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Adherence of Chemical, Biological, and Radiological Contaminants to Drinking Water Storage Tank Sediment

Office of Research and Development
National Homeland Security Research Center

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Adherence of Chemical, Biological, and Radiological Contaminants to Drinking Water Storage Tank Sediment

U.S. Environmental Protection Agency
Cincinnati, OH 45268

DISCLAIMER

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Questions concerning this document or its application should be addressed to:

Jeff Szabo, Ph.D., P.E.
National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, OH 45268
szabo.jeff@epa.gov

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ABBREVIATIONS/ACRONYMS

ASTM	ASTM International
BaS	*Bacillus anthracis* Sterne (spores)
CBR	chemical, biological, or radiological
CDW	contaminant drinking water
CFU	colony forming units
COC	chain of custody
COR	Contracting Officer's Representative
°C	degrees Celsius
DI	deionized
DW	drinking water
E. coli	*Escherichia coli*
ECD	electron capture detector
EPA U.S.	Environmental Protection Agency
GC	gas chromatography
ICP-MS	inductively-coupled plasma mass spectrometer
LRB	laboratory record book
L	liter
µL	microliter
mg	milligram
mL	milliliter
mmol	millimole
MS	matrix spike
ND	not detectable
NHSRC	National Homeland Security Research Center
PBST	phosphate buffered saline
pdf	portable document format
PE	performance evaluation
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
QCS	quality control standard
QMP	Quality Management Plan
rcf	relative centrifugal force
RMO	Records Management Office
rpm	revolutions per minute
SOP	standard operating procedure
TEC	total exchange capacity
TOC	total organic carbon
TSA	technical systems audit
TTEP	Technology Testing & Evaluation Program
WA	work assignment
WAL	Work Assignment Leader

EXECUTIVE SUMMARY

This study evaluated the adherence of four target contaminants onto sediments that were collected from drinking water storage tanks located across the United States. The target contaminants for this study were non-radioactive cesium (Cs-133), the insecticide lindane, *Escherichia coli,* and *Bacillus anthracis* Sterne *(BaS),* an avirulent strain.

Experimental Design. Between 2012 and 2014, twenty-five sediment samples were collected from drinking water storage tanks in 12 different states and were named by their state of origin. The eight samples with a sufficient amount of sediment were used for contaminated adherence testing with each of the four contaminants. Background levels of each of the four target contaminants were measured prior to the adherence experiments to establish baseline concentrations before introducing the target contaminant. Before beginning the contaminant adherence experiments, the physical and chemical properties of the sediment samples were determined in order to provide for the possibility of correlating contaminant adherence and sediment characteristics in the future. Sediment characteristics included particle size, pH, total exchange capacity, total organic carbon, and organic matter. Individual solutions of contaminated drinking water of each target contaminant were prepared at pH 7.5 and pH 8.5. Aliquots of the sediment samples were then placed in centrifuge tubes and the contaminated drinking water was added to the tubes. These samples were rotated for 16 hours (cesium and lindane), or 6 hours (*E.coli* and *BaS* spores*)* to enable adherence. Following rotation, the supernatant was analyzed to determine the amount of contaminant partitioning from the solution to the sediment.

Results. Across all the samples collected, cesium sediment adherence percentages ranged from 5% for one Tennessee sample to 88% for the Arkansas sample. Lindane sediment adherence ranged from 7% in the Tennessee sample to 88% in one Ohio sample. More than 50% of the *E.coli* adhered to all of the sediments studied except for two samples. The largest extent of *E.coli* sediment adherence occurred in the Arkansas sample with 99% and 100% adherence at pH 8.5 and 7.5, respectively. In general, the *BaS* adhered more readily to the sediments than the *E.coli*. The adherence percentages for *BaS* ranged from 31% for one North Carolina sediment, to 100% for the Arkansas samples. However, most *BaS* sediment adherences were greater than 90%. The pH differences in the contaminated drinking water did not consistently impact the adherence results.

1.0 Introduction

The U.S. Environmental Protection Agency (EPA) National Homeland Security Research Center (NHSRC) conducts research to protect, detect, respond to, and recover from terrorist attacks on the nation's water and wastewater infrastructure. One concern is the adsorption of chemical, biological, or radiological (CBR) contaminants to sediments in drinking water storage tanks and reservoirs. Sediments can serve as sinks for contaminants. Therefore, adhesion to sediments following the introduction of any intentional contamination must be taken into account when developing treatment and decontamination strategies. The objective of this project was to collect data the adherence of selected contaminants on sediments collected from drinking water storage tanks located across the United States. Sediments were characterized so that correlations between sediment characteristics and contaminant adherence could occur in the future.

2.0 Test Design and Procedures

This study evaluated the adherence of four target contaminants onto sediments that were collected from drinking water storage tanks located across the United States. The target contaminants for this study were non-radioactive cesium (Cs-133), the insecticide lindane, *Escherichia coli,* and spores of *Bacillus anthracis* Sterne *(BaS),* an avirulent strain. Non-radioactive Cs-133 acted as a surrogate for radioactive Cs-137. Lindane is an organic chemical. *E. coli* is a coliform bacteria of interest in the drinking water community. *BaS* spores acted as a surrogate for pathogenic *B. anthracis* spores. This work was performed under the auspices of the Quality Management Plan for the National Homeland Security Research Center, Office of Research and Development, U.S. EPA, August 2009.

2.1 Sediment Sampling

Battelle and EPA identified drinking water utilities that would be willing to provide tank sediment and water samples while draining their tank for cleaning. Some of these utilities were identified through Utility Service Group (Utility Service), a tank cleaning and Maintenance Company that had been contracted to provide tank cleaning/maintenance services. The rest were identified through email communication asking utilities if they were planning to clean their storage tanks and if so, would they be willing to collect samples for this project. Following initial contact with the utilities, Battelle would discuss the project with them. If they agreed to participate, Battelle provided a sampling kit and detailed sampling instructions to either Utility Service (if they were going to perform sampling during tank maintenance) or directly to the utility (if the utility was going to perform the sampling). In either case, Battelle would talk on the phone with the crew that would actually be performing the sampling so the sampling instructions were clear.

The sampling kit included all the necessary supplies for sample collection (e.g., pre-paid shipping cooler packed with pre-cleaned sampling tools, sample containers and labels, and miscellaneous supplies such as sterile gloves, permanent markers, and tape). In most cases the sediment samples were collected from the drinking water storage tanks after the water had been drained in preparation for tank cleaning. The objective of sediment sampling was for the

sampling crew to fill five one-gallon containers with sediment from the tank. In addition, the sampling crew filled four one-liter containers with water from a faucet connected to the tank or a sampling point immediately downstream from the tank. Depending on the moisture content of the sediment, as much as 20 liters (L) of sediment sample was required in order to have enough material to complete the characterization, background, and adherence tests. A summary of the samples received can be seen in Table 2-1.

Table 2-1. Sediment Sample Inventory

Tank Location	Source Water	Tank Details	Sediment Description	Enough Sediment for Adherence Testing
Alabama	surface	5 million gal, ground storage	Five gallons of water/sediment slurry containing ~50% sediment (by volume).	Yes
Arizona	ground	500,000 gal surface	Five gallons of water/sediment slurry, <25% sediment (by volume).	No
Arizona	ND	ND	Muddy clay-like sediment.	Yes
Arkansas	surface	ground storage	Five gallons of water/sediment slurry containing ~50% sediment (by volume).	Yes
California	ND	ND	One container half full of rocky sediment and one container mostly water with a small amount of sand.	No
California 1	ND	ND	Small amount of watery sediment. Sediment was collected with a vacuum.	No
California 2	ND	ND	Not enough sample for adherence testing.	No
California 3	ND	ND	Not enough sample for adherence testing.	No
Florida	ND	ND	Small sample with no water.	No
Georgia	ground	500,000 gal elevated	One gallon of water/sediment slurry containing 25-50% sediment (by volume).	No
Illinois	surface	elevated	4, one-liter bottles collected aseptically containing sandy sediment.	Yes
Maryland	ND	ND	Mostly water.	No
North Carolina	ground	TBD	Five gallons of dark water/sediment slurry containing ~50% sediment (by volume).	Yes
Ohio 1	surface	elevated	Approximately 3 kg of dry sediment.	Yes
Ohio 2	surface	elevated	~300 g moist soil-like sediment.	No
Ohio 2013 A	ND	ND	~1 quart of muddy/rocky sediment.	No
Ohio 2013 B	ND	ND	1 gallon container ~1/3 full of muddy paint chips.	No
Ohio 2013 B	ND	ND	1 gallon container ~1/4 full of watery, muddy paint chips and sediment.	No
Ohio 3	surface	elevated	~ 1800 grams moist soil/sand texture.	Yes
Ohio 4	surface	elevated	~1800 grams moist clay/soil texture.	Yes
Pennsylvania 1	ground	1.1 M gal, standpipe	Five gallons of water/sediment slurry containing <25% sediment (by volume).	No
Pennsylvania 2	ND	ND	3 of the 4 sediment sample containers were open when received.	No
Southern OH 1	ground	150,000 gal elevated	Three gallons of water/sediment slurry containing ~50% sediment (by volume).	No
Southern OH 2	ground	600,000 in-ground	One gallon of water/sediment slurry containing less than <25% sediment (by volume).	No
Tennessee	ground	6 M gal, surface	Two gallon of water/sediment slurry containing 50-75% sediment (by volume).	Yes

