs were represented by at least three unique probes. Subsets consisting of 5,699 and 2,570 contigs were represented by five and four unique probes, respectively. In all instances, probes were designed to represent putative, unique exons. The remainder of each sub-array (35,297 probes) included sequence reads that lacked homology with any other (i.e., singletons). Initial experiments were conducted with cadmium and focused on differentiating aqueous from dietary exposures. These experiments included two treatment groups (aqueous and dietary cadmium) and a control group, following a complete loop design with each group represented by four independent samples. Response signatures for cadmium exposures were compared to control fish and against each other. Data were statistically analyzed using a linear model (LIMMA) and provided unique signatures of exposure that differed between exposure route. Future studies will expand to include other metals assayed individually and as components of complex mixtures.

This work is funded under SERDP Project ER-1503.
APPLICATION OF TOOLS TO MEASURE PCB MICROBIAL DECHLORINATION AND FLUX INTO WATER DURING IN-SITU TREATMENT OF SEDIMENTS: MICROBIAL DEGRADATION RESULTS

PIULY PAUL
University of Maryland Baltimore County
TRC Building
5200 Westland Blvd
Baltimore, MD 21227
(410) 455-3568
piuly1@umbc.edu

CO-PERFORMERS: Dr. Joel E. Baker and Dr. Andrew Chang (University of Washington Tacoma); Dr. Upal Ghosh (University of Maryland Baltimore County); Dr. Kevin Sowers and Dr. Birthe Kjellerup (University of Maryland Center for Marine Biotechnology)

This SERDP-funded research project (ER-1502) is quantifying the two most important long-term loss processes for polychlorinated biphenyls (PCBs) in sediments: (1) microbial degradation, and (2) diffusive and resuspension related losses to the water column. This work addresses natural PCB microbial degradation activity in sediment affected by activated carbon sequestration. The experimental approach is based on determining the identity and activity of the microbial population responsible for PCB degradation in natural sediments, as well as in sediment treated with activated carbon. These results will be integrated into a model developed in the current project describing sediment-water exchange, particle coagulation, and PCB desorption rates.

Aerobic degradation of PCB was studied in the Grasse River sediment. In an aerobic slurry of the sediment, a significant decrease in the mass of di- and trichlorobiphenyls was observed as compared to an abiotic control after 60 days and one year of incubation. Activated carbon amended sediment showed slower rates of biodegradation and a decrease in the volatilization of PCBs. Also, anaerobic dechlorination was studied in Baltimore Harbor sediment samples spiked with Aroclor 1260. The results showed improved dechlorination in the presence of activated carbon. The dominant dechlorination products formed in activated carbon treated samples were mono- and di-chlorinated congeners, whereas the main products in untreated samples were tetra-chlorinated congeners as observed previously. In addition, the microbial populations were analyzed with polymerase chain reaction based denaturing high-performance liquid chromatography (PCR-DHPLC) at Day 0 and Day 500 to evaluate whether the observed change in dechlorination pattern was due to a change in the microbial populations or the activity associated with these populations. The DHPLC chromatograms show that the major phylo-types in the samples were identical, but small changes were observed in phylo-types constituting a minor part of the total population. The results show that PCB dechlorination can occur in the presence of activated carbon with changes in the dechlorination pattern, but without major changes in the dechlorinating microbial populations. The results indicate that activated carbon treatment might successfully be followed by aerobic treatment to obtain complete microbial PCB degradation.
APPLICATION OF TOOLS TO MEASURE PCB MICROBIAL DECHLORINATION AND FLUX INTO WATER DURING IN-SITU TREATMENT OF SEDIMENTS: RESUSPENSION AND DESORPTION RESULTS

DR. JOEL BAKER
University of Washington Tacoma
1900 Commerce Street
Tacoma, WA 98402
(253) 692-5659
jebaker@u.washington.edu

CO-PERFORMERS: Dr. Andrew Chang (University of Washington Tacoma); Dr. Kevin Sowers and Dr. Birthe Kjellerup (University of Maryland Center for Marine Biotechnology); Dr. Upal Ghosh and Piuly Paul (University of Maryland Baltimore County)

This SERDP-funded research project (ER-1502) is quantifying the two most important long-term loss processes for polychlorinated biphenyls (PCBs) in sediments: (1) microbial degradation, and (2) diffusive and resuspension related losses to the water column. This work addresses the mobility of PCBs as sediments are resuspended – as affected by activated carbon (AC) amendments. This project’s approach employs particle entrainment microcosms coupled with laser-based particle size measurements, and solid phase microextraction (SPME)-based PCB congener speciation measurements. The results, along with the microbial degradation studies described in the companion work (Paul, ER-1502), will be integrated into a model developed in the current project describing sediment-water exchange, particle coagulation, and PCB desorption rates. A series of experiments were conducted with Grasse River sediment, activated carbon, and activated carbon-amended sediment (3.43% by weight) using a particle entrainment simulator (PES) (Tsai and Lick, 1986). After consolidation, each sediment type was resuspended under shear stresses ranging from 0.05 to 0.4 Pa (Lavelle and Davis, 1987), and suspended solids, particle size distribution, total activated carbon, particulate and dissolved PCBs were measured. Not surprisingly, bulk activated carbon had the smallest critical shear stress value, and AC alone was easily eroded. When the Grasse River sediment was amended with activated carbon, the critical shear stress decreased; this was perhaps due to changes in the sediment structure as the sediment and carbon were mixed for 30 days. The steady state suspended solids concentration in the overlying water increased with higher shear stress for all sediments. At a given level of bottom stress, the AC-treated Grass River sediment had a higher TSS concentration compared to the untreated sediment, suggesting the AC may change the physical properties of the consolidated sediment. The AC was selectively eroded relative to bulk sediment (i.e., the suspended solids were enriched in AC relative to the consolidated sediments), with the extent of enrichment increasing as applied shear increased. The implication of these results is that in situ treatment of sediments with activated carbon may be compromised in erosional environments without further stabilization or capping.
REACTIVE CAP DESIGN FOR CONTAMINATED SEDIMENT

