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Research Report on

The Joint Risks of Anticipated Sea-Level Rise and Coastal Contaminated Sites: Economic and Scientific Evidence

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Introduction to the Joint Risk: Anticipated Sea-Level Rise and Contaminated Sites

An emerging scientific consensus points to anticipated global sea-level rise (SLR) associated with increases in the frequency, magnitude, and duration of coastal flooding (Pachauri, 2007). In the United States, 39% of the population lives in coastal counties, where the average population is projected to increase by 37 people per square mile by 2020, versus an expected average increase for the entire nation of 11 people per square mile (NOAA 2014a). At the same time, a transformation of the U.S. economy continues from predominantly manufacturing and production to increased service-oriented industries. This economic transformation has resulted in numerous abandoned or underused contaminated sites, often along the coast where industrial production has the longest history. Contaminated sites, including but not limited to brownfields and Superfund sites, are a local disamenity and carry a broad set of potential negative environmental and health impacts. SLR and contaminated sites are problems that have long attracted research. However, as Figure 1 describes, these research agendas, though integrated across disciplines, have not been studied jointly.

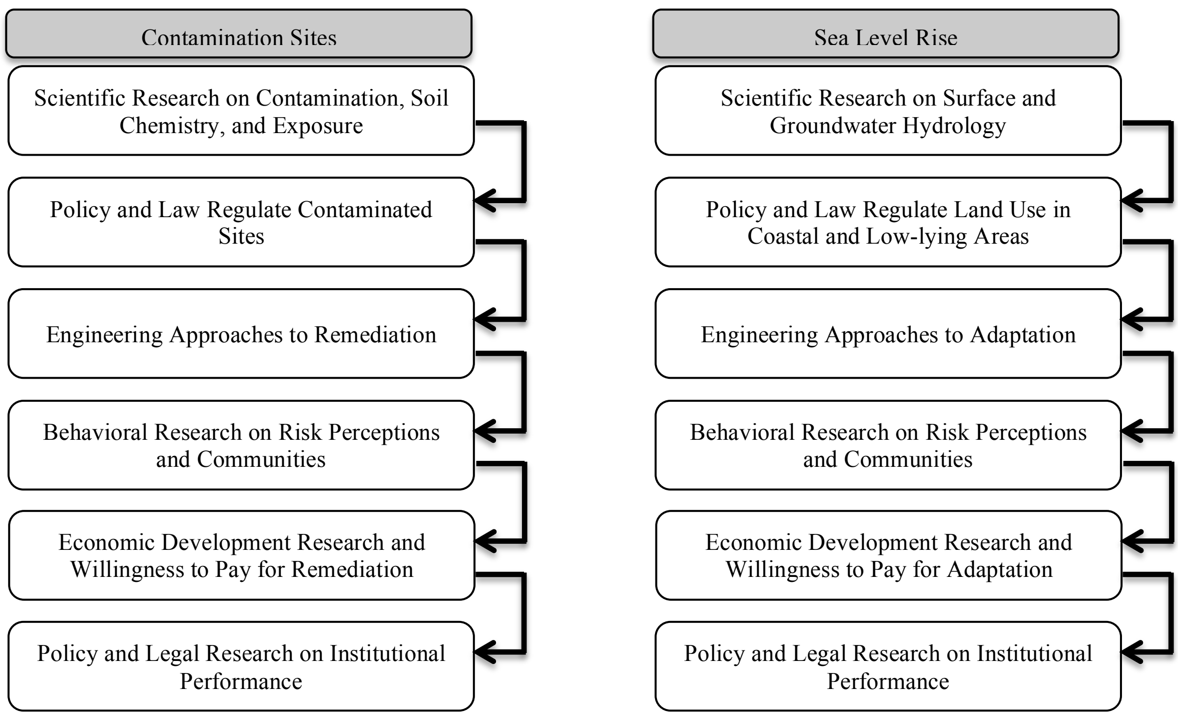

Figure 1: Current independent contaminated-site and SLR integrated research agendas.

The purpose of this research report is to examine the *joint risks* of both SLR and contaminated sites. To date, only a few studies have even recognized this joint risk (e.g, Zimmerman and Faris, 2010; Pope et al., 2011; Rosenzweig et al., 2011). The projected interaction of SLR and contaminated sites is a poorly understood problem, but a significant one, positioned at the interface of natural science and social science.

The scientific problem of this joint risk is complex, given factors such as the chemical effects of salinity, pH, reduction-oxidation (redox), the physical effects of changes in hydraulic gradients, rising water tables, marsh drowning, new areas inundated by storm surges, and the risk that currently immobilized constituents may be released. Meanwhile, human behavior and decisions vary, depending on human processing of perceived risks and the distributional patterns of received benefits and costs across different populations. Policy responses also vary, including technological solutions for surge prevention, remediation technologies for contaminants, and abandonment of affected areas. Understanding how the public responds to risk, including research on responses when the risk is communicated in different ways, will provide insights toward improving risk management.

Approach

An exploratory-research team at the University of Delaware was formed to investigate how water sustainability needs are affected by the joint impacts of contaminated sites and SLR. This is a global challenge, but it will be examined in a specific area as a laboratory. Specifically, the research was guided by this central question:

> ***How will water sustainability needs and anticipated sea-level rise affect the economic opportunities, ecosystems, and quality of life in the coming decades for populations in the coastal zone of the Mid-Atlantic region of the United States?***

The purpose of this research report is to review existing research literature and the institutional environment that begins to inform this question. This research report sketches the chemistry and hydrology of contaminant transport and cycling within the context of SLR and storm surge. The paper also summarizes what is known about the independent risks of SLR and contaminated sites from hydrology, biogeochemistry, civil engineering, economics, social science, and policy.

A major component of this exploratory research was an integrated research workshop on Sea Level Rise and Contaminated Sites, which was conducted at the University of Delaware on November 22, 2013. The workshop's purpose was to provide a forum for experts from various disciplines to share knowledge and identify unknowns related to these risks. Table 1 presents the topics and speakers from the workshop. Results from the workshop are referenced throughout the paper.

One outcome of this exploratory research is a set of research questions and hypotheses aimed at improving understanding and develop optimal adaptation strategies. To assist in this process of hypothesis generation, the research team sought to create a theoretical framework for a predictive understanding of water quality encompassing the interactions of SLR, soil contamination, water contamination, remediation, ecosystem services, economic choice by the public, and policy response. The hypotheses involve diverse topics, including: (1) how a rising sea level affects contaminated soils located near tidal rivers and coastlines; (2) how the threat of contaminant transport is affected by marsh changes from SLR, including the implications of marsh drowning and decline, and associated reduction of natural contaminant buffering; (3) how to model contaminant dispersal spatially, in light of SLR; (4) how various technical abatement strategies affect contaminant dispersal; (5) how communities are affected by mobilized contaminants; (6) how different adaptation efforts are perceived by residents; (7) how changes in any given process might feed back into other processes; and (8) what scientific and social scientific results would be needed for the design of an optimal policy to address these joint risks.

Table 1: Workshop topics and speakers.

Speaker	Title	Topic
Joshua Duke	Professor of Applied Economics and Statistics, University of Delaware	Introduction to the Problem & Objectives of the Workshop
Joel Eisen	Professor of Law and Austin Owen Research Fellow, University of Richmond School of Law	Stigmatized Sites and Urban Brownfield Redevelopment: Legal, Economic, and Policy Issues
James Kirby	Edward C. Davis Professor of Civil and Environmental Engineering, University of Delaware	Understanding of Processes of Surface Water Dynamics Causing Storm Surge Flooding
Adam Langley	Assistant Professor of Biology, Villanova University	How Sea Level Rise Affects Tidal Marshes and Wetlands
Holly Michael	Unidel Fraser Russell Chair for the Environment and Associate Professor of Geological Sciences, University of Delaware	Understanding of Processes of Groundwater Flow and Salt Transport in the Subsurface
Don Sparks	Director of Delaware Environmental Institute and S. Hallock du Pont Chair in Soil and Environmental Chemistry, University of Delaware	Assessment of Metal Cycling and Speciation in Delaware Contaminated Soils
Jeff Bross	Chairman, Duffield Associates Inc.	The Impact of Sea Level Rise on Metals Remediation Strategies
Patrick Walsh	Economist, U.S. Environmental Protection Agency	Adaptation, Sea Level Rise, and Property Prices in the Chesapeake Bay Watershed
Kent Messer	Unidel Howard Cosgrove Chair for the Environment and Associate Professor of Applied Economics and Statistics, University of Delaware	Investigations of the Behavioral Response to Contamination Risk
Marian Young	President, BrightFields, Inc.	Historical Issues of Contamination in Delaware
Susan Love	Project Manager of the Sea Level Rise Advisory Committee for the Delaware Department of Natural Resources and Environmental Control	Preparing for Sea Level Rise: Development of an Adaptation Strategy for Delaware and the Social Dimensions of Risk

Joint SLR and Contaminated Site Risk: An Emerging Problem

Anticipated SLR has captured public and scientific attention as part of the concern about climate change. The popular and policy debates tend to focus on SLR risks that are most salient to people, such as inundation of coastal areas, increased intensity and damage from weather events, human and infrastructure adaptation, and abandoning low-lying coastal areas. Although some of the media attention on SLR is informed by science, a large share of this media attention seems to be unsystematically selected for coverage. In other words, there is no process that guarantees that the magnitude of SLR media coverage matches the magnitude of the threat. Also, the more devastating events will be expected to receive more media attention than the slow, incremental threats. Therefore, media attention alone is unlikely to lead to political pressure for optimal planning. Instead, media attention likely leads to reactionary policy—policy that tends not to incorporate the best scientific evidence on expected SLR. Because contaminated site risks often are incremental and reveal harm long after contaminants are placed in the environment, the joint risks of SLR and contaminated sites are unlikely to be addressed optimally by media attention. Therefore, one rationale for this research report is to help recognize what joint risks of SLR and contaminated sites are predictable, given current science. A second rationale is to help establish a research agenda regarding unknown processes associated with SLR and contaminated sites. Policy can therefore plan for these known and unknown joint risks in the near future and prevent ad hoc reactionary planning.