ND-not determined
Shading indicates a sample used in adherence experiments.

On a dry basis, 700 grams (g) of sediment was required for the characterization and background tests, and another 80 g for the adherence tests. However, when the crews would sample sediment from the tanks, they often found that there was not an adequate amount of sediment in the tanks to fill all of the sampling containers. Therefore, they collected as much sample as possible. Twenty five drinking water tank sediment and water samples were collected from 2012

through the first half of 2014, but only eight of these samples contained enough sediment to perform sediment adherence experiments.

2.2 Sediment Characterization

Out of the 25 sediment samples collected, 8 samples contained enough sediment to be fully or partially characterized, with enough sediment left over to complete adherence testing. The characterization methods are listed in Table 2-2.

Table 2-2. Sediment Characterization Methods

Test Parameter	Method	Sources
Total Organic Carbon	Automated instrumental analysis of carbon and nitrogen in plant and soil samples (Comparable to EPA Method 9060A)	McGeehan, S.L., and D.V. Naylor. 1988. Automated instrumental analysis of carbon and nitrogen in plant and soil samples. Commun. Soil Sci. Plant Anal. 19:493-505. U.S. EPA, EPA Method 9060A, Total Organic Carbon, Rev. 1, November 2004.
Organic matter	Estimation of soil organic matter by weight, loss on ignition (Comparable to EPA Method 160.4)	Schulte, E.E., and B.G. Hopkins. 1996. Estimation of soil organic matter by weight Loss-On-Ignition. P. 21-32; in: Soil Organic Matter: Analysis and interpretation. (ed.) F.R. Magdoff, M.A. Tabatabai, and E.A. Hanlon, Jr. Special publication No. 46. Soil Sci. Soc. Am. Madison, WI. U.S. EPA, EPA Method 160.4, Volatile Residue, Rev. 1, 1971 in *Methods for Chemical Analysis of Water and Wastes*, EPA/600/4-79/020, March 1983.
Particle Size Analysis (Sand, Silt, and Clay)	ASTM D422 (sieve/hydrometer)	ASTM Standard D422, 1998, "Standard Test Method for Particle-Size Analysis of Soils," ASTM International, West Conshohocken, PA, www.astm.org.
pH	EPA Method 9045C rev 3	U.S. EPA, EPA Method 9045C, Soil and Waste pH, SW-846, Rev. 3, January 1995
Elemental analysis	Aluminum – EPA Method 200.8	U.S. EPA, EPA Method 200.8, Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma - Mass Spectrometry, Revision July 1991 in: *Methods for Chemical Analysis of Water and Wastes.* EPA/600/4-79/020
	Boron – EPA Method 200.8	
	Calcium – EPA Method 200.8	
	Copper – EPA Method 200.8	
	Iron – EPA Method 200.8	
	Magnesium – EPA Method 200.8	
	Manganese – EPA Methods 200.8	
	Phosphorus – EPA Method 200.8	
	Potassium – EPA Method 200.8	
	Silica – EPA Method 200.8	
	Sulfur – EPA Method 200.8	
	Sodium – EPA Method 200.8	
	Zinc – EPA Method 200.8	
Cation Exchange Capacity (CEC)	Soil Sampling and Method of Analysis Canadian Society of Soil Science - Ammonium acetate replacement (Comparable to EPA Method 9080)	Soil Sampling and Methods of Analysis. (ed.) M.R. Carter and E.g. Gregorich, "Ion Exchange and Exchangeable Cations." W.H. Hendershot, H. Lalande, and M. Duquette. Ch. 18 pp. 197-206. Canadian Society of Soil Science: Pinawa, Manitoba. 1993. Method 19.4.2.2. U.S. EPA, EPA Method 9080, Cation Exchange Capacity in Soils. Rev. 0, 1986.

2.3 Measurement Methods

Investigation of the adsorption of Cs-133, lindane, *E.coli*, and *BaS* spores onto the selected sediment samples included the determination of the background concentrations of these target contaminants in the sediments and water samples used for adherence experiments. The background concentration of each contaminant in the sediment and water samples was accounted for in the adherence experiments. These analyses were performed following the methods shown in Table 2-3.

For Cs-133, sediments were acid digested and the digestate analyzed by inductively-coupled plasma mass spectrometry (ICP-MS). The water samples were analyzed directly (no acid digestion) following the same method. Lindane was determined by gas chromatography – electron capture (GC-ECD) detection of the resulting extract obtained during Soxhlet extraction of the sediment and liquid-liquid extraction of the water. The background biological growth from each sediment sample was observed by rinsing of the sediment samples with 0.01% phosphate buffered saline Triton® (Alfa Aesar, Ward Hill, Massachusetts (PBST) solution and plating the supernatant solution on tryptic soy agar plates (tank water samples were plated directly).

Table 2-3. Selected Sediment and Corresponding Water Sample Analyses

Contaminant	Laboratory	Method	Sources
Cesium	Analytical Balance Corporation (Middleboro, MA)	Modification to EPA Method 200.8 - inductively-coupled plasma mass spectrometry (ICP-MS)	U.S. EPA, EPA Method 200.8, Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma - Mass Spectrometry, Revision July 1991 in: *Methods for Chemical Analysis of Water and Wastes.* EPA/600/4-79/020
Lindane	Brookside Laboratories[a] (New Bremen, OH), Alloway[b] (Marion, OH)	EPA Method 8081- gas chromatography with sediment extraction by 3540C. EPA Method 508 with liquid-liquid extraction by 3510C	U.S. EPA, EPA Method 8081B, Organochlorine Pesticides by Gas Chromatography, SW-846, Rev.2, February 2007. U.S. EPA, EPA Method 3540C, Soxhlet Extraction, SW-846, Rev. 3, December 1996. U.S. EPA, EPA Method 508, Determination of Chlorinated Pesticides in Water by Gas Chromatography with an Electron Capture Detector, Revision 3.0, 1989. EPA 600/4-81-053 U.S. EPA, EPA Method 3510C, Separatory Funnel Liquid-Liquid Extraction, SW-846, Rev. 3, December 1996.
E.coli	Battelle (Columbus, OH)	Tryptic soy agar plate enumeration	NA
Bacillus anthracis Sterne	Battelle (Columbus, OH)	Tryptic soy agar plate enumeration	NA

[a] Sediment and water background analyses.
[b] Adherence measurements.

2.4 Contaminant Adherence Experiments

Prior to determining the adherence of a target contaminant, the moisture content of each sediment sample was determined by thoroughly mixing the sediment sample, then weighing approximately 100 g of wet sediment into a pre-weighed glass dish. The sediment was then dried for 24 hours at 100 °C. The dried sediment was allowed to cool completely and was then reweighed. After obtaining the percent moisture, the wet equivalent of 2 g of dry sediment (e.g., 50% moisture content, 4 g wet sediment would be equivalent to 2 g dry sediment) was calculated.