CHRIS MCGRAITH
U.S. Army Corps of Engineers-Engineer Research and Development Center
Environmental Processes Branch (EP-P)
3909 Halls Ferry Road
Vicksburg, MS 39180
(601) 634-3798
Chris.McGrath@usace.army.mil

CO-PERFORMERS: Dr. Carlos Ruiz and Dr. Paul Schroeder (U.S. Army Engineer Research and Development Center – Environmental Laboratory)

Cost-effective methods for passive in-situ treatment of contaminated sediments are needed for situations in which remedial action is deemed necessary, but the risks and/or costs associated with dredging are unacceptable. Capping has proven to be an effective and practical method for the isolation of contaminated sediments, but reactive capping technologies are still in their infancy. Placement of the reactive materials is of critical importance in treatment effectiveness, longevity, and maintenance.

The first phase of this investigation includes an evaluation of alternative distributions of reactive media – granular activated carbon (GAC) – in sandy cap material. Identical amounts of GAC are placed in side-by-side laboratory columns, with the following distributions: (1) disseminated within a sand cap, (2) placed as discrete layer within a sand cap, and (3) concentrated in a reactive chimney, through which flow is directed by a surrounding annular, impermeable cap. Slow upward flux of a copper bromide solution provides breakthrough characterization for both a conservative tracer (bromide) and a metallic cation (copper) retarded by adsorption to the GAC. Control columns with no GAC provide a benchmark for comparison.

At the field scale, each of these distributions would be expected to treat contaminated porewater flux arising from either groundwater seepage through or compaction dewatering from contaminated sediment. The potential advantages of the reactive chimney approach may include: (1) performance monitoring could be focused at outlets; (2) the reactive materials could be replaced with relative ease, without disruption of cap integrity; (3) placement could be targeted at points of elevated flux or bathymetry; and (4) chimney contents and diameter could be adapted to contaminant mixtures and flux.

This investigation is being conducted in the new ERDC Sediment Research Laboratory with support from the ERDC Dredging Operations and Environmental Research (DOER) Program.
**Bacterial Population Shifts Related to Anaerobic Reductive Dechlorination of Typical PCB Tracker Pairs in Hudson and Grasse Sediment Microcosms**

MS. YAN XU  
Carnegie Mellon University  
5000 Forbes Avenue  
Pittsburgh, PA 15213  
(814) 441-5345  
yanxu@cmu.edu

CO-PERFORMERS: Stacia Thompson, Edwin Minkley, Kelvin Gregory, and Jeanne VanBriesen (Carnegie Mellon University)

Polychlorinated Biphenyls (PCBs) are reductively dechlorinated by certain dechlorinating microorganisms under anaerobic conditions. After carefully analyzing PCB congener distributions in different Aroclor mixtures at different locations, specific ratios of PCB congeners were found to be indicators of PCB dechlorination. However, the trend of tracker pair ratio shifts was not well studied under controlled laboratory conditions. To better understand the relationship between dechlorination pathways and the bacterial population shifts, two sets of typical PCB tracker pairs, including PCB 5/PCB 12, PCB 64/PCB 71, PCB 105/PCB 114, PCB149/PCB 153/PCB 170 and PCB 5/PCB 12, PCB 64/PCB 71, PCB 82/PCB 97/PCB 99, PCB 144/PCB 170 respectively were spiked to both Hudson and Grasse River sediments as the potential electron acceptor at a total concentration of 50 ppm. Slurry samples were taken at different time points during the incubation period. Quantitative polymerase chain reaction (Q-PCR) were performed to quantify 16S rRNA gene copy numbers of total Bacteria (BAC), Chloroflexi group (CHL), *Dehalococcoides* group (DHC), and PCB dechlorinators (o-17/DF-1 clade). Together, denaturing gradient gel electrophoresis (DGGE) was conducted to obtain the fingerprints within each of the above bacterial groups. The preliminary results suggest that bacterial populations shift over time under the selective pressure of relatively high concentrations of specific PCBs in the microcosms. The enrichment of certain dechlorinating organism species may explain the rate and extent of changes to relative ratios of PCBs observed in field data.

This work is funded under SERDP Project ER-1495.
ASSESSING ALTERNATIVE ENDPOINTS FOR GROUNDWATER REMEDIATION AT CONTAMINATED SITES

ELISABETH L. HAWLEY
Malcolm Pirnie, Inc.
2000 Powell Street, Suite 1180
Emeryville, CA 94608
(510) 735-3027
ehawley@pirnie.com

CO-PERFORMERS: Dr. Rula A. Deeb, Robert O’Laskey, Lauren Kell, and Dr. Michael C. Kavanaugh (Malcolm Pirnie, Inc.)