On balance, the ways in which the risk of SLR may exacerbate the risk of contaminated sites is poorly understood. One might speculate that this joint risk is rarely studied because the risks associated with contaminated sites are rarely salient, even to those people likely to be affected. One easily imagines rising seas, but has difficulty understanding how the unknown toxins trapped in an industrial site may migrate so as to affect one's well being. A lack of data about the location of toxins, the mechanisms of exposure, and the response in humans to these exposures collectively complicates understanding contaminated site risk.

Although both contaminated sites and SLR are studied widely, only a few studies are raising alarms about their joint effects. These studies are summarized in this paragraph. Sources were found that identify this joint risk (Zimmerman and Faris, 2010), including a scientific study (Pope et al., 2011). There is some evidence that policy makers have begun to plan for joint impacts (see National Brownfield Association, 2010, referencing planning by the California Department of Toxic Substances Control, which calls this a "brand new issue"). Much of what is known to policy makers is detailed in a literature review by Barnett (2010), who found little recognition of the issue in 2009, but increasing policy discussion by 2010. Barnett's (2010) review describes two processes at work: (1) water displaces hazardous chemicals in brownfield sites; and (2) heavy saltwater may trigger a process in which contaminated groundwater approaches ground level. Barnett (2010, p. 2) further argues that the "direction of plume (of contaminated groundwater) migration may be difficult to predict without comprehensive geophysical analysis." More recent studies include DNREC (2012), discussed below.

Background on Sea-Level Rise

Geologic observations and instrument records indicate that the rate of SLR increased between the mid-19th and mid-20th centuries (IPCC, 2007). Two major processes cause global mean SLR: (1) the volume of water expands as the ocean warms, and (2) water is released to the oceans from land reservoirs such as glaciers and ice sheets during periods of climate warming (Titus et al., 2009). Tidal gauge data show that global sea level rose by an average of 1.7 mm/year since the late 19th to early 20th century (Church and White, 2006). On-going scientific research seeks to assess the rate at which SLR is accelerating. The projected global mean SLR is estimated at between 0.18 m and 0.59 m by the end of this century (National Oceanic and Atmospheric Administration [NOAA], 2012).

SLR prediction is affected by variation and uncertainty. Variations in ocean circulation related to temperature and salinity; wind and ocean currents; gravitational redistributions from shrinking ice masses; and the earth's rotation create spatial variability in SLR (Levermann et al., 2005; Landerer et al., 2007; Yin et al., 2009; Mitrovica et al., 2001; Perrette et al., 2013). A recent U.S. Geological Survey study (Sallenger et al., 2012) demonstrated that the rate of SLR is three to four times faster along the U.S. Mid-Atlantic coast than elsewhere in the world.

Accelerated SLR poses a particular threat to vulnerable low-lying coastal areas. Dense coastal populations that continue to grow compound this vulnerability. Ten percent of the world's population (634 million) lives along the coast (McGranahan et al., 2007), and the populations of 673 coastal counties in the United States increased from 120 million in 1980 to 153 million in 2003, approximately 28% (Crossett et al., 2004). The nation's coastal population is expected to continue to increase (NOAA, 2014a). FitzGerald et al. (2008) found that of the 25 most densely populated U.S. counties, all but two are coastal counties.

By definition, an increasing population in low-lying, coastal areas will increase the human impact of SLR. A Pew Center on Global Climate Change report (Neumann et al., 2000, p. iv) estimates the impact: "Based on a review of the existing literature, estimates of the cumulative impacts of a 50-cm sea-level rise by 2100 on coastal property range from about $20 billion to about $150 billion." In addition to inundating low-lying lands, eroding beaches, submerging marshes, and increasing the salinity of freshwater aquifers, SLR increases the vulnerability of coastal regions to flooding caused by storm surges and hurricanes (FitzGerald et al., 2008). As sea level rises and if severe storms become more frequent, waters from storms of a given magnitude reach higher elevations, producing more extensive areas of inundation (FitzGerald et al., 2008). Hurricane Sandy, in October 2012, which was blamed for 147 fatalities and more than $50 billion in property damage (NOAA, National Weather Service, 2013), is a stark reminder of the damage that can occur as a result of storm surges along the East Coast of the United States. In light of the damage caused by this one storm, it seems that estimates such as that by Neumann et al. (2000) are likely to be low.

Responses to Rising Sea Level

Planners and engineers generally recognize three types of possible responses to SLR. Traditionally, damage mitigation has focused on *structural engineering methods*, such as structural reinforcement (e.g., dams, levees, and channel improvements) and shoreline reinforcement (e.g., beach nourishment, armoring) (see Beatley et al., 2002). The Federal Emergency Management Agency (1986) estimated that more than $7 billion in public monies were spent on large-scale structural flood control works between the mid-1950s and mid-1980s. Other options include *nonstructural measures* such as land use planning, building codes, emergency planning, outreach programs, and insurance (Titus, 2011). Finally, *accommodation and retreat* could be an appropriate response in some circumstances. Accommodation involves developing strategies that allow people continued habitation in spite of the hazards (Titus, 2011). Retreat involves setback restrictions, restrictions on rebuilding in hazard areas, and landward relocation designed to limit vulnerability to erosion, hurricanes, and coastal storms (Beatley et al., 2002).

People also make decisions in response to rising sea level, which threatens coastal areas. According to the U.S. EPA (2009), options include shoreline armoring (i.e., seawalls and bulkheads), elevating buildings and land surfaces, adapting to the natural change in shorelines, and moving structures out of harm's way (i.e., implementing setback rules). These efforts are likely driven by personal beliefs about the future or are in response to economic incentives, such as nonrenewal of flood insurance by home insurers. Small groups such as neighborhood associations may even drive some responses.

Delaware as Case Study

To motivate the problem of joint risks, a real-world setting is offered. The exploration investigates Delaware, where 897,934 people lived in 2010, with a concentration of residents in the north—New Castle County. Southernmost Sussex County is growing rapidly; its population has increased by more than 25% in the last decade, especially in the eastern coastal area. Tourism, including beach resorts, and agriculture are both important industries in the state. Tourism generated $437 million within the state in taxes during 2011 (Delaware Tourism, 2013). Agriculture in Delaware has an industrial impact of $8 billion, of which poultry production is a large part.

A Long History of Contamination

A long industrial history in Delaware has left a legacy of soil contaminants, especially along the coast. Industries included tanneries, chemical companies, railroads, shipbuilding, and auto manufacturing. In the 19th and early 20th centuries, Wilmington had the second largest leather industry on the East Coast. The former tannery sites are now in use as both commercial and residential areas. Some sites have been remediated, some areas have been fenced off, and other areas are monitored but in use. Soils at the tannery sites have high concentrations of arsenic (As), chromium (Cr), and other metals. According to a newspaper analysis, Delaware has more than 700 contaminated sites (Montgomery, 2007) comprising 60,088 acres—approximately 4% of the state (DNREC 2012, p. 140). In northernmost New Castle County, which contains more than 70% of the state's population, there are more contaminated sites per square mile than in all but three other counties in the country (Montgomery, 2007).

Figure 2 shows Delaware's three counties; the state's largest city, Wilmington, with its cluster of contaminated sites near tidal areas; and the Indian River power plant, as well as areas of intensive poultry operations and crop production. Intensive poultry production is part of an integrated agricultural production process that potentially stresses coastal, terrestrial, and aquatic ecosystems. One of the most relevant impact from agriculture for this study is the potential for As contamination from poultry houses.