To initiate the contaminant adherence experiments, the wet sediment equivalent of 2 g dry sediment was then transferred into three separate glass centrifuge tubes (50 mL Glass Centrifuge Tubes, #45167-50 Kimble, Vineland, NJ) for lindane and three separate plastic centrifuge tubes each (50 mL Centrifuge Tube, #3252P Stockwell Scientific, Scottsdale, AZ) for Cs-133, *BaS*, and *E.coli*. In each contaminant-specific experiment, a volume of the applicable contaminated drinking water (CDW) was transferred into the centrifuge tubes to completely fill the tube (approximately 55 mL). CDW is a mixture of water from the tank spiked with contaminant. As an experimental control to determine the extent that contaminants adhered to the walls of the centrifuge tubes in the absence of sediment, 55 mL of CDW was added to three additional centrifuge tubes. The CDW pH was measured using a calibrated Thermo Orion meter with an Orion 9157 BNMD triode. If necessary, the pH was then adjusted to 7.5 or 8.5 using 1 N HCl (Fisher SA48-500, Lot 124379 expiration 7/2014) and 1 N NaOH (Fisher SS266-1, Lot 137688 expiration 11/2015).

The sample and control centrifuge tubes were sealed and placed on a sample rotator (Fisher Scientific Tube Rotator 05-450-200 and 05-450-201, Fisher Scientific, Pittsburgh, PA; or equivalent) and vertically rotated for 16 hours at 10 revolutions per minute (rpm) for cesium and lindane at room temperature (22 to 24 °C). This is based on the procedure used in the EPA Office of Solid Waste and Emergency Response *Batch-Type Procedures for Estimating Soil Adsorption of Chemicals* (1). During initial experiments it was discovered that *E.coli* began a significant replication during the 16 hour rotation at room temperature, so *E.coli* and *BaS* were rotated for approximately 6 hours at 2 to 8°C during adhesion experiments, which resulted in no growth of either organism. Following rotation, particles were allowed to settle for 10 minutes. The cesium and lindane samples were then centrifuged (2,500 relative centrifugal force [rcf]), for 10 minutes and the aqueous phase decanted for analysis. For the *E.coli and BaS* samples, 1 mL aliquots of the aqueous portion of the settled sample were removed and enumerated. These samples were not centrifuged, since centrifugation would remove the microorganisms from the supernatant. Each sample was analyzed following the reference methods given in Table 2-3. Table 2-4 details the experimental matrix for the sediment adherence experiments.

Table 2-4. Experimental Matrix for the Contaminant Adherence Study

		Water Matrix	
Contaminant	**Sample**	**Sediment Specific Drinking Water Replicate Samples at pH 7.5**	**Sediment Specific Drinking Water Replicate Samples at pH 8.5**
Cesium	Adherence replicate1	3	3
	Adherence replicate 2	3	3
	Adherence replicate 3	3	3
	Control (CDW only)	3	3
	Total cesium samples	12	12
Lindane	Adherence replicate 1	3	3
	Adherence replicate 2	3	3
	Adherence replicate 3	3	3
	Control (CDW only)	3	3
	Total lindane samples	12	12
E. coli	Adherence replicate 1	3	3
	Adherence replicate 2	3	3
	Adherence replicate 3	3	3
	Control (CDW only)	3	3
	Total *E. coli* samples	12	12
BaS	Adherence replicate 1	3	3
	Adherence replicate 2	3	3
	Adherence replicate 3	3	3
	Control (CDW only)	3	3
	Total *Bacillus anthracis* Sterne samples	12	12
Cesium Lindane *E.coli* *BaS*	Sediment Blank	3	3
	Total sediment blank samples	3	3

CDW-contaminant drinking water

It should be noted that the rotation of sediment and contaminated water was designed to produce good contact between the sediment and contaminant so that adherence could be observed. Should a water tank actually become contaminated, the contact between the sediment and contaminant may not be so vigorous.

The adherence of the four target contaminants were evaluated separately for each sediment sample at two different pH levels. Before each adherence experiment, separate aliquots of the CDW were prepared with each target contaminant as follows:

- Cs-133 - A 1000 mL CDW of Cs-133 with a concentration of 5 mg/L was prepared by diluting 5 mL of a 1,000 mg/L Cs-133 standard (1,000 mg/L Cs-133 standard solution, Catalog # CGCS1-1, Inorganic Ventures, Christiansburg, VA) to 1000 mL using the drinking water from the storage tank from which the sediment had been collected).
- Lindane - A 1000 mL CDW of lindane, also known as gamma-hexachlorocyclohexane, with a concentration of 5 mg/L was prepared by diluting 5 mL of a 1,000 mg/L lindane standard (1,000 mg/L lindane standard in methanol, Catalog # 32226, Restek, State College, PA) to 1000 mL using the drinking water from the storage tank from which the sediment had been collected. The concentration of lindane was verified following EPA Method 508 (see table 2-3 for a full reference).
- For *E.coli*, a lyophilized stock (ATCC 8739, Catalog # 0483E7, Microbiologics, St. Cloud, MN) was rehydrated and streaked onto tryptic soy agar for colony isolation. This

plate was stored at 2-8°C and used as needed for up to one month. Prior to each test, an isolated colony was grown overnight in tryptic soy broth to make a concentrated stock of approximately 1 x 10^9 cfu/ml. The concentration was estimated by measuring the optical density and then calculating the concentration using a predetermined OD_{600} versus cell density value (derived from previous *E. coli* growth curve data). For *BaS* spores (BEI Resources #34F2 (NR-1400), BEI Resources, Manassas, VA), a spore stock was prepared by incubating the purchased *BaS* in generic sporulation broth at 35 °C for 5 days, which yielded a concentration of approximately 1 x 10^9 cfu/ml. Spores, suspended in sterile water, were stored at 2-8°C until ready for use. Suspensions of 100 ml of *E. coli* or *BaS* spores at 1 x 10^6 CFU/mL were prepared by serially diluting the 1x10^9 cfu/mL suspensions in the appropriate test water at pH 7.5 or 8.5. The densities of both the *E.coli* and *BaS* suspensions were confirmed using Standard Method 9222G (2) and the 1 x 10^6 CFU/mL stock solutions were stored at 3°C.

Each of the three sediment adherence samples were analyzed in triplicate. The resulting concentration is that of the contaminant remaining in the aqueous component of the mixture when at equilibrium with the sediment phase (C_{as}) or with the centrifuge tube walls (C_{aw}). These measurements were used to determine the percent adherence (*%A*) of the target contaminant to the sediment in each centrifuge tube as follows:

$$\overline{m_{aw}} = \overline{C_{aw}} \times 50\ mL \quad (1)$$

$$m_{as} = C_{as} \times 50\ mL \quad (2)$$

$$m_s = \overline{m_{aw}} - m_{as} \quad (3)$$

$$\%A = \frac{m_s}{m_{aw}} \times 100 \quad (4)$$

where $\overline{m_{aw}}$ is the average amount of target contaminant in the aqueous phase of the three control replicates when there is no sediment present (equilibrated with the walls of the centrifuge tube only), m_{as} is the amount of target contaminant in the aqueous phase in each of the centrifuge tubes containing sediment, and m_s is the amount of target contaminant adhered to the sediment at equilibrium. Use of $\overline{m_{aw}}$ in Equation 4 provides correction for possible contaminant adherence to the centrifuge tube walls. The *%A* was calculated and reported for each replicate sample. This process was repeated for each water matrix and contaminant combination.

Included in the adherence experiment was a separate blank control sample consisting of uncontaminated sediment specific water and the applicable sediment sample (the sediment blank in Table 2-4). In order to generate this control sample, the wet sediment equivalent of 2 g dry sediment sample was weighed into three separate centrifuge tubes and a volume of sediment specific uncontaminated water was added to each centrifuge tube to completely fill the tube (approximately 55 mL). The sediment blank was subjected to the same experimental protocol as the sediment adherence test samples. The aqueous phase of the blank samples was analyzed for each target contaminant to determine background levels of the target contaminants that partitions from the sediment to the water and any interferences that may have partitioned to the water from the sediment.