This poster will highlight statistics and case studies from an ongoing ESTCP project (ER-0832) designed to broaden Department of Defense (DoD) knowledge of alternative endpoints for groundwater remediation, including technical impracticability (TI) and other Applicable or Relevant and Appropriate Requirement (ARAR) waivers, similar designations under state and local jurisdictions such as groundwater management zones, Alternate Concentration Limits (ACLs), use of monitored natural attenuation (MNA) over long timeframes, and more. The primary objective of this project is to provide environmental managers and regulators at DoD sites with tools, metrics, and information needed to evaluate alternative endpoints for groundwater remediation at complex sites. DoD has many complex sites where remedial timeframes to achieve Maximum Contaminant Levels (MCLs) or background concentrations in groundwater throughout the aquifer are on the order of 100 years or more. Since complex sites frequently constitute the majority of a cleanup program budget, alternative remedial endpoints may save DoD significant money while providing the same level of protection to human health and the environment. Other benefits of alternative groundwater remedial endpoints include the ability to move DoD sites forward in the remedial process towards site closure and the latitude to define realistic performance objectives for source reduction or containment technologies. The Malcolm Pirnie project team has recently reviewed the CERCLA Record of Decision (ROD) database and identified illustrative examples of alternative endpoints applied at RCRA sites and in other cleanup programs. A statistical analysis of CERCLA sites receiving TI waivers will be presented as well as case studies of other types of alternative endpoints to illustrate the technical analyses used to formulate and document the cost, timeframe, and predict the impact of potential remedial technologies. Numeric cleanup goals depend on site circumstances (including current and future resource/land use), the location of points or compliance, and stakeholder agreement on an acceptable timeframe to achieve cleanup goals. Flexibility in one or more of these variables can serve as the basis for alternative remedial endpoints. One component of the project includes technology transfer workshops for DoD, their consultants, and regulators. These workshops will improve understanding and promote dialogue about the underlying technical limitations to complete groundwater restoration, tools and lines of evidence that have been used to predict restoration potential at other sites. Dates and locations for workshops will be presented in the poster, as well as an overview of the project report, designed to help DoD and regulators recognize the opportunity for alternative endpoints and metrics at complex sites.
The objective of these microcosms is to verify existing PCB dechlorination processes, previously observed in PCB-contaminated sediments, and to evaluate the effect of geochemical conditions on the extent of dechlorination in different sediments. Additionally, PCB tracker pairs were used to test their reliability as an indicator of anaerobic reductive dechlorination based on the quantitative results of spiked PCB tracker pairs and their first generation daughter PCB congeners. The 10 tracker pairs used in these experiments were selected based on the following criteria: (1) interesting behavior in both Grasse and Hudson River tracker pair analyses from field data; (2) tracker pairs include parent congeners reported in dechlorination processes; (3) tracker pairs do not co-elute in the gas chromatography – electron capture detector (GC-ECD) lab method; (4) first generation daughters do not overlap with spiked congeners; (5) tracker pairs have a minimal number of co-eluting daughter products; (6) congeners are at greater than 1% in commercial Aroclors; and (7) congeners have public health relevance, including dioxin-like congeners and congeners associated with non-carcinogenic risk.

For the PCB spiked microcosms, the first set of tracker pairs includes PCB 5/PCB 12, PCB 64/PCB 71, PCB 105/PCB 114, PCB 149/PCB 153/PCB 170 and the second set of tracker pairs includes PCB 5/PCB 12, PCB 64/PCB 71, PCB 82/PCB 97/PCB 99, PCB 144/PCB 170. Due to different observed sediment characteristics in the Hudson and Grasse Rivers, some sediment microcosms were also amended with 20 mM sodium sulfate and 50 mM FeOOH to study the effect of sulfate and Fe on PCB dechlorination. Initial measurements of TOC, total phosphate, ammonia, nitrate, sulfate, and sulfide were collected for both sediments. At each sampling point, PCBs were extracted from a 2 mL subsample and analyzed by GC-ECD method for specific congener concentrations. Preliminary results suggest that there is a relationship between the initial PCB tracker pairs and the extent of PCB dechlorination. These experiments are ongoing, but preliminary results suggest that sediment characteristics and the presence of specific PCB congeners influences dechlorination pathways.

This work was funded under SERDP Project ER-1495.
MESOCOSM-SCALE INVESTIGATION OF PCB DECHLORINATION IN SEDIMENTS WITH LOW CONCENTRATION HISTORICAL PCB CONTAMINATION

PROFESSOR DONNA FENNELL
Rutgers University
Department of Environmental Sciences
14 College Farm Road
New Brunswick, NJ 08901
(732) 932-9800
fennell@envsci.rutgers.edu

CO-PERFORMERS: Dr. Songyan Du, Professor Lisa Rodenburg, Dr. Joong-Wook Park, Dr. Valdis Krumins, Professor Lee J. Kerkhof, and Professor Max M. Häggblom (Rutgers University)

As part of SERDP Project ER-1492, this work investigates potential enhancements to stimulate microbial reductive dechlorination of polychlorinated biphenyls (PCBs) and chlorinated pesticides in sediments from two contaminated sites: (1) the Anacostia River, a tidal freshwater waterway in Washington, D.C. containing 2.1 mg/kg total PCBs, and (2) Kearny Marsh, a freshwater impoundment in the New Jersey Meadowlands with 1.2 mg/kg total PCBs, along with various chlorinated pesticides including p,p'-DDT.

Sediment mesocosms (~6 L) were amended with electron donors, halogenated co-substrates (tetrachlorobenzene or pentachloronitrobenzene) as “primers,” indigenous microbial communities pre-activated on haloprimers, and/or *Dehalococcoides ethenogenes* strain 195. Mesocosm treatments were also compared between capped (Aquablok) and uncapped systems. These treatments were evaluated as a means to increase dechlorinator populations and dechlorination activity for in situ bioremediation.