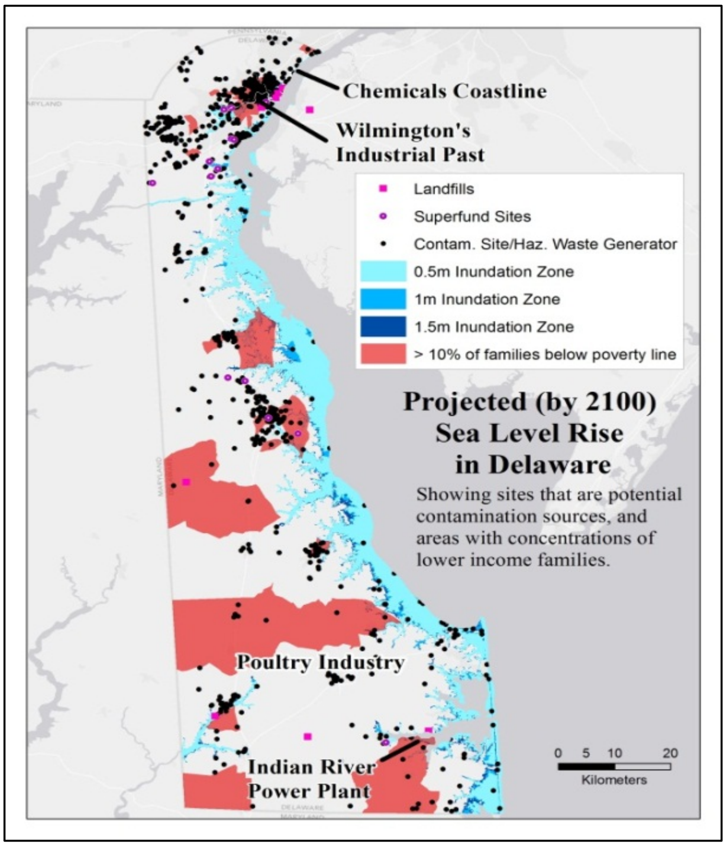

Figure 2: Projected inundation zone and contaminated sites in Delaware.
(Source: A. Homsey, Delaware Water Resource Center)

Contaminated sites are now close to commercial and residential areas, including older neighborhoods populated by low-income and often ethnic minority residents but also including recently redeveloped neighborhoods populated by higher-income residents. Some of these areas have unusually high levels of cancer and asthma that may be attributed to environmental pollution. Thus, in addition to adaptation challenges, the joint risk presents associated policy and environmental justice issues. Large population centers along much of the Mid-Atlantic coast—and, indeed, urbanized coastal areas around the world—share this legacy of contaminated sites.

Sea-Level Rise: What It May Mean for Delaware

Located in the center of the Mid-Atlantic coast, with all three of its counties adjacent to a tidal bay or the ocean, Delaware is especially at risk for the effects of SLR, including loss of coastal lands, saltwater intrusion, and increased frequency of coastal flooding. The eastern border of the state is a 90-mile coastline, with inland geography characteristic of the coastal plain. The estuary is a large, brackish body of water adjacent to extensive marshlands that are critical fish and crab habitats. Parts of the coastal zone have been designated as national wildlife refuges, and they serve as critical parts of the Atlantic Flyway, a major migratory bird flight path.

The Delaware Department of Natural Resources and Environmental Control (DNREC) estimates that 8–11% of the state's land area could be inundated by SLR by the year 2100 (DNREC, 2012). Areas that may be inundated include 84–98% of the total freshwater tidal wetland acreage; 3–7% of land identified for future development by Delaware's Strategies for State Policies and Spending report (DNREC, 2012); 16–25% of the acreage of heavy industrial lands in the coastal area (as permitted by Delaware's Coastal Zone Act); 97–99% of the state's tidal wetlands; 3–7% of both domestic and industrial wells; 1–2% of irrigation wells; and 2–10% of public wells (DNREC, 2012).

Summary of Workshop Presentation on Preparing for Sea-Level Rise and Adaptation Considerations for Delaware (part 1)
by Susan Love

Workshop speaker Susan Love (Love, 2013), the Director of the Sea Level Rise Advisory Committee for DNREC, reported on the current state-level planning for SLR. Delaware's Sea-Level Rise Advisory Committee was created in 2009 and tasked with assessing Delaware's vulnerability to inundation from SLR and developing recommendations to adapt to its potential effects. The final product was an "adaptation plan," a document that describes the potential impacts and recommends actions that can be taken by governments, businesses, and individuals, but it does not create new regulations or legislation (Love, 2013).

Love reports that the first phase of the adaptation planning process was development of a statewide SLR vulnerability assessment, which was completed in July 2012 and published in September 2012. It assesses 79 different resources ranging from wells and septic systems to roads and wetlands, finding that SLR affects all of Delaware with direct effects in all three counties and 31 of the 57 towns. Eight to eleven percent of Delaware's total land area, with a tax-assessed value of $1.5 billion, could be inundated or permanently flooded, by SLR under three scenarios. Of the 79 resources, the committee found that 16 were of special concern: industrial areas and ports, railroads, roads and evacuations routes, dams and dikes, future development areas, tourism, habitats and protected lands, wells, and others.

Adaptation strategies for sea level rise include:

- Protection—building protective structures to hold back water;
- Accommodation—changing behaviors and lifestyles to deal with encroaching water;
- Retreat—moving structures out of flooded areas and/or letting nature take its course; and
- Avoidance—not placing new structures in at-risk areas.

Decisions about which strategy (or combination of strategies) will be made by a variety of different stakeholders at many different geographic scales. The Sea Level Rise Advisory Committee's Recommendations for Adapting to Sea Level Rise in Delaware does not specify which adaptation strategies should be employed where, but outlines ways the state can build the capacity to make those decisions. All of these actions will be complicated by contaminated soils and newly mobilized contaminants (Love, 2013)—this is described further below.

Policy and Law on Contaminated Sites

Relative to SLR, there is a comparatively long history of collective efforts to address contamination. During the mid-19th century, it became apparent that the rise in toxic pollution could not adequately be addressed by the private law of nuisance. News media coverage and public outcry gave rise to legislation and policy responses. This section offers a brief review of these efforts.

Brownfields and Superfund Institutions

The term "contaminated sites" refers to a broad class of industrial parcels where a legacy of localized pollution affects current ability to repurpose these sites. Although brownfields are often thought of as abandoned, that is not always true, and this research aims to apply more broadly than just to abandoned sites. The federal definition of brownfield is more precise:

> "Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." 42 U.S.C. §§ 9601(39)(A) (2002).

According to the U.S. Environmental Protection Agency (2014), there are over 450,000 brownfields in the United States. The most recent survey found an estimated 24,896 brownfield sites in 188 responding cities. Approximately 1,578 sites in 150 cities have been redeveloped, with another 1,235 in progress (in 168 cities) (U.S. Conference of Mayors, 2008, p. 9).

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (a.k.a. Superfund) of 1980 addresses abandoned hazardous waste sites. As of December 2, 2013, 1,313 sites were on the National Priorities List (NPL) (U.S. EPA, 2013), indicating that they were of greatest concern for cleanup. The stages in the Superfund program are remedial assessment, remedial design, construction, completion, and deletion from the NPL (Daley and Layton 2004). The assessment and cleanup processes are very costly and lengthy, and there is very strict liability on cleanup responsibility (Eisen, 2012).

Forty-nine states have voluntary cleanup programs (VCPs) through which a potential developer can voluntarily come to the state and initiate dialogue to lead site remediation (Eisen, 1996). Participating states provide developers tools such as liability relief, grants, and loans to address cleanup costs (Solitare and Lowrie, 2012). Daley (2007, p. 167) writes that "all states prohibit federal Superfund sites from participation in" VCPs. VCPs allow shorter cleanup processes with more finality (including release of the brownfield purchaser from liability) and lesser cleanup standards that in some cases would allow less costly means of addressing contamination at the sites (Eisen, 2012). Some cities have brownfields that are too small to be suitable for VCPs, although the sites may interest developers (Wernstedt et al., 2010). These cities often lack institutional capabilities for redevelopment activities.

Summary of Workshop Presentation on Brownfield Redevelopment: Legal, Economic, and Policy Issues by Joel Eisen

Workshop speaker Joel Eisen (Eisen, 2013) reported on the legal, policy, and economic issues that affect remediation of contaminated sites. Eisen reports there is increasing use of green technology on contaminated sites, leading to the coining of a new term—"brightfields." This suggests that if joint risks of SLR and contaminated sites are coherently planned, then brownfields remediation and development can be an important component of climate change planning.

Eisen argues that many brownfield sites are close to highways, rivers, and/or rail transport, which can make them attractive for development. Revitalization of these sites can be a major asset to a city, but the question of whether the sites are efficiently remediated depends upon the benefits of remediation. Fiscally, it also depends on who pays. Brownfield development has the advantage of avoiding further loss of "greenfields"—new development, usually in the suburbs or exurbs, that is often associated with sprawl and loss of open space and wildlife habitat.

Brownfields pose many problems and issues (Eisen, 2013). The type and extent of contamination is usually not known until the site is investigated. Brownfields contribute to urban blight, and may pose public health risks. They can lower tax revenue for a neighborhood, contribute to social and economic decay, and help drive neighbors to move away. Many municipalities face tight finances and lack the resources needed to effectively address rehabilitation and redevelopment of brownfields. Municipalities may not have the engineering expertise needed to properly assess a site and its cleanup prospects.