The uncertainty of each of the individual measurements required to calculate the %A (i.e., uncertainty in the measurements required to determine the control and experimental results) was used to propagate the uncertainty in the %A calculation. The combined experimental uncertainty

in the %A calculation (Δ%A) was determined using the method of propagation of errors and is defined below:

$$\Delta\%A = \sqrt{\left(\frac{SD_{CS}}{C_{CS}}\right)^2 + \left(\frac{SD_{TS}}{C_{TS}}\right)^2} \times \%A \quad (5)$$

Where SD_{ACS} and SD_{ATS} are the standard deviations of the contaminant concentrations measured in the contaminated control sample and sediment adherence (test) sample, respectively, being compared. Similarly, C_{CS} and C_{TS} are the average contaminant concentrations of the contaminated control sample and the sediment adherence (test) samples, respectively, being compared.

In order to further clarify the data throughout the section, t-tests were performed to determine if the contaminated control and sediment adherence (test) samples were different from one another at the 95% confidence interval. The null hypotheses of the t-tests were that the difference in contaminant concentrations between the contaminated control and the sediment adherence samples was zero. The probabilities (p) generated by the t-test were the probabilities of the null hypothesis being confirmed. Therefore, p-values less than 0.05 indicated a small likelihood the difference between the two data sets was zero, and thus, are considered to be significantly different from one another. These p-value are presented for each experimental replicate in Section 4.

3.0 Quality Assurance/Quality Control

3.1 Quality Control Samples

Table 3-1 summarizes the controls included in this study. The controls are important because the results of the sediment adherence experiments are dependent on the original concentration of each target contaminant in the water matrix.

Table 3-1. Experimental Controls

Component of Sediment Adherence Test	Type of Control	Description
Sediment Background Measurements	Pre-test measurement	Allows determination of background concentration of the target contaminants.
Uncontaminated Sediment Blank	Two blanks (one for each pH level) per target contaminant adherence experiment	A sediment sample that is rotated with uncontaminated sediment-specific water. Uncontaminated sediment blanks are treated identically to the contaminated sediment samples to control for any background contamination that might be present in the sediment samples.
Contaminated Solution Control	Two contaminated control samples (one per pH level) per target contaminant adherence experiment	A volume of contaminated sediment-specific water that contains no sediment. The contaminated control solution is treated identically to the contaminated sediment samples to control for contaminant adherence to the tube walls.

3.2 Measurement Methods

3.2.1 Cesium

The analytical method that was used for cesium was EPA Method 200.8 "Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma – Mass Spectrometry". Calibration standards were prepared in ASTM Type 1 water with external standards and acidified. A six-point calibration curve was generated prior to sample analyses. A calibration blank was also prepared using ASTM Type I water and acidified with the same acid matrix as the calibration standards. The calibration levels bracketed the sample concentration. The limit of quantification for this method was approximately 0.001 mg/L. Two continuing calibration check solutions were analyzed after every 10 samples and at the end of the sequence in order to verify instrument sensitivity and calibration throughout the analysis. The results of these samples were always between 90 -110% of the known concentration. A laboratory reagent blank consisting of ASTM Type I water was analyzed and no contamination was found. A laboratory fortified matrix sample was analyzed with each batch of samples. Recoveries for these samples were always within the acceptable range of 85-115%.

3.2.2 Lindane

The analytical method that was used for lindane was EPA Method 508 "Determination of Chlorinated Pesticides in Water by Gas Chromatography with and Electron Capture Detector".

Calibration standards were prepared in methyl tert-butyl ether (MTBE). A six-point calibration curve was generated prior to sample analyses. A calibration blank was also prepared using the same acid matrix as the calibration standards. The calibration levels bracketed the sample concentration. The practical quantification limit (PQL) for this method was 0.021 mg/L. Two continuing calibration check solutions were analyzed after every 10 samples and at the end of the sequence in order to verify instrument sensitivity and calibration throughout the analysis. The results of these samples were always between 90 -110% of the known concentration. A laboratory fortified blank was analyzed every 20 samples and no background contamination was found. A laboratory fortified matrix sample was analyzed with each batch of samples. Recoveries for these samples were always within the acceptable range of 85-115%.

3.2.3 E.coli and BaS

The concentration of *E.coli* and *BaS* in the samples was measured by tryptic soy agar enumeration. After rotation and settling, an aliquot of the supernatant from the centrifuge tubes was serially diluted using a sterile PBST solution. The resulting solutions were plated in triplicate by dispensing 100 µL onto tryptic soy agar plates (BD, #221283, Becton Dickinson and Company, Franklin Lakes, NJ). Using a spreader, the aliquot was evenly distributed on the plates then incubated for 24-48 hrs at 35-37°C. After incubation, the distinguishable colonies on each plate were counted. In order to be considered a viable plate count, the number of colonies on a given plate was required to be between 30 and 300. If the number of colonies was higher than the most dilute plate, an additional dilution was performed and the extracts re-plated to achieve countable results. If the number of colonies were below this range, either a more concentrated extract was plated, or the result was considered "too few to count". To obtain the number of colonies on the coupon, the average number of colonies was divided by the plated volume and then multiplied by the inverse of the combined dilution factors.

3.3 Audits

3.3.1 Performance Evaluation Audit

Performance evaluation audits were conducted to assess the accuracy of the ICP-MS reference method (EPA Method 200.8) and the GC-ECD method (EPA Method 508). A performance evaluation sample containing 0.250 mg/L cesium, and 0.400 mg/L of lindane were provided for analysis. Accuracy of the measurement was expressed in terms of the percent error (%E), as calculated from the following equation:

$$\%E = \frac{|d - C_R|}{C_R} \times 100$$

where C_R was the standard or reference concentration of the performance evaluation sample and d is the measurement obtained using the reference method. Ideally, if the reference value and the measured value are the same, there would be a percent error of zero percent. The results of the reference methods indicated %E of 2% for cesium, and 20% for lindane which are within the acceptable %E of 20%.

3.3.2 Technical Systems Audit (TSA)

The Battelle QA manager conducted a TSA at the Columbus, OH testing location to ensure that the evaluation was performed in accordance with the QAPP for this study. As part of the audit, the Battelle QA manager reviewed the reference sampling and analysis methods used, compared actual evaluation procedures with those specified in the QAPP, and reviewed data acquisition and handling procedures. No significant adverse findings were noted in this audit. The records concerning the TSA are permanently stored with the Battelle QA manager.

3.4 Deviations from the QAPP

The drinking water used for adherence tests was adjusted to pH levels 7.5 and 8.5 instead of each utility's reported minimum, maximum, and average pH values. In some cases a utility's reported pH range was very small making it unlikely that a difference in adherence would be seen at the various pH values. Upon discussion with EPA, the pH targets were adjusted to 7.5 and 8.5 for consistency.

The sediment specific contaminated water samples for cesium and lindane were prepared at 5 mg/L instead of 1 mg/L. In order to perform replicate measurements during the contaminant adherence experiments, more sample volume was required than what the centrifuge tubes allowed for. Preparing the contaminated water solutions at a higher concentration allowed the samples to be diluted after they were rotated. Diluting the samples created the extra sample volume necessary to perform replicate measurements.

Bacillus atrophaeus subsp. *globigii* was the original *B. anthracis* surrogate planned for this study. *B. anthracis* Sterne was used instead, but the method used to enumerate the spores was the same for both organisms.

3.5 Data Quality Audit

At least 10% of the data acquired during the evaluation were audited. The Battelle QA manager traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

3.6 QA/QC Reporting

Each assessment and audit was documented in accordance with the QAPP. Once an assessment report was prepared by the Battelle QA manager, it was routed to the work assignment manager and Battelle Testing and Evaluation contract program manager for review and approval. The Battelle QA manager then distributed the final assessment report to the EPA Contracting Officer's Representative, QA manager, and Battelle staff.

4.0 Results

The adherence of several target contaminants to eight sediment samples from separate drinking water storage tanks was determined. Drinking water storage tank sediment and the corresponding tank water were collected from eight storage tanks located across the United States. Each sample was characterized prior to beginning adherence testing to provide information about the chemical/physical interaction between the target contaminants and the sediment.