Treatment effectiveness was assessed by tracking DNA-based markers of dechlorinating bacteria and reductive dehalogenase genes. Changes in the chlorination level of the pre-existing PCBs and chlorinated pesticides in the sediment also were examined. A congen specific PCB analytical method was developed using a Waters Quattro Micro gas chromatography-dual mass spectrometry system with an Agilent DB5 capillary column. This instrument provides detection limits similar to an Electron Capture Detector, while also allowing the unequivocal identification of more PCB congeners. PCB dechlorination and dechlorination pathways were investigated through identification and quantification of historical PCB congeners and potential dechlorination products eluting from the Gas Chromatography tandem Mass Spectrometry (GC-MS-MS) system. The PCB method resolved approximately 113 chromatographic peaks representing approximately 147 PCB congeners.
RATIONAL SELECTION OF TAILORED AMENDMENT MIXTURES AND COMPOSITES FOR IN SITU REMEDIATION OF CONTAMINATED SEDIMENTS

UPAL GHOSH
University of Maryland Baltimore County
1000 Hilltop Circle
Baltimore, MD 21250
(410) 455-8665
ughosh@umbc.edu

CO-PERFORMERS: Dr. Brian Reed, Dr. Seokjoon Kwon, and Jeff Thomas (UMBC); Dr. Victor Magar and Laura Levine (Environ Corporation); Dr. Cindy Gilmour (Smithsonian Environmental Research Center)

Important needs in in situ sediment remediation include the selection of efficient sorbent amendments and an improved scientific understanding of how amendments reduce biouptake. Seventy five potential metal sorbents were screened to yield a list of eleven sorbents that were used for further sorption testing of metals and organics. Based on pH-edge sorption tests, natural sorbents were eliminated due to inferior performance. A thiol-amended mesoporous silica (Th-SAMMS) and a titanosilicate mineral (ATS) demonstrated the highest sorption capacity for Cd and Pb, respectively. Sequential extraction tests demonstrated transfer of metal contaminants from a weakly bound state to a more strongly bound state. Cd biouptake into freshwater oligochaetes was reduced by 98% when sediment was amended with Th-SAMMS. The Cd speciation was also altered with large reductions in the easily extractable fractions. However, the biouptake reduction of native Pb was insignificant while the treatment reduced easily extractable portions of Pb in the sediment.

Th-SAMMS demonstrated the highest sorption capacity for Hg in both freshwater and saltwater matrices. Treatment of Peninsula Harbor freshwater sediment resulted in lower MeHg bioaccumulation factors (BAF) in benthic organisms (P<0.05). The treatments reduced MeHg worm BAF by 54% (GAC), 58% (HGR), and 83% (Thiol-SAMMS). Biouptake reduction of Hg and methylmercury was achieved for both spiked and native mercury present in sediments. Thiol-SAMMS treatment along with activated carbon reduced bioaccumulation of native Hg, Me-Hg, and PCB present simultaneously in sediments.

Most amendments were nontoxic in chronic exposures. Organism survival in sediment amended with ATC, ATS, ConSepC, and HGR was not statistically different from the control for all endpoints evaluated. The toxicity observed for Thiol-SAMMS at 5% dosage was moderate with a reduction in H. azteca survival from 98% to 73%. Although Thiol-SAMMS reduced survival in clean control sediments, it may also increase survival of organisms in mercury contaminated sediments to levels that may be acceptable for meeting remediation goals. For example, L. plumulosus survival in diluted Augusta Bay sediment was 24% compared to a survival of 69% in the same sediment with Th-SAMMS amendment. It is anticipated that the technology developed through this project will be transitioned to full scale remedial applications through recently started and future pilot-scale studies.

This work is funded under SERDP Project ER-1491.
TEST AND VALIDATION OF MULTI-CRITERIA DECISION ANALYSIS TOOLS IN SUPPORT OF WEIGHT-OF-EVIDENCE EVALUATION AND REMEDY SELECTION IN MANAGEMENT OF CONTAMINATED SEDIMENTS

DR. IGOR LINKOV
U.S. Army Corps of Engineers-Engineer Research and Development Center
696 Virginia Road
Concord, MA 01742
(617) 233-9869
 Igor.linkov@usace.army.mil

CO-PERFORMERS: Dr. Christy Foran, Dr. Todd Bridges, Laure Canis, Alex Tkachuk, and Dr. Burton Suedel (U.S. Army Corps of Engineers-Engineer Research and Development Center); Dr. Dawn Hayes, Leslie Karr, and Stacey Curtis (U.S. Navy); Dr. Marc Greenberg (Environmental Protection Agency); Dr. Trina von Stackelberg (ERS)