Eisen argues that expected future SLR and other effects of climate change seem to be increasingly drawing the attention of federal policy makers. President Obama's 2013 Climate Action Plan directs the U.S. EPA to consider climate change impacts and adaptations when reviewing brownfields cleanup grants. The federal Department of Housing and Urban Development requires that grants to people in the area affected by Hurricane Sandy account for SLR. However, older federal and state site remediation laws and programs, including states' VCPs, are only beginning to account for smart growth or climate change concerns.

Non-Superfund brownfield sites, which constitute the vast majority of brownfields, can receive federal cleanup funds through a variety of different grant programs administered under the EPA's Brownfields Program (Eckerd and Keeler, 2012). The Brownfields Program began awarding competitive grants in 1995 and awarded 436 grants totally $87 million by 2002 (Greenberg and Issa, 2005). Unlike funding provided for Superfund sites, these grants are very unlikely to fully cover remediation costs (Dull and Wernstedt, 2010). As of July 2014, the state of Delaware has over 200 certified brownfield sites, including 103 in the city of Wilmington (DNREC, 2014). By 2013, there were 191 certified sites (Young, 2013).

The Beginning of a Research Agenda: Preliminary Framework for Future Research

Alterations in hydrology and chemistry of contaminated soils in urban areas, industrial sites, and waste disposal sites from SLR could enhance release and mobility of contaminants, threatening drinking water supplies and food sources. These joint impacts are likely to trigger significant environmental challenges in the future. However, single-discipline science is unable to develop optimal mitigation-of-risk strategies. Several important questions guide our research in this area:

- Will anticipated SLR cause previously immobile contaminants to be transported?
- How will SLR and newly mobilized contaminants affect land use and agricultural production near water bodies and the coastline?
- How best to model the risk of these processes, reflecting site and contaminant characteristics?
- What technologies are available to mitigate or adapt to these risks?
- How do the various technologies available affect water quality and quantity?
- How will human health be affected by these risks?
- Do people value risks of contamination to water quality differently than risks to other resources and infrastructure?
- Will human impacts be concentrated on certain population segments, such as limited-resource urban populations?
- How will human behavior change in response to the various risks and abatement strategies? If people recognize risk, will they relocate to avoid risk or will they stay and avert risk?
- Will recognition, avoidance, and averting behavior vary with demographic indicators or location?

These broad, significant questions are of particular concern in densely populated areas, such as the Mid-Atlantic coast, that are affected by a legacy of industrial and agricultural operations. Yet little scientific information exists to develop answers. This study provided the integrated research framework (Figure 3) needed.

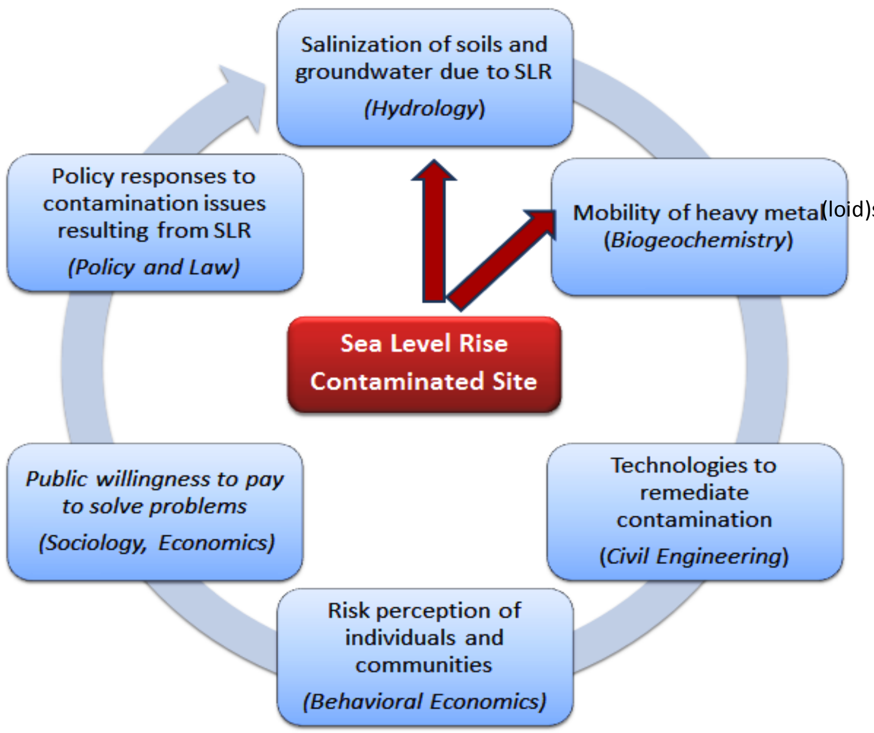

Figure 3: Proposed model for addressing joint risks of SLR and contaminated sites.

As this research report begins to present what is known about these questions in greater depth, a preliminary framework helps to organize what is known in the various relevant disciplines about these issues, how relevant experts define the problem, what they identify as the most pressing questions in the field, and how they suggest approaching the research questions.

The questions listed above motivated the November 2013 workshop presentations. The experts sought to provide scientific evidence about what is known and unknown concerning this problem of joint risk of SLR and coastal contamination.

Hydrologic Processes

This section describes three areas of research on water, which are relevant to SLR and contaminated sites: subsurface water, surface water, and marsh functioning.

Subsurface Water[1]

Coastal groundwater salinization occurs due to two primary mechanisms (Figure 4). "Classical" or lateral seawater intrusion is caused by reduced hydraulic gradients: Lower hydraulic heads on land relative to sea level. This occurs as a result of groundwater pumping, reduced groundwater recharge, and/or SLR. Overtopping with seawater in areas where underlying groundwater is fresh occurs during storm surges and tsunamis, and as a result of SLR. This results in vertical infiltration of saline or brackish surface water and groundwater salinization. Examples of such events are Hurricanes Sandy and Katrina and the South Asian tsunami of 2004.

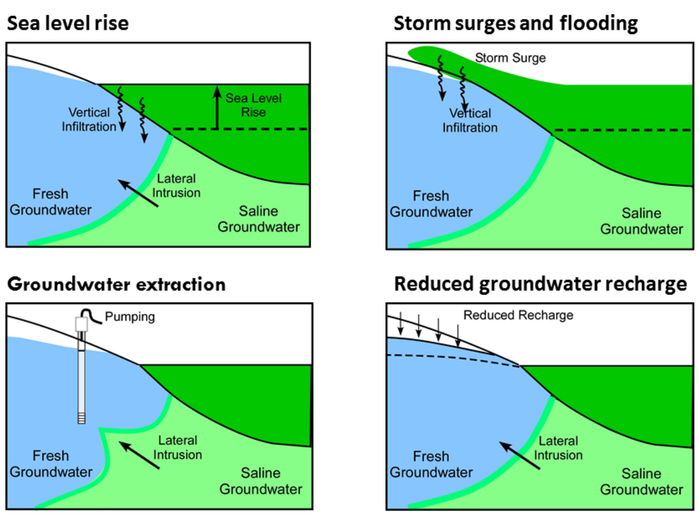

Figure 4: Coastal groundwater salinization.

Although field studies of these processes are rare, measurements and modeling of the 2004 South Asian Tsunami indicate that salinity is likely to persist in shallow aquifers for years or decades (Kume et al., 2009; Villholth and Neupane, 2011, Violette et al., 2009; Vithanage et al., 2012). Climate change affects both horizontal and vertical infiltration as a result of 1) changes in sea

[1] This subsection is an expanded version of the workshop presentation by Michael (2013).

level and groundwater recharge, which result in changing hydraulic gradients, 2) coastline migration, resulting in inundation of previously fresh aquifers and ocean surges that extend farther inland, and 3) increases in frequency and intensity of storm surges as well as changes in the elevation of the water table that affect the amount of infiltration that occurs during storm surge flooding.

Both lateral and vertical salinization mechanisms threaten water supply; only about 1% seawater ruins a freshwater resource. However, the time scale of salinization can differ greatly. Initial simulations indicate that vertical salinization occurs much faster than lateral salinization, on the order of months to decades, rather than decades to millennia (Yu et al., 2010; Post et al., 2013). In addition to occurring more quickly, vertical salinization is likely more important for contaminant mobilization because surface soils are often the most highly contaminated. Physical barriers may reduce surface flooding, but salinization may occur due to shallow groundwater flow beneath them.