4.1 Background and Sediment Characterization Results

Lindane and viable *E. coli* and *BaS* were not detected in any of the sediment background samples. The chemical (non-radioactive) form of cesium was detected in Alabama, Arkansas, Ohio 4 and Arizona samples at levels ranging from 0.3 to 0.4 µg/kg. Any measurable cesium leaching from the sediments to the test water was at least 50 times less than the concentration of the contaminated water, thus too small to interfere with the adherence experiments. Given the non-specific culture media, several of the sediment samples produced a background flora when the non-diluted rinse was plated. However, none of the colony morphologies were consistent with that of *E. coli* or *BaS*. Also, with each adherence experiment, a sediment sample was rotated with uncontaminated tank water and the resulting solution plated at a tenfold dilution. No growth of *E. coli*, *BaS*, or any other background microorganism was ever observed at those dilution levels. Also, *E. coli* and *BaS* were contaminated at a relatively high density of approximately 10^6 cfu/ml in the adherence experiment solutions.

The results from the sediment characterization are presented in Table 4-1. The total exchange capacity varied greatly across samples with the lowest being the Tennessee sample at 3 (mmol/L)/100 g, and the highest being the Arizona sample at 154.14 (mmol/L)/100 g. However, the sediment pH ranged from 6.6 to 8.2. There was also a wide range in the percentage of total organic carbon (TOC) and organic matter. The highest TOC was found in the Arizona sample, and the highest percentage of organic matter was found in the Illinois sample. While most of the particle size distributions were predominately greater than 75% sand, the Illinois and Arizona samples provided two samples of smaller particle distributions.

Table 4-1. Sediment Characterization Results

Tank Location	Particle Size			pH	Total Exchange Capacity ((mmol/L)/100g)	Total Organic Carbon (%TOC)	Organic Matter (%)
	% Clay (<0.005 mm)	% Silt (0.005-0.74 mm)	% Sand (0.075-2 mm)				
Tennessee	0.4	1.06	98.54	8.2	3	0.42	0.43
North Carolina	7.63	23.39	68.98	7.6	110.8	3.11	5.45
Ohio 1	1.36	6.7	91.94	7.1	26.7	0.25	0.89
Alabama	2.73	2.33	94.94	7.8	12.2	0.42	0.88
Arkansas	3.91	14.44	81.65	6.7	12.17	2.78	11.45
Ohio 4	1.68	21.67	76.65	6.6	57.34	2.09	5.9
Arizona	7.35	34.34	58.31	6.7	154.14	9.42	4.08
Illinois	41.68	21.39	36.93	7.6	9.66	1.69	16.52

4.2 Contaminant Adherence Results

Tables 4-2 through 4-33 provide the results from all the sediment adherence experiments. Each table includes the residual concentrations (with standard deviations) of contaminants in the aqueous component of the adherence experiment as well as the control experiments. It also includes the p-value of the comparison between the adherence experiment and the control, as well as the %A for each replicate along with the propagated uncertainty. Because three reference measurements were collected for each cesium and lindane experiments, an average and standard deviation of the individual %A was determined. This was not determined for *BaS* and *E.coli* because only one reference samples (based on three enumerations) was measured.

The results from the cesium and lindane adherence tests conducted on the Tennessee sediment sample are presented in Table 4-2 and Table 4-3, respectively. The Tennessee sample was over 98% sand, and had the lowest total exchange capacity (TEC), total organic carbon (TOC), and organic matter compared to the other sediment samples that were characterized. Less than 10% of the cesium and lindane adhered. The *E.coli* and *BaS* adherence results for the Tennessee sample can be found in Table 4-4 and Table 4-5. *E.coli* had an average adherence of 54%, while *BaS* had an average adherence of 82-86%. No significant difference was seen between the two pH levels.

Table 4-2. Tennessee Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	398	74	4.8E-01	-1	-0.1	5	5
	Adherence Rep 2	372	5	2.8E-02	6	0.2		
	Adherence Rep 3	360	8	1.0E-02	9	0.4		
	Control - contaminated water, no sediment	395	14					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	356	8	4.1E-03	11	0.4	9	1
	Adherence Rep 2	364	3	5.0E-03	9	0.3		
	Adherence Rep 3	365	11	1.4E-02	8	0.4		
	Control - contaminated water, no sediment	398	13					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-3. Tennessee Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A	%SD
					Sediment	Δ%A		
7.5	Adherence Rep 1	423	6	1.2E-03	8	0.2	7	1
	Adherence Rep 2	423	4	6.7E-04	8	0.1		
	Adherence Rep 3	429	7	3.4E-03	7	0.1		
	Control - contaminated water, no sediment	459	6					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	432	4	5.9E-04	8	0.2	7	2
	Adherence Rep 2	450	12	2.6E-02	5	0.1		
	Adherence Rep 3	440	8	3.7E-03	7	0.2		
	Control - contaminated water, no sediment	472	6					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-4. Tennessee *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	7.8E+05	7.7E+05	6.0E+04	7.1E-04	53	54	6
	Adherence Rep 2	7.1E+05				57		
	Adherence Rep 3	8.3E+05				50		
	Contaminated Control Rep 1	1.8E+06	1.7E+06	1.5E+05				
	Contaminated Control Rep 2	1.7E+06						
	Contaminated Control Rep 3	1.5E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	7.5E+05	7.4E+05	5.8E+03	1.2E-05	54	54	2
	Adherence Rep 2	7.4E+05				55		
	Adherence Rep 3	7.4E+05				55		
	Contaminated Control Rep 1	1.7E+06	1.6E+06	5.8E+04				
	Contaminated Control Rep 2	1.6E+06						
	Contaminated Control Rep 3	1.6E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-5. Tennessee *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	2.2E+04	2.2E+04	8.1E+02	3.1E-04	87	86	11
	Adherence Rep 2	2.2E+04				86		
	Adherence Rep 3	2.3E+04				86		
	Contaminated Control Rep 1	1.7E+05	1.6E+05	2.1E+04				
	Contaminated Control Rep 2	1.4E+05						
	Contaminated Control Rep 3	1.8E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	2.5E+04	3.3E+04	7.1E+03	3.5E-04	86	82	20
	Adherence Rep 2	3.8E+04				79		
	Adherence Rep 3	3.5E+04				80		
	Contaminated Control Rep 1	1.6E+05	1.8E+05	2.1E+04				
	Contaminated Control Rep 2	1.8E+05						
	Contaminated Control Rep 3	2.0E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Results from the North Carolina cesium and lindane adherence tests can be seen in Table 4-6 and Table 4-7. The North Carolina sediment sample had a TEC of 110.8 (mmol/L)/100g. This sample also had one of the highest percentages of silt of those studied with 23% (7.6% clay, and 69% sand). Cesium adhered more readily to the North Carolina sample than for the Tennessee sample with approximately 20% of the cesium adhering to the sediment. Lindane also adhered more readily to the North Carolina sediment with average %A of 40% and 27% for the two pHs. The *E.coli* and *BaS* adherence results for the North Carolina sediment sample are presented in Table 4-8 and Table 4-9. *E.coli* generated higher average adherences (66% and 78%) than *BaS* (31% and 49%), but the *E.coli* results had rather large uncertainties making differences unlikely.

Table 4-6. North Carolina Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	295	3	3.5E-05	21	0.5	20	1
	Adherence Rep 2	303	7	1.3E-04	19	0.6		
	Adherence Rep 3	301	1	3.9E-05	19	0.4		
	Control - contaminated water, no sediment	373	8					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	299	12	8.7E-04	22	1	21	2
	Adherence Rep 2	298	10	6.5E-04	22	1		
	Adherence Rep 3	311	16	2.5E-03	19	1		
	Control - contaminated water, no sediment	383	16					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-7. North Carolina Lindane Adherence Data