The Comprehensive Environmental Resource, Conservation, and Liability Act of 1980 (CERCLA) sets forth a process for cleaning up contaminated sites to protect valuable environmental resources. This project develops a set of tools to promote robust and transparent decision support for evaluating and selecting sediment remedial alternatives. Risk assessment (RA) methodology, mandated by EPA, will be supplemented by multi-criteria decision analysis (MCDA) tools to integrate diverse lines of evidence related to impacts of contaminated sediments on ecological receptors and humans. MCDA allows integration of technical information and inevitable expert judgment on strength of associations in a transparent and reproducible way. Decision Evaluation in Complex Risk Network Systems (DECERNS) software will be used to develop an integrated RA/MCDA model for use by project managers and stakeholders at two demonstration sites. Once active, the user-friendly, web-based DECERNS application will be compared to a standard weight-of-evidence (WOE) approach. We anticipate that the DECERNS-based method will provide a stable, inclusive, repeatable, and transparent process for achieving a Record of Decision (ROD). Clarity of the decision process is of substantial value in evaluating, communicating, and defending the rationale behind the Remedy Selection presented in the ROD, given the significant legal and financial consequences of these documents. This decision support model will elevate remedy selection to a new level of robustness by providing a transparent, unbiased method for evaluating alternatives on both technical and social (e.g., stakeholder, regulatory) attributes.
Passive sampling with sorbents has been demonstrated to be an excellent means of measuring interstitial water concentrations of organic contaminants. Recent research has also tied interstitial water concentrations to contaminant availability and effects, including bioavailability and toxicity in benthic organisms. Under ESTCP Project ER-0624, a profiling solid phase microextraction (SPME) approach is used to define vertical profiles in interstitial water concentration. This is not only used to define interstitial water concentration but also gradients in interstitial water concentration, which can be linked to rates and mechanisms of contaminant transport. This approach can also be used to infer any differences in near surface contaminant (<1-2 cm) availability compared to deeper depths, and to evaluate cap performance by examining contaminant concentrations beneath and within a sediment cap. These capabilities have been explored in field studies at Anacostia River, Washington D.C. and Hunter’s Point, CA, as well as at several other sites. Contaminants of concern have included both polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). In each of these field studies, SPME measurements are compared to caged animal bioaccumulation. The experiences and results from these field applications will be presented. All passive sampling approaches exhibit limited detection limits, short retention time of volatile contaminants on retrieved SPME, and slow uptake kinetics of high molecular weight PCBs. Approaches to managing these problems and typical limitations of the technique will be presented.
THE ROLE OF ORGANIC CARBON IN CONTROLLING METAL BIOAVAILABILITY AND TROPHIC TRANSFER IN INTERTIDAL FOOD WEBS

DR. CELIA CHEN
Dartmouth College
Department of Biological Sciences
HB 6044
Hanover, NH 03755
(603) 646-2376
celia.chen@dartmouth.edu

CO-PERFORMERS: Jessica Dutton and Dr. Nicholas Fisher (Stony Brook University); Jason Williams (TerraGraphics Environmental Engineering, Inc.)

In the mixing areas of intertidal zones in estuaries, metals and organic matter are deposited in sediments and dissolved in the water column where communities of potentially exposed fauna include benthic and pelagic organisms of different functional feeding groups. The objective of this project was to conduct field and laboratory studies of metal bioavailability and bioaccumulation in intertidal food webs. Field studies were performed at estuarine sites in the Gulf of Maine and Narragansett Bay with varying amounts of metal and carbon in sediments. Across five sites, sediments and biota, including benthic infauna, epifauna, and pelagic organisms, were sampled. The metal concentrations (Hg, MeHg, Cd, As, and Pb), Simultaneously Extracted Metals/Acid-Volatile Sulfide (SEM-AVS), and total organic carbon (TOC) in sediments were measured, as well as metal concentrations and stable isotope signatures (delta 15N and 13C) in biotic tissues. To examine the influence of dissolved organic carbon (DOC) on metal bioaccumulation, laboratory studies were conducted using the intertidal fish species, Fundulus heteroclitus, exposed to radioisotopes of Hg, MeHg, and Cd in varying concentrations of humic acid. The field studies indicated that sediment concentrations are poor predictors of metal in biota. Moreover, bioaccumulation measured as a Benthic-Sediment Concentration Factor (BSCF) was strongly related to sediment TOC, but not SEM-AVS for all four metals. Food source measured as delta 13C was predictive of MeHg and Hg bioaccumulation, but not other metals. Results of the radioisotope experiments indicate that humic acid in water, like TOC in sediments, reduces the bioaccumulation of Hg and MeHg in killifish but not Cd. These results show that the bioavailability of metals is strongly influenced by factors other than water or sediment metal concentrations alone, and that carbon may play an important role in mediating both benthic and pelagic bioaccumulation of metals.

This work is funded under SERDP Project ER-1503.
QUANTIFYING ENHANCED MICROBIAL DEHALOGENATION IMPACTING THE FATE AND TRANSPORT OF ORGANOHALIDE MIXTURES IN CONTAMINATED SEDIMENTS

PROFESSOR MAX HAGGBLOM
Rutgers University
Department of Biochemistry and Microbiology
76 Lipman Drive
New Brunswick, NJ 08901
(732) 932-9763
haggblom@aesop.rutgers.edu

CO-PERFORMERS: Joong-Wook Park, Hui Liu, Donna E. Fennell, Valdis Krumins, Songyan Du, Lisa Rodenburg, and Lee J. Kerkhof (Rutgers University); Kevin Sowers and Birthe Kjellerup (University of Maryland Biotechnology Institute)