The vulnerability of groundwater resources to salinization is affected by the nature of the hydrogeologic system and human activities. Factors that tend to increase infiltration are high aquifer permeability, pumping (that both lowers water tables and increases vertical flow rates), low water tables (that allow greater infiltration), and the existence of open wells and surface depressions. Factors that tend to increase the extent of ve rtical flow and mixing are low hydraulic gradients, a high contrast in density between surface water and groundwater, and pumping rates. Factors that tend to increase the time scale of flushing are low aquifer permeability, low hydraulic gradients, and particular configurations of aquifer heterogeneity. The extent to which each of these factors increases the risk of salinization is not well known. In addition to affecting risk, the time scale of salinization and flushing may be important in determining the extent of contaminant mobilization and subsequent transport.

Summary of Workshop Presentation on Surface Water
by James Kirby

To plan effectively for SLR effects on contaminated sites, one must consider the dominant mechanisms and time scales of salinization of soils and groundwater due to storm surges and SLR. There are several approaches to predictive modeling of surface flooding with seawater. In the first approach, bathtub modeling, dry regions adjacent to open water are assumed to be filled to the same surface elevation as open water. Sophisticated applications of this method are accurate enough to avoid filling enclosed or protected regions, such as polders.

Kirby reports that ocean surges and SLR have different time scales and impacts. For example, a tsunami involves higher water, a faster retreat of that water, and less total flooded area than a storm surge. One must consider whether it is reasonable to use bathtub modeling for events, such as tides, storms, and tsunamis, occurring on shorter time scales than SLR due to climate change. Bathtub models probably provide a conservative estimate of inundation depths. However, overdoing predictions of inundation on short time scales could lead to overestimation of scope of related chemical transport problems.

Bathtub models reveal nothing about dynamics, such as how floodwaters are routed and what will be the transport pathways for sediments and mobilized contaminants. In reality, the world is not a bathtub, and more sophisticated modeling will be required to make better predictions. The natural landscape responds to increasing sea level with 1) upward and landward adjustments of barrier islands through overwash processes, and 2) marsh platform accretion. People respond to SLR with interventions to reduce risk of inundation (polders, etc.), storm system modeling, etc. (Kirby, 2013).

These questions can be approached with numerical modeling of both surface water inundation and associated groundwater salinization. Models can improve understanding of expected extent and duration of surface water inundation, and how inundation affects infiltration into aquifer systems. We can then model groundwater flow and solute (salt or contaminant) transport. For contaminants, the transport properties (such as sorption isotherms or reactivity) must be known; these can be obtained from biogeochemical measurements and experiments. Field measurements and monitoring can demonstrate the geochemical response to changes in hydraulic heads and salinity, particularly during extreme events, such as storms, and over long time scale changes such as seasons. Measuring the contaminant concentration and speciation response to these hydrologic fluctuations will enable prediction of response to more extreme or longer-term fluctuations that can then feed back into the numerical models.

The human response to mitigate these risks may take several forms. Maintenance of coastal vegetation, marshes, dunes, and other natural barriers aids in flood prevention. Engineered flood protection can also mitigate risks. Measures can be taken to minimize infiltration during flood events. This could include plugging open wells, pumping wells after an overtopping event, and removing standing water from surface depressions and water bodies. Flushing of infiltrated water may also be increased by enhancing fresh recharge—through injection of fresh water, for example.

Workshop Presentation on Marsh Health and Stability
by Adam Langley

Langley (2013) argues that the decline in the health and size of marshlands is a pressing environmental issue. A healthy marsh system provides numerous ecosystem services, such as coastal stability and nutrient storage, flood control and buffering, and sediment capture. This directly relates to contamination because marshes are sinks for nutrients and contaminants. Contaminants in wetlands can remain relatively inert as long as the marsh survives. If a marsh collapses, contaminants are likely to circulate.

Marsh viability, according to Langley, is influenced by many factors, including carbon dioxide levels, nutrient levels, and sea levels. However, predictions of marsh viability are challenging, because the level at which carbon dioxide will peak is unknown, and therefore the total amount of SLR is unknown. As of April 2014, global mean carbon dioxide was nearly 400 ppm and still rising (NOAA, 2014b). Around the United States, there is already significant loss of coastal marshes. In the Gulf of Mexico, about 20 hectares of marsh are lost each day to SLR. More locally, Blackwater National Wildlife Refuge, on Maryland's Eastern Shore, has lost about 50% of its marsh area in the last 50 years (Langley, 2013).

Langley notes that through growth and accretion from slow decomposition of vegetation, coastal wetlands can keep up with slow SLR, but there are limits to how fast wetlands can grow vertically. These limits are determined by sediment dynamics (whether sediment is being lost or accumulated in the marsh); by organic matter accumulation, which depends on the type of vegetation and the health of the marsh; and by nutrient loads. If nitrogen is higher, the roots of marsh plants shrink and the marsh loses elevation. In general, when nutrients in coastal water are high, salt marsh is lost as creek banks collapse and vegetated marsh is converted into a mudflat, which does not provide the same benefits to humans or habitat for fish and wildlife (Deegan et al., 2012). With higher carbon dioxide, root growth is higher and the marsh gains elevation.

Langley concludes that although SLR threatens marsh viability, atmospheric carbon dioxide, nutrient availability, and plant community composition are also important factors. Generally, healthy marsh roots improve coastline stability. In a low-elevation coastal area with a fragile ecosystem, it is critical to develop models that incorporate linkages between environmental and social processes that can be used to predict the impacts of climate variability and change, land use, and human activity on water systems—all to develop a sustainable, cost-effective approach to managing water (Langley, 2013).

Recent work focusing on groundwater impacts involves model predictions. Site-specific modeling efforts include Oude Essink et al. (2010) and Loaiciga et al. (2011), while generic modeling studies include Chang et al. (2011), Werner and Simmons (2009), Webb and Howard (2010), and Michael et al. (2013).

Summary-Questions in Hydrology and Hydrogeology

The science of hydrological processes depends on the current and future ability to model complicated phenomena. Clearly, integrated models of hydrologic changes and contaminant transport will need to be developed if the joint risks of SLR and contamination are to be studied. This review of the hydrological processes focuses on SLR and suggests that future research will be tackling some of the questions below.

In terms of surface water inundation, integrated modeling is needed to explain how much SLR can coastal marshes withstand. A modeling challenge is to explain at various time scales how hydrologic properties influence the salinization mechanisms.

An open question is whether surface water modeling has a sufficiently accurate and detailed measure of topography, the built environment, and other land use patterns to allow predictions (Kirby, 2013). For instance, as little as 15 cm elevation can substantively affect the types of marsh vegetation (Kirby, 2013). Moreover, developing efficient computational approaches to handle this level of detail is difficult and an area for future research (Kirby, 2013).

SLR raises important issues about salinization and contamination of groundwater. For instance, with vertical salinization, how much seawater infiltrates, how much fresh soil and water does it contact (how deep does it get and how much does it mix), and how quickly does it flush away (Michael, 2013)? We know that the answers to these questions depend on hydrology/climate; hydrogeologic properties; system geography, such as topographic slope and hydraulic divides; type and scale of future changes in SLR and climate; and human impacts, such as pumping. Moreover, what do the answers to these questions mean for contaminant mobilization and cycling? How do timescales of hydrologic change and salinization relate to timescales of contaminant mobilization? How do mobilized contaminants move through the hydrologic system and where do they go? Are they a threat to human health, water supplies, and ecosystems? (Michael, 2013).

Biogeochemistry: Metal Cycling and Speciation in Delaware Contaminated Soils

Metal Cycling and Speciation[2]

The biogeochemical study of contamination has produced extensive scientific results, many of which are relevant for this study. Arsenic and chromium are common soil pollutants highly relevant for this research because of their reduction-oxidation (redox) sensitivity and varying toxicity levels dependent upon redox state. Other pollutants common in Delaware soils and elsewhere include mercury (Hg), iron (Fe) (not harmful), manganese (Mn) (not harmful), copper (Cu), zinc (Zn), and nickel (Ni). Pollutants also include nutrients such as nitrate, phosphate, and ammonium.

Both redox conditions and pH are known to greatly affect heavy metal solubility in soil by changing the metal's speciation (Masscheleyn et al., 1991; Wang et al., 1993). The level of the freshwater table is the primary factor controlling fluctuations in redox state (Seybold et al., 2002). Storm surges and SLR can cause elevated water tables on land and more widespread occurrence of freshwater surface flooding. Beneath the water table, redox gradients often exist as conditions change from oxic in unsaturated soils to anoxic in groundwater-saturated soils. Saltwater from seawater intrusion can cause changes in soil pH and redox conditions, which control the cycling and transformations of contaminants such as arsenic and chromium. Empirical relationships among SLR and cycling, mobility, and speciation of As and Cr can be affected by environmental conditions (initial work: Sparks et al., 2007).

Arsenite (As^{III}) is soluble, mobile, and toxic; arsenate (As^{V}) is less toxic and less mobile (more strongly bound to soil). There are two main oxidation states for chromium in the environment, Cr^{III} and Cr^{VI}, the latter of which is more toxic. Speciation of metals influences their mobility, toxicity, and bioavailability. Increased knowledge about how speciation changes under different conditions will facilitate more accurate predictions about the mobility, toxicity, and bioavailability of metals.