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	107	13	9.8E-03	48	12	40	7
	Adherence Rep 2	133	12	2.4E-02	36	8		
	Adherence Rep 3	131	39	7.2E-02	37	13		
	Control - contaminated water, no sediment	207	44					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	122	10	1.8E-01	18	5	27	12
	Adherence Rep 2	116	17	1.5E-01	22	7		
	Adherence Rep 3	87	6	3.6E-02	41	12		
	Control - contaminated water, no sediment	149	43					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-8. North Carolina *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	2.0E+05	6.3E+05	3.7E+05	5.1E-03	89	66	39
	Adherence Rep 2	8.8E+05				52		
	Adherence Rep 3	8.1E+05				56		
	Contaminated Control Rep 1	1.8E+06	1.8E+06	5.2E+04				
	Contaminated Control Rep 2	1.9E+06						
	Contaminated Control Rep 3	1.8E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	4.8E+05	4.0E+05	1.0E+05	1.6E-04	74	78	21
	Adherence Rep 2	4.3E+05				76		
	Adherence Rep 3	2.8E+05				85		
	Contaminated Control Rep 1	2.0E+06	1.8E+06	1.5E+05				
	Contaminated Control Rep 2	1.8E+06						
	Contaminated Control Rep 3	1.7E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-9. North Carolina *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.8E+04	1.8E+04	1.5E+03	2.7E-02	30	31	5
	Adherence Rep 2	1.6E+04				38		
	Adherence Rep 3	1.9E+04				26		
	Contaminated Control Rep 1	2.4E+04	2.6E+04	3.8E+03				
	Contaminated Control Rep 2	2.3E+04						
	Contaminated Control Rep 3	3.0E+04						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	2.2E+04	2.2E+04	4.0E+03	1.4E-03	49	49	9
	Adherence Rep 2	1.8E+04				58		
	Adherence Rep 3	2.6E+04				40		
	Contaminated Control Rep 1	4.3E+04	4.3E+04	2.5E+03				
	Contaminated Control Rep 2	4.1E+04						
	Contaminated Control Rep 3	4.6E+04						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Four sediment samples were collected from Ohio locations (because of the availability of several tanks being cleaned), however only two locations were used for adherence testing. Those locations are referred to as "Ohio 1" and "Ohio 4". The cesium and lindane adherence results for the Ohio 1 sample can be seen in Table 4-10 and Table 4-11. The Ohio 1 sample had TOC and organic matter values of 0.25% and 0.89%, respectively. In addition, it was 92% sand. The cesium adhered to similar extent in both the pH 7.5 and the pH 8.5 solutions, with approximately 67% and 60%, for pH 7.5 and pH 8.5, respectively. Almost 90% of the lindane in both the pH 7.5 and pH 8.5 solutions adhered to the Ohio 1 sample. The adherence results for *E.coli* and *BaS* on the Ohio 1 sample can be seen in Table 4-12 and Table 4-13. For *E.coli*, the results indicated that pH may be a factor in the adherence with 72% adhering in the pH 7.5 solution, but only 27% adhering in the pH 8.5 solution. However, the uncertainty was rather large making differences unlikely. For *BaS*, pH did not make a significant difference as 93% and 99% of the *BaS* adhered to the Ohio 1 sediment.

Table 4-10. Ohio 1 Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	104	2	7.6E-09	69	1	67	5
	Adherence Rep 2	95	5	8.4E-08	71	4		
	Adherence Rep 3	128	2	1.2E-08	61	1		
	Control - contaminated water, no sediment	329	2					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	128	26	5.2E-04	52	11	60	8
	Adherence Rep 2	104	2	6.5E-06	61	3		
	Adherence Rep 3	84	1	3.9E-06	68	3		
	Control - contaminated water, no sediment	265	11					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-11. Ohio 1 Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	48	3	6.2E-08	87	6	87	0
	Adherence Rep 2	46	2	4.5E-08	88	4		
	Adherence Rep 3	46	3	6.0E-08	88	6		
	Control - contaminated water, no sediment	367	6					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	45	1	5.4E-06	88	5	88	0
	Adherence Rep 2	45	2	5.4E-06	88	6		
	Adherence Rep 3	45	2	5.5E-06	88	6		
	Control - contaminated water, no sediment	373	21					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-12. Ohio 1 *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	3.5E+05	5.0E+05	2.5E+05	1.2E-03	80	72	36
	Adherence Rep 2	3.5E+05				80		
	Adherence Rep 3	7.8E+05				56		
	Contaminated Control Rep 1	1.7E+06	1.8E+06	1.1E+05				
	Contaminated Control Rep 2	1.7E+06						
	Contaminated Control Rep 3	1.9E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	1.0E+06	9.3E+05	9.0E+04	4.0E-03	21	27	3
	Adherence Rep 2	9.7E+05				24		
	Adherence Rep 3	8.3E+05				35		
	Contaminated Control Rep 1	1.3E+06	1.3E+06	3.8E+04				
	Contaminated Control Rep 2	1.2E+06						
	Contaminated Control Rep 3	1.3E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-13. Ohio 1 *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.2E+03	1.4E+03	2.5E+02	1.0E-01	94	93	72
	Adherence Rep 2	1.4E+03				93		
	Adherence Rep 3	1.7E+03				91		
	Contaminated Control Rep 1	3.6E+04	1.9E+04	1.5E+04				
	Contaminated Control Rep 2	1.2E+04						
	Contaminated Control Rep 3	9.8E+03						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	1.3E+03	1.7E+03	4.0E+02	3.3E-04	99	99	28
	Adherence Rep 2	1.6E+03				99		
	Adherence Rep 3	2.1E+03				99		
	Contaminated Control Rep 1	2.3E+05	2.0E+05	3.1E+04				
	Contaminated Control Rep 2	2.1E+05						
	Contaminated Control Rep 3	1.7E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

With the exception of exchange capacity, the Alabama sediment sample had similar characteristics to the Ohio 1 sample. The Alabama sample had a lower TEC at 12.2 (mmol/L)/100g as compared to 26.7 (mmol/L)/100g for the Ohio 1 sample. The cesium and lindane adherence results are shown in Table 4-14 and Table 4-15, respectively. Between 26% and 44% of cesium and lindane adhered to the Alabama sediment while between 52% and 88% adhered to the Ohio 1 sediment. Table 4-16 and Table 4-17 show the results for *E.coli* and *BaS* in the Alabama sediment sample. High percentages of both biological contaminants adhered to the Alabama sample: 72 to 76% of the *E.coli*, and 91 to 92% of the *BaS*.

Table 4-14. Alabama Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	233	7	8.2E-06	34	1	38	5
	Adherence Rep 2	197	2	6.9E-07	44	1		
	Adherence Rep 3	226	7	8.1E-06	36	1		
	Control - contaminated water, no sediment	353	6					
	Blank - sediment and uncontaminated water	2	NA					
8.5	Adherence Rep 1	240	4	3.9E-06	33	1	32	6
	Adherence Rep 2	265	13	1.9E-04	26	1		
	Adherence Rep 3	225	5	2.6E-06	38	1		
	Control - contaminated water, no sediment	360	6					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-15. Alabama Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	240	10	7.7E-05	38	2	37	1
	Adherence Rep 2	243	6	5.5E-05	37	2		
	Adherence Rep 3	247	6	6.0E-05	36	2		
	Control - contaminated water, no sediment	387	15					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	270	0	1.9E-04	29	1	31	6
	Adherence Rep 2	283	12	6.5E-04	25	2		
	Adherence Rep 3	237	15	2.1E-04	38	3		
	Control - contaminated water, no sediment	380	17					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-16. Alabama *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	5.6E+05	5.7E+05	1.0E+04	1.8E-05	77	76	4
	Adherence Rep 2	5.8E+05				76		
	Adherence Rep 3	5.7E+05				76		
	Contaminated Control Rep 1	2.4E+06	2.4E+06	1.3E+05				
	Contaminated Control Rep 2	2.3E+06						
	Contaminated Control Rep 3	2.5E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	5.3E+05	6.7E+05	2.5E+05	5.1E-04	78	72	27
	Adherence Rep 2	9.6E+05				61		
	Adherence Rep 3	5.3E+05				78		
	Contaminated Control Rep 1	2.6E+06	2.4E+06	1.7E+05				
	Contaminated Control Rep 2	2.3E+06						
	Contaminated Control Rep 3	2.4E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-17. Alabama *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.7E+04	1.5E+04	2.8E+03	5.5E-03	90	91	32
	Adherence Rep 2	1.2E+04				93		
	Adherence Rep 3	1.6E+04				90		
	Contaminated Control Rep 1	1.1E+05	1.7E+05	4.9E+04				
	Contaminated Control Rep 2	2.0E+05						
	Contaminated Control Rep 3	2.0E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	1.3E+04	1.4E+04	1.2E+03	1.2E-04	93	92	13
	Adherence Rep 2	1.3E+04				92		
	Adherence Rep 3	1.5E+04				92		
	Contaminated Control Rep 1	2.0E+05	1.8E+05	1.9E+04				
	Contaminated Control Rep 2	1.7E+05						
	Contaminated Control Rep 3	1.7E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

The Arkansas sediment had a similar TEC to the Alabama sample, but it contained more organic matter, with 11.5% compared to 0.9%, respectively. The results for the Arkansas sediment's cesium and lindane adherence tests are presented in Table 4-18 and Table 4-19. An average of

88% of the cesium in the pH 7.5 solution, and an average of 82% of the cesium in the pH 8.5 solution adhered to the Arkansas sediment. Lindane adherence was 41% and 43% at pH 7.5 and 8.5, respectively. The adherence results for *E.coli* and *BaS* on the Arkansas sample can be seen in Table 4-20 and Table 4-21. Almost all of both biological contaminants adhered to the Arkansas sample. The *E.coli* pH 8.5 sample exhibited a large uncertainty (121%) around the percent adherence result relative to other adherence testing results. The large uncertainty is driven by adherence replicate number three that had a higher post-adherence microbial density that the other two replicates. If that replicate were removed, the uncertainty would drop to 34%.