The overall objectives of this project are to extend techniques and amendments that enhance microbial dehalogenation for placement in sediments contaminated with organohalide mixtures, including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/F), and chlorinated pesticides, as well as develop methods and tools to monitor the effectiveness of the biostimulation process. Microbial reductive dechlorination may play an important role in natural detoxification of highly-chlorinated environmental pollutants, and in situ treatment of PCB contaminated sediments via microbial dechlorination is a promising alternative to dredging. Organohalide contaminated sediments typically contain a diverse population of dehalogenating microorganisms, although their activity is often limited. One effective strategy for stimulating dechlorination by sediment microorganisms, such as those in the Dehalococcoides genus, is the addition of alternate halogenated electron acceptors as co-substrates. Micro- and mesocosm studies demonstrated that active dechlorinating bacterial populations are present in organohalide contaminated sediments, and biostimulation may enhance the activity of both native and/or bioaugmented Dehalococcoides spp. Addition of appropriate amendments can enhance microbial dehalogenation of historic organohalide contaminant mixtures, including PCBs and PCDD/F. Phylogenetic approaches have been developed to monitor the effects of treatments on 16S rRNA genes of dehalogenating populations by terminal restriction fragment length polymorphism, nested PCR denaturing high performance liquid chromatography, and nested PCR denaturing gradient gel electrophoresis. Approaches were also developed to monitor the effects of treatments on populations of putative reductive dehalogenase (rdh) genes. The enhanced dechlorination correlated with increased numbers of respiratory dehalogenating populations and reductive dehalogenase genes, supporting the project’s hypothesis that the halogenated co-substrates enhance dechlorination of historic pollutants by supporting growth and activity of dehalogenating bacteria. This project provides evidence for a combined bioaugmentation/biostimulation approach to the bioremediation of sediments contaminated with chlorinated biphenyls, diphenyl ethers, dibenzo-p-dioxins, and/or dibenzofurans.

This work is funded under SERDP Project ER-1492.
Dechlorination of Polychlorinated Dibenzop-Dioxins in Soils and Sediments from Areas Sprayed with Agent Orange

PROFESSOR MAX HAGGBLOM
Rutgers University
Department of Biochemistry and Microbiology
76 Lipman Drive
New Brunswick, NJ 08901
(732) 932-9763
haggblom@aesop.rutgers.edu

CO-PERFORMERS: Vien M. Duong (Cantho University);
Joong-Wook Park (Rutgers University)

Dioxin-pollution hotspots in Vietnam are former military air-bases and areas heavily sprayed with Agent Orange, a defoliant used during the Vietnam War. Agent Orange was a mixture of 2,4-dichlorophenoxy acetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) contaminated with dioxins. Spraying of the Agent Orange defoliant at the former Aso military airbase, the adjoining areas of Aluoi of Thua Thien Hue province, and Cua of Quang Tri province in Vietnam may have enriched for polychlorinated dibenzo-p-dioxin (PCDD) - dechlorinating bacteria in soils/sediments. Soil analysis revealed a high concentration of polychlorinated dibenzo-p-dioxins at these Agent Orange-sprayed areas, particularly at the former airbase, where 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) reached 900 pg/g. This study examined the 12,3,4-TCDD and 2,3-DCDD dechlorinating capacity of the bacterial community of soils/sediments from Agent Orange-sprayed areas. Anaerobic microcosms were spiked with approximately 10 µM 1,2,3,4-TCDD or 2,3-DCDD for 19 soils/sediments collected from these sites. 1,2,3,4-TCDD dechlorinating activity was shown in all soils and sediments, with the exception of a sample collected from peatland at Camau, a supposedly non-polluted site. 2,3-DCDD dechlorinating activity occurred in 1 of 4 tested soils/sediments. High dechlorinating activity was shown at 4 sites, with almost all spiked 1,2,3,4-TCDD and 2,3-DCDD dechlorinated after four or six months of incubation at 27°C and with an accumulation of triCDD, diCDD, monoCDD and non-chlorinated dibenzo-p-dioxin daughter products. Two main dechlorination pathways in the different soil/sediments were observed, with initial peri or lateral dechlorination. A diverse Chloroflexi community was observed in the soil/sediment microcosms using Chloroflexi-specific 16S rRNA gene primers and DGGE analysis bacteria. The abundance of the Chloroflexi community increased after several months of incubation. The findings of this study indicate that PCDD dechlorinating bacterial communities may be ubiquitous in areas sprayed with Agent Orange over 40 years ago. The 1,2,3,4-TCDD or 2,3-DCDD dechlorinating activity is an important first step for further study on dechlorination of most toxic 2,3,7,8-TCDD and other PCDDs in polluted soils/sediments.

This work is funded under SERDP Project ER-1492.
SHALLOW APPLICATION OF ISCO USING ALKALINE-ACTIVATED PERSULFATE FOR TREATING PETROLEUM LNAPL IN HETEROGENEOUS FILL AQUIFER

MR. J. DAVID GROSE
CH2M Hill
15010 Conference Center Drive, Suite 200
Chantilly, VA 20151
(703) 376-5128
David.Grose@CH2M.com

CO-PERFORMERS: Brian E. Wallace (NAVFAC Washington); Ben Lebron, Gunarti Coghlan, and Steve Glennie (CH2M Hill); Jason Chebetar and Brett Caron (AGVIQ, LLC)

Petroleum compounds have been detected in groundwater at concentrations indicative of light non-aqueous phase liquid (LNAPL) in the surficial aquifer at the Underground Storage Tank (UST) Building 71 Case Study, at the Washington Navy Yard in Washington, D.C. Based on the monthly and quarterly sampling events since 2000, two LNAPL plumes have been persistently present with an average free-product thickness of 0.01 foot (North Plume) and of 0.1 foot (South Plume) in the shallow water bearing unit. This unit consists of heterogeneous fill with the average water table levels between 3 and 4 feet below ground surface (bgs).

The site provides parking for the Navy Museum and Building 71 is currently used as the main public restroom serving the museum visitors. Due to its location, the site is very active with many public visitors, making implementation of remediation activities challenging. In 2004, the Navy constructed an extensive decorative brick pavement around the Building, including areas impacted by LNAPL. Since 2000, the primary corrective action implemented includes periodic events of aggressive fluid/vapor recovery. Excavating the LNAPL-impacted area and implementing soil vapor extraction/air sparging were recommended in 2004 and 2005, respectively, but were not preferred alternatives because of the presence of the brick pavement and extensive underground utility network in the area.