Soil chemists use various techniques to study metals, including x-ray fluorescence (XRF) for chemical composition; x-ray absorption fine structure (XAFS) for chemical speciation; surface scattering and diffraction for surface structure and sorption processes; and microtomography for three-dimensional imaging of the internal microstructure. These studies are complicated by the tremendous heterogeneity of soil.

Sparks et al. (2007) sought to improve our ability to assess the risk of As to human and ecological health by increasing our understanding of the amounts, forms, solubility, and bioavailability of As in Delaware soils. The research primarily focused on two settings: (1) agricultural cropland, especially situations where broiler litter, well-known to be a long-term source of As to Delaware soils, had been used as a fertilizer for crop production, and (2) contaminated soils in urban/suburban environments where past industrial activities resulted in soils with very high concentrations of As.

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[2] This subsection is an expanded version of the workshop presentation by Sparks (2013).

Among the findings in Sparks et al. (2007) regarding agricultural sites were calculations and field data suggesting that regular application of broiler litter as crop fertilizer at agronomic rates could increase soil total As values above the current DNREC soil As standard (11 mg kg^{-1}) within one to two human generations. This raises questions about the sustainability of As use in poultry production. The study also recommended that best management practices for broiler litters to prevent As losses to ground and surface waters should focus on production and storage areas and land application methods. Because much (>40–50%) of litter total As is easily soluble in water, it is important to prevent direct interaction of litters with rainfall or snowmelt in settings where the potential for dissolved As transport to surface or groundwater is likely.

Sparks (2007) showed that the urban soils from old industrial sites in Wilmington had much higher total As concentrations and more complex As speciation than the agricultural or forested soils. The soils also contained very high concentrations of other metals and tended to be high in pH and calcium. Visual inspection showed most were not natural soils but were mixtures of soil, fill materials, and occasionally debris. Leachable and bioavailable As were significantly correlated with total As. A rapid sequential chemical fractionation procedure found that these soils varied widely in the distributions of total As into exchangeable, sorbed, and resistant As pools. Encouragingly, the fractionation method successfully identified As fractions that were well correlated with bioavailable As. This suggests that these methods could be used to identify soils of differing risk to human health and for further, more detailed investigation into As speciation by methods such as x-ray absorption fine structure analysis.

Summary-Questions in Biogeochemistry

Biogeochemistry will provide significant insight into the joint risks of SLR and contaminated sites. Future studies will begin to untangle how a rising sea level affects contaminated soils with various properties, especially those located near tidal rivers and coastlines. Given that marshes provide natural contaminant buffering, future biogeochemistry studies will examine contaminants in the context of marshes, especially in light of potential widespread marsh decline that may reduce natural contaminant buffering ecosystem functioning.

Civil Engineering Approaches

Dermont et al. (2008) reported that there are several remedial options when soil is contaminated with metals. One option is simply to extract metals either in situ or ex situ (Dermont et al., 2008). A second option is to immobilize the metals either in situ or ex situ (Dermont et al., 2008). These options have been developed for addressing contaminant threats; however, when one considers SLR challenges, certain options may become even more promising. For instance, ex situ immobilization of metal contaminants from a low-lying coastal site may be preferable to in situ solutions because of the threat of future mobility.

Remediation strategies, although based on regulatory requirements, typically focus on reducing the risk of exposure or bioavailability. The particular strategy used for any site typically depends on the physical and chemical form of the metal, the site characteristics, the desired degree of long-term risk aversion, and the cost. Dermont et al. (2008, p. 190) classified remediation technology in terms of:

1. "the nature of action that is applied on the metals (immobilization or extraction)";
2. "the location where the process is applied (in situ or ex situ)"; and
3. "technology type, i.e., containment/disposal methods; chemical, physical, thermal, and biological treatments; or monitored natural attenuation."

There are four basic remediation technologies (Dermont et al., 2008): isolation with cover/capping/subsurface barriers; immobilization through solidification/stabilization, chemical treatment, or vitrification; toxicity reduction through a chemical or biological treatment; and extraction of contaminated soil for offsite treatment.

Summary of Workshop Presentation on the Impact of Sea Level Rise on Metals Remediation Strategies by Jeff Bross

Bross (2013) reports on contaminated site remediation. Metals trigger more Superfund actions than any other industrial chemical or waste product. Sixty-five percent of the National Priorities List sites were polluted with metals in 1994 and 77% in 2003 (U.S. EPA, 2004). Lead is the most common problem metal, but As, Cr, Zn, Cd, Cu, and Hg are also important. These metals are found naturally in soils, but are also added to soil via fertilizers and pesticides; biosolids, manures, and wastewater; mining, milling, and industrial wastes; airborne emissions; and ammunition.

Metals are generally persistent in the environment, bioaccumulating and biomagnifying, meaning that metals concentrations tend to be higher in animals higher up the food chain because they ingest many smaller animals with lower metals loads. The fate and transport of metals in the environment depend on their chemical form and speciation. Delaware has a wet, humid climate, so this abundance of water leads to concerns about leaching of soluble metals harming groundwater quality. A similar concern involves the impact of erosion of insoluble metals, creating a sediment quality issue.

Bross (2013) discussed the challenges of future site remediation in Delaware given the joint risk of projected SLR. Delaware is flat, low-lying, coastal, and wet, and is expected to become lower-lying and wetter with predicted future climate change and subsidence. The full list of all contaminated sites in the state has not yet been identified, and little-studied underground storage tanks may be the biggest potential problem.

Many legacy industrial sites are located along the coast and waterways. SLR may have direct impacts on the chemistry and mobility of some metals-contaminated sites, but those impacts will be based on site-specific conditions and will occur over time (Bross, 2013). Even in the most fast-paced SLR scenarios, the timeframe for inundation or impact may be significantly longer than that for the investigation and remediation schedules for many contaminated site projects.

Bross (2013) also assessed the influence of SLR on different classes of remediation sites. Remediation sites are classified according to the following scheme: "New sites" are currently unidentified, but expected to be found in the future. "Active sites" are currently undergoing active investigation and/or remediation. "Closed sites" are remediated to the point of closure. SLR can affect the remediation of metals-contaminated sites based on their status. New sites require broader risk considerations (Bross, 2013). One must consider their inundation potential and the possibility of a rise in the groundwater table, as well as their geochemical/biological properties. For example, is the groundwater fresh or saline? Is the soil aerobic or anaerobic? As a specific example, if agricultural lands or golf courses are inundated, accumulated fertilizer may be likely to mobilize. Although many would not perceive these to be contaminated sites, SLR introduces new risks and the contaminants could be significant.

Summary of Workshop Presentation on the Impact of Sea Level Rise on Metals Remediation Strategies by Jeff Bross (continued)

Bross (2013) argues that for active sites where removal is the treatment option, it is unlikely SLR would affect long-term remediation because removal should be complete before SLR occurs. However, when stabilization/immobilization is under way, long-term in situ remediation may be affected. Engineers must assess possible chemical and mobility changes with SLR. Where isolation is under way, long-term remediation requiring cover, cap, or subsurface barriers may be affected as engineers assess possible chemical and mobility changes with SLR. For a closed site, inundation by SLR is grounds for reopening if contaminants were not removed. Engineers need to assess whether the changing chemistry will affect mobility and whether barriers will still be effective. This may be one of the most significant, new impacts of SLR on contaminated sites.

Bross (2013) assessed how potential SLR inundation might alter site remediation. Remediation is done to different standards, depending on the targeted medium. Soil cleanup standards are largely based on human exposure. Sediment cleanup standards are largely based on exposure to aquatic life and indirectly on human ingestion. Water cleanup standards are based on direct (consumption) and indirect exposure.

To help conceptualize the challenges of joint risks, Bross (2013) offered two case studies to understand how remediation solutions may differ if SLR is considered in the remediation planning stages. Site A is contaminated with polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), and metals in soils. Site A has a human health risk, and the remediation methods are hot spot removal and covering with 2 feet of soil to reduce human exposure. If SLR inundates this site, the cover will likely erode, mobilizing the contaminants. With elevated groundwater, the risk of direct human contact with contaminants is reduced, but the exposure risk to aquatic life is increased. In this situation, engineers may decide to reassess site risk and may order: (1) diking or armoring to prevent erosion or inundation; (2) removal of the soil; or (3) that no action be taken. If SLR is recognized and addressed before applying a solution, the engineers would likely consider expanded risk scenarios. Engineers might opt for stabilization instead of a soil cover, for soil removal, or for the construction of a resistant cap.

For the second case study, Bross (2013) describes Site B, which has lead-impacted soils and which constitutes a human health risk. The remediation method is immobilization with phosphate. With SLR the stability of the metal could be compromised. Inundation or elevation of groundwater would reduce the risk of direct human contact, but it would increase the risk of exposure to aquatic life. In this situation, engineers would: (1) reassess risk; (2) evaluate the resistance of phosphate-treated soil; (3) consider diking or armoring to prevent inundation or erosion; or (4) consider removal of soil. If SLR is recognized and addressed before applying a solution, engineers would evaluate the effectiveness of the immobilization plan and/or consider removal of soil or construction of a resistant cap.