Table 4-18. Arkansas Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	47	0	3.5E-08	88	1	88	3
	Adherence Rep 2	57	2	4.5E-08	85	3		
	Adherence Rep 3	37	1	3.2E-08	90	2		
	Control - contaminated water, no sediment	387	6					
	Blank - sediment and uncontaminated water	6	NA					
8.5	Adherence Rep 1	52	1	1.4E-10	83	1	82	2
	Adherence Rep 2	54	0	8.0E-11	82	0		
	Adherence Rep 3	63	1	3.7E-10	80	1		
	Control - contaminated water, no sediment	308	1					
	Blank - sediment and uncontaminated water	6	NA					

Table 4-19. Arkansas Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	103	6	1.7E-05	41	2	41	2
	Adherence Rep 2	99	1	1.1E-09	43	0		
	Adherence Rep 3	107	6	1.7E-05	39	2		
	Control - contaminated water, no sediment	175	0					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	140	0	2.3E-04	31	2	43	10
	Adherence Rep 2	110	0	5.0E-05	46	2		
	Adherence Rep 3	100	0	3.4E-05	51	3		
	Control - contaminated water, no sediment	203	10					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-20. Arkansas *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.1E+04	1.1E+04	1.8E+03	1.4E-04	100	100	20
	Adherence Rep 2	9.5E+03				100		
	Adherence Rep 3	1.3E+04				100		
	Contaminated Control Rep 1	2.9E+06	2.7E+06	3.2E+05				
	Contaminated Control Rep 2	2.3E+06						
	Contaminated Control Rep 3	2.8E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	9.6E+03	4.2E+04	5.1E+04	2.5E-04	100	99	121
	Adherence Rep 2	1.5E+04				99		
	Adherence Rep 3	1.0E+05				97		
	Contaminated Control Rep 1	2.5E+06	2.9E+06	4.0E+05				
	Contaminated Control Rep 2	3.3E+06						
	Contaminated Control Rep 3	2.9E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-21. Arkansas *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	5.7E+03	5.4E+03	4.6E+02	3.6E-04	100	100	18
	Adherence Rep 2	4.9E+03				100		
	Adherence Rep 3	5.7E+03				100		
	Contaminated Control Rep 1	1.9E+06	1.6E+06	2.5E+05				
	Contaminated Control Rep 2	1.4E+06						
	Contaminated Control Rep 3	1.6E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	4.0E+03	4.8E+03	7.2E+02	3.8E-04	100	100	22
	Adherence Rep 2	5.4E+03				100		
	Adherence Rep 3	5.0E+03				100		
	Contaminated Control Rep 1	1.4E+06	1.3E+06	2.1E+05				
	Contaminated Control Rep 2	1.1E+06						
	Contaminated Control Rep 3	1.5E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

The cesium and lindane adherence results for the Ohio 4 sample can be seen in Table 4-22 and Table 4-23. Only 28% and 11% of the cesium in the pH 7.5 and pH 8.5 solutions adhered to the Ohio 4 sample, which is relatively low compared to the other sediments. Average lindane %A was 39% and 44% at pH 7.5 and 8.5, respectively. The adherence results for *E.coli* and *BaS* on the Ohio 4 sample can be seen in Table 4-24 and Table 4-25. Most of both biological contaminants adhered to the Ohio 4 sample.

Table 4-22. Ohio 4 Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	262	12	1.1E-04	26	1	28	6
	Adherence Rep 2	231	9	1.1E-05	35	1		
	Adherence Rep 3	269	15	3.1E-04	24	1		
	Control - contaminated water, no sediment	354	2					
	Blank - sediment and uncontaminated tank water	7	NA					
8.5	Adherence Rep 1	269	1	1.1E-01	6	0	11	5
	Adherence Rep 2	239	13	1.4E-02	17	2		
	Adherence Rep 3	260	7	5.2E-02	10	1		
	Control - contaminated water, no sediment	287	21					
	Blank - sediment and uncontaminated tank water	8	NA					

Table 4-23. Ohio 4 Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	217	6	0.0000	38	1	39	3
	Adherence Rep 2	220	10	0.0000	37	2		
	Adherence Rep 3	203	6	0.0000	42	1		
	Control - contaminated water, no sediment	350	0					
	Blank - sediment and uncontaminated water	ND	NA					
8.5	Adherence Rep 1	213	6	0.0000	46	2	44	2
	Adherence Rep 2	220	10	0.0000	44	3		
	Adherence Rep 3	230	10	0.0001	42	2		
	Control - contaminated water, no sediment	393	15					
	Blank - sediment and uncontaminated water	ND	NA					

Table 4-24. Ohio 4 *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. % A.	Δ%A
7.5	Adherence Rep 1	1.2E+05	1.1E+05	1.2E+04	7.6E-03	84	85	27
	Adherence Rep 2	1.2E+05				84		
	Adherence Rep 3	1.0E+05				87		
	Contaminated Control Rep 1	9.4E+05	7.7E+05	2.3E+05				
	Contaminated Control Rep 2	5.1E+05						
	Contaminated Control Rep 3	8.5E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	8.7E+04	7.8E+04	1.0E+04	6.2E-03	86	88	28
	Adherence Rep 2	6.7E+04				89		
	Adherence Rep 3	8.1E+04				87		
	Contaminated Control Rep 1	6.5E+05	6.3E+05	1.8E+05				
	Contaminated Control Rep 2	4.4E+05						
	Contaminated Control Rep 3	8.0E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-25. Ohio 4 *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.3E+04	1.1E+04	2.5E+03	5.5E-06	98	99	23
	Adherence Rep 2	1.2E+04				98		
	Adherence Rep 3	8.2E+03				99		
	Contaminated Control Rep 1	7.6E+05	7.7E+05	4.0E+04				
	Contaminated Control Rep 2	8.1E+05						
	Contaminated Control Rep 3	7.3E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	7.5E+03	7.3E+03	6.7E+02	2.7E-04	99	99	33
	Adherence Rep 2	7.9E+03				99		
	Adherence Rep 3	6.6E+03				99		
	Contaminated Control Rep 1	6.5E+05	5.6E+05	7.9E+04				
	Contaminated Control Rep 2	5.3E+05						
	Contaminated Control Rep 3	5.0E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

The cesium and lindane adherence results for the Arizona sample can be seen in Table 4-26 and Table 4-27. The Arizona sample had one of the lower percentages of sand, and the highest percent of silt of those studied as it was comprised of 58% sand, 34% silt, and 7% clay. In

addition, it had the highest TEC value at 154.14 (mmol/L)/100g. More than half of the cesium adhered to the sediment in both pHs of water and more than 80% of the lindane adhered to the Arizona sediment. There was no significant difference in cesium or lindane adherence with the pH 7.5 and pH 8.5 solutions. The adherence results for *E.coli* and *BaS* on the Arizona sample can be seen in Table 4-28 and Table 4-29. More than 75% of both biological contaminants adhered to the Arizona sample.