In situ chemical oxidation (ISCO) using alkaline-activated sodium persulfate as an oxidant, was selected as the most appropriate treatment approach to accommodate the site restrictions and address the LNAPL and dissolved hydrocarbons. In June 2009, a total of 2,376 gallons of sodium persulfate solution activated with sodium hydroxide was delivered into the accessible area within the LNAPL plumes, using direct push technology (DPT) injection method. Persulfate was delivered into the target treatment interval between 3 and 7 feet bgs at 47 injection locations. A predicted radius of influence of 5 feet or larger was achieved.

This paper will present the implementation of the ISCO activities, as well as the effectiveness of ISCO in treating the petroleum contamination. The effectiveness will be evaluated based on the quarterly monitoring events conducted between July 2009 and May 2010. This paper will also discuss the challenges associated with ISCO injection in a shallow aquifer over a small interval with heterogeneous soil located in an active public area.
MODELLING AND SPME MEASUREMENT OF PORE WATER PAH TRANSPORT IN AMENDED SEDIMENT CAPS

MR. PHILIP GIDLEY
University of Maryland Baltimore County
5200 Westland Blvd.
Baltimore, MD 21227
(443) 717-4322
pg6@umbc.edu

CO-PERFORMERS: Neil Agarwal, Seokjoon Kwon, and Upal Ghosh
(University of Maryland Baltimore County)

Capping is a common remediation strategy for contaminated sediments that creates a physical barrier between contaminated sediments and the water column. Diffusive flux of contaminants through a sediment cap is small. However, under certain hydrodynamic conditions such as groundwater discharge and tidal pumping, groundwater advection can accelerate contaminant transport. Hydrophobic organic contaminants such as polycyclic aromatic hydrocarbons (PAH) could be transported through the cap under advective conditions. To better understand PAH migration under advective conditions, physical models of sediment caps were evaluated in the laboratory through direct measurement of pore water using solid phase micro-extraction with gas chromatography and mass spectrometry. Contaminated sediment and capping material was obtained from an existing Superfund site that was capped at Eagle Harbor, Washington. The majority of the PAH demonstrated breakthrough of the capping material after 8 bed volumes of flow. Organic carbon amendment in the form of peat moss (0.2% dry wt.) extended the breakthrough time to at least 72 bed volumes for the majority of the PAH measured. With 0.2% activated carbon amendment, breakthrough of PAH was not observed even after 167 bed volumes. A PAH dissolution model and an advection-dispersion model with retardation using published and measured organic carbon-water partitioning coefficients (Koc) was used to compare to measured PAH in the sediment and cap pore water of the physical model.

This work is funded under SERDP Project ER-1491.
IN SITU BASED MONITORING APPROACHES FOR IMPROVED RISK ASSESSMENT OF CONTAMINATED SEDIMENTS

G. ALLEN BURTON
University of Michigan
Cooperative Institute for Limnology and Ecosystem Research
440 Church Street
Ann Arbor, MI 48109-1041
(734) 763-3601
burtonal@umich.edu

CO-PERFORMERS: Gunther Rosen and Dr. D. Bart Chadwick (SPAWAR Systems Center Pacific); Dr. Marc Greenberg (EPA Environmental Response Team)

Laboratory-based toxicity and bioaccumulation assays have been extensively evaluated and are useful. However, concern remains with respect to their accuracy in measuring risk due to uncertainties associated with linking in situ exposures to effects. Among the inherent limitations of laboratory-based tools is the possibility of altered exposure in the lab via sample manipulation and loss of exposure sources (e.g., upwelling contaminated groundwater or episodic exposure associated with storm events). Two novel in situ-based monitoring tools are described for potentially improving the assessment of ecological risk and recovery at contaminated, or previously contaminated, sediment sites: (1) toxicity screening on in situ collected interstitial water samples for rapid mapping of “hot spots”; and, (2) deployment of multi-parameter in situ platforms. The Trident probe is a multi-sensor sediment probe device that samples pore water and has been field tested at multiple Superfund sites. Its use has been modified to provide samples for chemical and toxicological analyses; thereby reducing artifacts associated with collection of interstitial water using ex-situ processes. Short-term, small volume, bioassays were compared for use as cost-effective, rapid mapping tools. For in situ toxicity and bioaccumulation testing, a platform (Sediment Ecotoxicity Assessment Ring - SEA Ring) was developed that houses various exposure chamber designs, allowing for simple deployment. Compartments of exposure (i.e., water column, sediment-water interface, surficial sediment) were assessed (short-to long-term) using multi-parameter sensors and a variety of estuarine/marine amphipods, polychaetes, mussels, and mysid shrimp. The platform also included biomimetics (e.g., solid phase microextraction [SPME] fibers and diffusion gradient in thin-films [DGT]) for potentially simpler assessments of exposure. Deployments in San Diego Bay, CA and Naval Air Station Pensacola were successful, with exposures of all assays and supplemental comparisons to SPME, bivalve and polychaete uptake from 2 to 21 days. Toxicity responses varied between species (42 to 100% survival) and stations. Amphipods and polychaete endpoints consistently yielded good results, while some assays were either not practical for routine use or require further refinement. Since chemical exposure and biological effects are assessed together in situ, potentially more accurate, multiple line-of-evidence-based risk assessments are possible, allowing for more effective decisions on site ranking, second tiered testing needs, or remediation effectiveness.