Bross' (2013) case studies demonstrate that effective and efficient long-term solutions to site remediation need to consider SLR. Only since about 2012 has this issue even occurred to engineers as something to consider. The risk assessment changes depending on the type of risk we consider (e.g., human vs. ecological). Some remedial technologies will be more effective than others for sites where SLR may be an issue. SLR can surely be a "reopener," and it is likely to drive expanded effort and cost in future site remediation work.

Ex situ solidification/stabilization (S/S) technology is used as the remedial action at 80% of sites contaminated with metals (Dermont et al., 2008). The S/S process aims to sequester the metals in the soil (Dermont et al., 2008). The main advantage of S/S technologies is their ability to treat a wide variety of soil types and metal forms (Dermont et al., 2008). The most frequently used established treatment technologies for contaminated soils are on- and off-site incineration, solidification/stabilization (S/S), soil vapor extraction (SVE), and thermal desorption (Dermont et al., 2008). Overall, metal-contaminated groundwater is treated aboveground through pump and treat (P&T) technologies. Groundwater treatment accounts for 50% of Superfund remedial actions (Bross, 2013).

Summary-Questions in Civil Engineering

The review of civil engineering perspectives on the joint risks of SLR and contaminated sites suggests how careful planning today can produce significant future gains. However, the quality of planning will depend on greater scientific understanding of the processes at work. Dermont et al. (2008, p. 188) writes, “Further research is needed to improve understanding of phytoremediation and in situ metal stabilization processes.” The long-term stability of the S/S matrix is unknown (Lemming et al., 2010). Further research is needed into bioremediation, the effects of temporary versus permanent inundation of a contaminated site, and the effects of seawater on metals and other contaminants.

Recognition of joint risks may trigger fundamental engineering research to identify and compare a fuller slate of mitigation strategies available for remediation of contaminated soils near tidal rivers, coastlines, and marshes. This research must also explore the environmental benefits and costs. In addition, these engineering solutions ought to be compared to the cost of doing nothing, especially abandonment or retreat.

Social Science and Economics

To a social scientist, contamination and SLR both constitute stochastic risks. Economists know that people attempt to adjust their behavior in response to risks but that this process of adjustment is fraught with challenges—such as the difficulty of comprehending low-probability risks—that interfere with optimal risk management. A key failure arises with the unknowns (or unknowability) of many contamination and SLR risks. Although people can conceptualize the risk of a carcinogen or toxic metal in their drinking water or a flooding risk, there is little information about when this risk might manifest, if ever. There is also little information about the severity of the impact. For instance, will the flood be severe or modest? Will chemical exposure lead to cancer or not?

The causal relationships associated with these risks are also difficult to understand. Contamination threats today probably occurred in the distant past with little hope of traceability or understanding how much contamination exists. SLR is the outcome of innumerable worldwide decisions. Individually, SLR and contamination pose some of the most difficult risks to manage. Their joint risks are even more challenging.

Policy is positioned to help. Risk management can be dealt with using insurance instruments. The challenge with insurance-type solutions is that without an incentive-based policy, it will be difficult to alter individual behavior—those exact behaviors that exacerbate the risks.

The sustainable use of land resources requires careful decision making about the reuse of contaminated sites. Economically, contamination increases the cost of using old industrial sites, which are often located near population centers, and thus reduces the relative cost of converting “greenfields” such as agricultural or forested lands. Truly sustainable land use must find the legacy of pollution costs built into the costs of the industrial products. This form of liability is implemented (albeit imperfectly) by CERCLA, or “Superfund.” Other important aspects of contaminated sites include the health impacts on nearby residents (especially in densely populated urban areas) and impacts on nearby property values.

Summary of Workshop Presentation on Adaptation, Sea-Level Rise, and Property Prices: A Case Study in the Chesapeake Bay Watershed
by Patrick Walsh (Based on joint work with Charles Griffiths, Dennis Guignet, and Heather Klemick)

Global mean sea level has climbed by an average of 3.1 mm/year since 1993. It is projected to increase another 0.18–0.59 meters by 2100. Population in U.S. coastal shoreline counties increased by 39% from 1970 to 2010. Thirty-nine percent of the U.S. population lived in coastal shoreline counties in 2010 (NOAA 2014a). Those counties will be on the frontlines of adaptation to higher sea levels in the next century.

Walsh et al. (2013) reports that, in the last 70 years, the level of the Chesapeake Bay rose a foot. This rate is double the average rate worldwide. NOAA predicts that this is what we should expect in the next century:

- SLR of 2–5 feet
- Increase in storm intensity and more destructive storm surges
- Decreased shellfish growth due to increased water acidification
- More variable precipitation and water salinities (+/- 10%)
- Increased plant and algae growth as a result of increased carbon dioxide
- Change in plant and animal ranges due to changes in temperature, salinity, and food distribution (e.g., rockfish, eelgrass)
- 3–10° F increase in water temperature

Walsh et al. (2013) leads a team from the EPA's National Center for Environmental Economics, which studied coastal property values in Anne Arundel County, Maryland, to determine whether SLR adaptation structures and SLR zones are capitalized into home prices. The county has more than 530 miles of shoreline on the main stem of the bay and on the Patuxent River. GIS analysis revealed two categories of properties at risk of inundation from SLR: (1) up to 2 feet; and (2) up to 5 feet (Table 2). Municipal data on the average and median assessed values were collected, as were data on shoreline features (land use, bank condition, shoreline structures).

Table 2: Properties at risk and assessment values.

	0–2 ft inundation	0–5 ft inundation
# of properties at risk	11,607	18,850
Average assessment value	$223,854	$202,018
Median assessment value	$143,027	$133,700
Total assessment value	$2,904,959,889	$4,135,714,067

Source: Walsh et al. (2013)

Walsh et al. (2013) analyzed 5,281 waterfront property sales occurring from 2003 to 2008, with a range of values of $30,000–$4,000,000. The hedonic analysis isolates the traditional factors that influence the sale price for a home from the impacts associated with SLR. These impacts include the presence of any SLR adaptation structure, type of SLR adaptation structure (four kinds, both offensive and defensive), and whether or not the property was in an SLR zone. They found that the presence of shoreline protection features increases property values. Groinfields—low-profile structures that sit perpendicular to the shore to trap sediment moving along shore and protect the shoreline behind the system—were not significant to property values.

There are also more complex ways in which these sites shape proximate economic opportunities. For instance, a brownfield has a direct environmental impact on neighbors, but it also indirectly shapes local economic opportunities by altering land prices and encouraging jobs to relocate to the suburban/rural boundary. The presence of a brownfield can lead to general neighborhood deterioration as lower property values result in lower tax revenue, leading to a decline in the quality of community services and amenities, such as schools and parks. Furthermore, falling property values may dissuade homeowners from maintaining and improving their homes, thereby causing a cycle of subsequent value loss in those neighborhoods. During the past 30 years, a great deal of scholarship has informed the science and policy of remediation, though actual remediation on the ground has proceeded more slowly.

The economics and policy literature offers data about the effects of contaminated sites on real estate values. Several studies have found mixed evidence on valuing contaminated property and estimating the impact of the contamination on market price (Schoenbaum, 2002; Thomas, 2002). The larger hedonic studies show that contaminated sites drive down prices of surrounding properties (Jackson, 2001; Ihlanfeldt and Taylor, 2004; Simons and Saginor, 2006; Kaufman and Cloutier, 2006; Messer et al., 2006). In addition, a number of empirical studies focus on factors influencing investment decisions in the redevelopment and remediation of contaminated properties (De Sousa, 2000; Howland, 2003; Wernstedt et al., 2006; Blackman et al., 2010). Most hedonic studies focus on Superfund sites. The influence of small-scale sites and effects on commercial and industrial neighbor values are understudied (Ihlanfeldt and Taylor, 2004; Jackson, 2001).

Walsh et al.'s (2007) research is one of the first studies to show how people's behavior in housing and land markets are beginning to reflect the potential risks of SLR. Adaptation structures appear to be incorporated into home prices, but the impact depends on location and structure. Protection from SLR raises issues of cost, social justice, and coordination among property owners as adaptation structures are considered.

Contamination Risk Processing[3]

Messer and his colleagues conducted several studies on how human behavior changes in light of risk, specifically at the nexus of contamination, stigma, and the role of information. Messer and colleagues measured people's willingness to accept risk of drinking a beverage contaminated with different levels of As. They found that how risk from As is communicated can significantly affect how people perceive this risk, thus influencing their behavior in subjecting themselves to exposure to this risk (Kerley et al., 2008). Providing people with information related to scientific standards, such as those used by the EPA, was effective at lowering these risk responses when compared to a situation in which no risk information was given or in which only scientific information related to cancer risk was provided. Multiple sources of risk information were the most effective means of reducing risk concerns in situations where the contamination levels were known.