Table 4-26. Arizona Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	106	6	1.2E-04	64	7	58	6
	Adherence Rep 2	120	1	1.4E-04	59	5		
	Adherence Rep 3	142	11	3.4E-04	51	6		
	Control - contaminated water, no sediment	291	25					
	Blank - sediment and uncontaminated water	2	NA					
8.5	Adherence Rep 1	118	2	1.4E-06	63	2	57	6
	Adherence Rep 2	137	7	4.4E-06	57	3		
	Adherence Rep 3	154	6	6.1E-06	52	3		
	Control - contaminated water, no sediment	321	9					
	Blank - sediment and uncontaminated water	4	NA					

Table 4-27. Arizona Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	41	2	6.2E-05	89	10	86	2
	Adherence Rep 2	52	1	7.1E-05	86	9		
	Adherence Rep 3	55	3	7.4E-05	85	10		
	Control - contaminated water, no sediment	363	38					
	Blank - sediment and uncontaminated tank water	NA	NA					
8.5	Adherence Rep 1	59	1	1.3E-04	82	10	83	1
	Adherence Rep 2	55	4	1.2E-04	83	12		
	Adherence Rep 3	52	5	1.2E-04	84	12		
	Control - contaminated water, no sediment	327	38					
	Blank - sediment and uncontaminated tank water	ND	NA					

Table 4-28. Arizona *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	3.7E+05	3.1E+05	6.5E+04	2.1E-05	75	79	17
	Adherence Rep 2	3.1E+05				79		
	Adherence Rep 3	2.4E+05				84		
	Contaminated Control Rep 1	1.4E+06	1.5E+06	5.8E+04				
	Contaminated Control Rep 2	1.5E+06						
	Contaminated Control Rep 3	1.5E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	3.8E+05	3.8E+05	8.5E+04	2.4E-04	77	77	18
	Adherence Rep 2	4.7E+05				71		
	Adherence Rep 3	3.0E+05				82		
	Contaminated Control Rep 1	1.6E+06	1.6E+06	1.5E+05				
	Contaminated Control Rep 2	1.8E+06						
	Contaminated Control Rep 3	1.5E+06						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-29. Arizona *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.1E+04	9.4E+03	1.4E+03	7.2E-05	98	98	17
	Adherence Rep 2	8.7E+03				98		
	Adherence Rep 3	8.6E+03				98		
	Contaminated Control Rep 1	5.2E+05	5.5E+05	5.5E+04				
	Contaminated Control Rep 2	5.1E+05						
	Contaminated Control Rep 3	6.1E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				
8.5	Adherence Rep 1	8.6E+03	9.1E+03	7.6E+02	1.8E-04	98	98	15
	Adherence Rep 2	8.8E+03				98		
	Adherence Rep 3	1.0E+04				98		
	Contaminated Control Rep 1	6.5E+05	5.7E+05	7.2E+04				
	Contaminated Control Rep 2	5.3E+05						
	Contaminated Control Rep 3	5.2E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

The cesium and lindane adherence results for the Illinois sample can be seen in Table 4-30 and Table 4-31. The particle size characteristics for the Illinois sample were different than the other sediments. The Illinois sample had the highest amount of clay by a large margin; it had almost

42% clay whereas the other sediments were less than 8% clay. Additionally, the Illinois sample had the lowest percentage of sand with 37%. The Illinois sample was only tested with the pH 7.5 solution due to the small amount of sediment received. An average of 20% of the cesium adhered, and an average of 27% of the lindane adhered to the Illinois sediment. The adherence results for *E.coli* and *BaS* on the Illinois sample can be seen in Table 4-32 and Table 4-33. Less than 50% of the *E.coli* adhered and more than 90% of the *BaS* adhered to the Illinois sample.

Table 4-30. Illinois Cesium Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	246	14	5.2E-02	8	1	20	11
	Adherence Rep 2	195	4	1.5E-04	27	1		
	Adherence Rep 3	197	4	1.6E-04	26	1		
	Control - contaminated water, no sediment	266	10					
	Blank - sediment and uncontaminated water	NA	NA					

Table 4-31. Illinois Lindane Adherence Results

pH	Description	Avg. (µg/L)	SD	p-value; compared to control	% Adherence (%A)		Avg. %A.	%SD
					%A	Δ%A		
7.5	Adherence Rep 1	253	6	4.5E-05	30	1	27	3
	Adherence Rep 2	267	6	7.6E-05	26	1		
	Adherence Rep 3	273	6	1.0E-04	24	1		
	Control - contaminated water, no sediment	360	10					
	Blank - sediment and uncontaminated water	0.23	NA					

Table 4-32. Illinois *E.coli* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	1.5E+05	1.5E+05	3.0E+04	1.3E-01	42	42	18
	Adherence Rep 2	1.8E+05				31		
	Adherence Rep 3	1.2E+05				54		
	Contaminated Control Rep 1	3.6E+05	2.6E+05	9.5E+04				
	Contaminated Control Rep 2	1.7E+05						
	Contaminated Control Rep 3	2.5E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

Table 4-33. Illinois *BaS* Adherence Results

pH	Sample Description	Measured Conc. (cfu/mL)	Avg. Conc.	SD	p-value; compared to control	% Sediment Adherence	Avg. %A	Δ%A
7.5	Adherence Rep 1	8.5E+03	1.3E+04	3.8E+03	3.8E-04	99	98	33
	Adherence Rep 2	1.5E+04				98		
	Adherence Rep 3	1.5E+04				98		
	Contaminated Control Rep 1	9.4E+05	8.0E+05	1.2E+05				
	Contaminated Control Rep 2	7.5E+05						
	Contaminated Control Rep 3	7.1E+05						
	Blank - sediment and uncontaminated water	ND	NA	NA				

5.0 Results Summary

Tables 5-1 through 5-4 summarize the percent adherence data for all contaminant-sediment combinations at pH 7.5 and 8.5. In general, the biological contaminants adhered more readily than the chemical contaminants. The average cesium adherences ranged from 5% to 88%. The range of adherences for lindane was 7% to 88%. All adherences for *E.coli* were greater than 50% except for the pH 8.5 Ohio 1, and pH 7.5 Illinois samples. Out of the four target contaminants, *BaS* had the highest percentages of adhesion. All *BaS* samples had average adherences greater than 90% except the Tennessee and North Carolina samples although the Tennessee adherences were greater than 80%. Overall, adherences at different pH levels were often within the experimental uncertainty of the measurements. The results of this work suggest that when sediment is present, chemical and biological contaminants do adhere to the sediment.

Table 5-1. Average Cesium Adherence

Sediment	pH	Average % A	% SD
Tennessee	7.5	5	5
	8.5	9	1
North Carolina	7.5	20	1
	8.5	21	2
Ohio 1	7.5	67	5
	8.5	60	8
Alabama	7.5	38	5
	8.5	32	6
Arkansas	7.5	88	3
	8.5	82	2
Ohio 4	7.5	28	6
	8.5	11	5
Arizona	7.5	58	6
	8.5	57	6
Illinois	7.5	20	11

Table 5-2. Average Lindane Adherence

Sediment	pH	Average % A	% SD
Tennessee	7.5	7	1
	8.5	7	2
North Carolina	7.5	40	7
	8.5	27	12
Ohio 1	7.5	87	0
	8.5	88	0
Alabama	7.5	37	1
	8.5	31	6
Arkansas	7.5	41	2
	8.5	43	10
Ohio 4	7.5	39	3
	8.5	44	2
Arizona	7.5	86	2
	8.5	83	1
Illinois	7.5	27	3

Table 5-3. Average *E.coli* Adherence

Sediment	pH	Average %A	Δ%A
Tennessee	7.5	54	6
	8.5	54	2
North Carolina	7.5	66	39
	8.5	78	21
Ohio 1	7.5	72	36
	8.5	27	3
Alabama	7.5	76	4
	8.5	72	27
Arkansas	7.5	100	20
	8.5	99	121
Ohio 4	7.5	85	27
	8.5	88	28
Arizona	7.5	79	17
	8.5	77	18
Illinois	7.5	42	18

Table 5-4. Average *Bacillus anthracis* Sterne Adherence

Sediment	pH	Average %A	Δ%A
Tennessee	7.5	86	11
	8.5	82	20
North Carolina	7.5	31	5
	8.5	49	9
Ohio 1	7.5	93	72
	8.5	99	28
Alabama	7.5	91	32
	8.5	92	13
Arkansas	7.5	100	18
	8.5	100	22
Ohio 4	7.5	99	23
	8.5	99	33
Arizona	7.5	98	17
	8.5	98	15
Illinois	7.5	98	33

6.0 REFERENCES

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