This research is funded under ESTCP Project ER-1550.
FIELD DEPLOYMENT OF ACTIVE CAPS – ASSESSMENT OF METAL BIOAVAILABILITY, EROSION, AND TOXICITY

DR. ANNA KNOX
Savannah River National Laboratory
Savannah River Site, Building 773-42A
Aiken, SC  29808
(803) 725-7021
anna.knox@srnl.doe.gov

CO-PERFORMERS: Danny Reible (University of Texas); M. Paller and K. Dixon (Savannah River National Laboratory); J. Roberts (Sandia National Laboratories); I. Petrisor (Haley & Aldrich)

In this study, the effect of active caps on metal bioavailability, erosion resistance, and toxicity was evaluated in a pilot-scale experimental active caps in Steel Creek, at the Savannah River Site near Aiken, South Carolina. There are eight plots with four treatments: two controls consisting of uncapped sediments; two caps composed of apatite and sand; two caps composed of a layer of biopolymer/sand slurry over a layer of apatite and sand; and two caps composed of a top layer of biopolymer/sand slurry, a middle layer of apatite and sand, and a bottom layer of organoclay and sand.

Metal concentrations in pore water collected within and beneath each cap more than six months after cap placement were lower than metal concentrations in pore water collected before cap placement or outside the caps. The clearest reduction was observed for As, Cd, Co, Cu, Pb, and Zn in all tested caps. These data show that downward migration of the amendments used in active caps can neutralize contaminants located deeper in the sediment profile (i.e., in the zone of influence [ZOI]).

Seven months after cap deployment, sediment cores were collected and analyzed by the Adjustable Shear Stress Erosion Transport (ASSET) Flume. The results from the field-collected cores are consistent with the laboratory evaluation of biopolymers. In the laboratory and field, long-term tests of the biopolymers showed that guar gum cross-linked with xanthan (Kelzan) became less erosion resistant after two months. The application of biopolymers in the field as the top layer of active caps is beneficial for a short time for erosion resistance. Another benefit of biopolymer is that the addition of biopolymers reduced sediment suspension during cap construction and caused the rapid settling of other amendments that were placed below the biopolymer layer. A third benefit of biopolymer addition in this study was an increased pool of carbon in the sediment beneath the cap and lower released of metals and other element, especially phosphorus, in comparison with apatite only.

Active biomonitoring was conducted in the experimental plots using California blackworms, freshwater clams, and Hyalella azteca. The tested organisms were placed in small screened cages that contained cap materials and returned to the caps. The cages were retrieved after four weeks or 10 days (Hyalella azteca), and the organisms were removed from the sediment to assess their survival. Survival of all tested organisms was good in all of the experimental caps except those containing biopolymers.
BACTERIA, POLYCHAETE, & GEOCHEMICAL RESPONSE TO Apatite AND CHITIN IN METALS CONTAMINATED SEDIMENTS

DR. Y. MERIAH ARIAS-THODE
SPAWAR Systems Center Pacific
53560 Hull Street
CODE 7175, BS, 111
San Diego, CA 92152
(619) 553-2671
yolandam@spawar.navy.mil

CO-PERFORMERS: Gunther Rosen and Jim Leather (SPAWAR System Center Pacific); Kirk Scheckel (U.S. Environmental Protection Agency, Ohio); Yanbing Wang, Anna Obraztsova, Jinjun Kan, and Kenneth Nealson (University of Southern California)

The amendments apatite (5% weight for weight [w/w]), chitin (2.5% w/w), and mixtures of apatite and chitin are currently under examination for remediation of contaminated sediments. The objective of this research is to evaluate toxicity to polychaetes (Neanthes arenaceodentata) that serve as a marine benthic community surrogate. N. arenaceodentata was exposed to the amendments in contaminated sediments from Mare Island Naval Shipyard for 28 days in the laboratory. Polychaete mortality was not observed. Enhanced growth of N. arenaceodenatata relative to controls, however, it was observed in the chitin treatments. Chitin treatments also resulted in overlying and pore water ammonia concentrations substantially higher than other treatments. Microbial activities play critical roles in remediation in natural environments, and increased growth could result in increased activities. Results indicate that bacterial cell counts (~2 x 10^5 cell mL^-1) in the overlying water did not change over time, except those containing chitin, and apatite/chitin mixtures. By day 28, cell counts in the chitin treatments increased two-fold.

Geochemical analysis was performed to aid in identification of the metal speciation and mobility. The technique X-ray absorption spectroscopy was used to analyze zinc (Zn) speciation in the solid phase. Linear combination fitting (LCF) was used to quantify the different Zn species present in each sample. The LCF results indicate that hydroxide-like Zn (70%) and sorbed Zn (30%) species are present in the sample. Hydroxide-like Zn species are considered bioavailable. After amendment with the apatite and chitin mixtures, approximately half of the hydroxide-like Zn species in the treated sample transitioned to hopeite, a Zn phosphate mineral (34%), with the remainder Zn in a hydroxide-like Zn phase (36%) and sorbed Zn phase (30%). Pore water and tissue concentrations of copper (Cu), zinc (Zn), and arsenic (As) were also evaluated. In the presence of amendments, Cu and Zn concentrations were generally decreased in the pore water and in the polychaete tissue. Arsenic pore water levels and polychaete tissue levels were also decreased, but only under apatite conditions. Interestingly, arsenic levels were significantly increased in the polychaete tissue concentration under chitin conditions. It was concluded that this increase in As in the N. arenaceodenatata tissue was due to a preferential feeding of bacteria or chitin material that likely absorbed the As, since As is known to bind organic acids. Therefore, regulators need to be aware of potential contaminant interactions when applying amendments for sediment remediation. This work is funded under SERDP Project ER-1551.