Furthermore, other prior work suggests that subjective risk perceptions and stigma can prevent cleanup programs such as Superfund from delivering the expected economic benefits (Messer et al, 2006). People's behavioral response will likely depend on the exposure path to the risk—for example, drinking, touching, or proximity—and how the risks of this exposure are conveyed,

[3] This subsection is an expanded version of the workshop presentation by Messer (2013).

such as through acceptable threshold levels (as is currently done), through more detailed risk information, or both. The policy implications of this research may include a different prioritization of sites for remediation because the sites with the most cost-effective "objective" benefits and costs might be different from those recommended by accounting for both objective and "perceived" risks. Finally, this work warrants economic lab and field experiments to measure and explain variability in remediation benefits by treatments such as time but also engineering solutions. In effect, time and engineering solutions become treatments to test utility-accrual processes in the experimental economics laboratory. These laboratory experiments can also be connected to issues related to ethics, as the risks from SLR and contamination will not likely be equally distributed throughout society. Likewise, if public funds are used, then the distribution of the tax costs associated with these programs will likely not be equal (see Messer et al., 2010; Messer et al., 2013; and Keisner et al., 2013 for examples and discussion of ethics and social preference in the context of risk and experimental economics).

Nonmarket Valuation and Optimal Policy Design[4]

One objective of this exploratory work was to develop hypotheses about the public's value for changes in risk and behavioral response to risk. Public values for changes in risk are measurable using economic choice experiments, which can provide considerable insight. Choice experiments are experimentally designed survey techniques in which the economic benefits of each facet of an environmental improvement given different information sets can be isolated using mixed logit regression analysis (Duke and Johnston, 2010; Johnston and Duke, 2007). For instance, exploratory research may identify a set of engineering solutions to mitigate contamination risk (each implementable at varying levels or intensities), as well as status quo alternatives (doing nothing), averting options (self-protection solutions, such as buying bottled water), and abandonment options (such as relocation). Choice experiments allow researchers to calculate the value of the public's received benefits of the environmental changes associated with each option as a function of the intensity with which it is pursued. Mixed logit allows one to estimate any heterogeneity in the population's preferences. The hypotheses developed are statistical tests of whether these attributes of risk processing produce benefits that are different from zero. This results in a series of benefit measures that can be compared to engineering cost measures and the costs of doing nothing, averting, and relocating. Then, a cost-effectiveness analysis shows what the optimal solution(s) is(are) for any given remediation standard. This is important because it shows that the economics of contaminated site cleanup are not simple.

[4] This subsection arises from the research of Duke.

Summary of Workshop Presentation on Working on Sensitive Issues with Communities by Susan Love

Love (2013) argues that selecting an appropriate adaptation strategy for a resource or a geographic area does not happen in a vacuum, but instead involves communities that should be incorporated into the planning and implementation process. Problems such as joint risk of SLR and contamination are multidisciplinary, and there are numerous barriers to taking immediate action. These barriers include lack of adequate data, policy issues, funding, fear, or lack of willingness to act.

Moreover, Love argues that adaptation is an iterative process that may change over time in response to changing conditions. Delaware's Sea-Level Rise Advisory Committee made the following recommendations, among others:

- Science: Recommend research into timing and extent of inundation from SLR and storms, saltwater intrusion into ground and surface waters, and combined modeling of storm surges and increased rainfall.
- Policy: Recommend regulatory changes and governmental coordination based on emerging information.
- Funding: Recognize need to get more funding through a variety of means.
- Contaminants: Focus on their importance to specific sites, which include about half of the 60,000 acres potentially inundated. The committee's work showed that about 40% of 785 contaminated site in Delaware may be inundated.
- Social science: Recommend a broad strategy of education and outreach, public participation, equity, and local empowerment, as well as studies to increase understanding of risk perception and barriers to action.

People and communities need to be empowered to make their own decisions at a local scale. Policy makers need to accommodate considerations for social justice in many communities. Policy makers will benefit from sociological and other research that provides insight about what it takes to make communities and people want to act and where thresholds for action may be found.

Specifically, Love (2013) argues that support from local communities will arise from recognition of a common problem, open dialogue and education about risks and pros and cons of taking action, trust amongst all parties, and time. Community buy-in is uncertain. People are the most important component of the adaptation solutions. In a perfect world, policy makers may have the best data in the world on contaminant fate and effects, the best inundation model, and the best policy solution, but they will also need the affected community to accept the solution. The affected community will not necessarily trust "subject matter experts," especially if the affected community has been harmed in the past. The affected community may not believe there is an issue or may believe that the solution may be worse than inaction. Policy makers may encounter resistance, and no adaptation or "maladaptation" will occur. Love (2013) defines maladaptation as an action taken that results in increased vulnerability over time for various reasons.

In the case of SLR risk, Love (2013) argues that obstacles to taking action will likely include concerns about effects on housing prices. If a retreat strategy is pursued, housing prices will fall, but public efforts to protect properties will increase prices and risk gentrification. Another obstacle would be the potential for changing the community character. Quality of life and health impacts would also be expected. Finally, it is easy to overlook other problems when thinking about "solving" SLR risks for a community. The community may see SLR as important, but far less important than other challenges such as crime and education. Public efforts on SLR may therefore be resisted as being lower priority.

Love (2013) argues that even getting a community to admit there is a problem can be challenging. In Delaware, some people have protested that the Sea-Level Rise Advisory Committee's SLR maps would affect home values and should not have been released. Frequent bad-news stories may unintentionally stigmatize a community, which may be difficult to overcome, regardless of policy solutions. In other words, those who strive to help must carefully consider the unintended consequences of drawing attention to problems in communities. Policy makers also have obligations to avoid wasting time and effort from community leaders and to avoid unduly raising anxiety levels. Love (2013) argues policy makers should ensure that the proposed solutions truly provide a tangible outcome and are based on trust by receiving permission before acting, keeping promises, and over-delivering rather than over-promising. Indeed, although researchers may be excited by new opportunities to study and solve problems, it is important for policy makers and researchers to understand that when research intersects with communities, it affects those communities. Love (2013) concludes her policy-maker perspective by noting that researchers and policy makers have a responsibility to the citizens and communities of Delaware not to misrepresent or exaggerate a potential problem to gain publicity, funding, or partnerships. This requires reflection about one's intent, wording, and messaging. This risk is particularly problematic when we are dealing with already-struggling communities.

Summary-Questions in Social Science and Economics

Improving scientific knowledge on the risks of SLR and contaminated sites is essential. The review of select social science results in the mid-Atlantic region shows that risks permeate behavior and market decisions, but also the potential policy solutions. This suggests that a broad view on risks—i.e., studying multiple risks simultaneously—may be most appropriate. Social science research, however, largely focuses on assessing one risk at a time. Integrating future studies will be essential to creating an optimal planning approach to the joint risks of SLR and contaminated sites.

Another complication is that risk processing is dynamic in the sense that it evolves over time. For instance, that market participants understand risk is the key assumption in hedonic studies, which measure how risk deflates property values. If these risks are unknown, then hedonic studies may be incompletely informative. If knowledge about risks abruptly changes because of new science, then market prices will also abruptly change. The current market can separately reflect the stigma created by contaminated sites and SLR. However, it probably does not reflect the joint risks because these are largely unknown. Although expectations are being formed, they will likely change dramatically in the future.

The review of social science approaches to joint risks raises many questions that merit research. Studies should focus on measuring the public value for the various environmental and risk-reduction benefits associated with different adaptation and mitigation strategies. These strategies can be operationalized in terms of the aforementioned engineering approaches. Research should examine both the processes and outcomes of these approaches. In particular, this research ought to seek a functional relationship between the level of risk reduction (or reduction in uncertainty) and received benefits. Another productive approach involves characterizing spatial and socioeconomic patterns in benefit estimates. Choice experiments are the valuation technique well positioned to answer these types of questions. However, in situations where the public not only does not understand the risks faced but has difficulty processing these risks, experimental economic techniques are well positioned to value risks. Experimental economics is also best positioned to study behavioral changes in light of changing risks and for test-bedding new policy approaches. Hedonic analysis is well suited to derive the processing of risk in capital markets. Future studies will productively examine the risks of SLR and contaminated sites in tandem, as studies heretofore examine these risks in isolation.

Economically efficient policy responses can be formulated by comparing these derived benefit measures and the engineering costs. In other words, cost-effectiveness analysis shows what would be the optimal solution over the various remediation approaches and performance standards.

As this section clarifies, the economically efficient solution, which assumes away most implementation challenges, should also be compared to the acceptable solution in a community. Policy implementation is not simple, and the costs of doing it right raise the relative acceptability of maintaining the status quo. Although the implementation cautions are important to recognize, it is also important to balance the risk of inaction. Researchers must be cognizant that if they self-censor their research topics so as to protect communities, important policy topics will not be studied. Researchers should seek to vigorously discuss these risks, but should carefully consider the forums in which the debates occur. The debate and risks messaging should be more carefully communicated when outside academic circles so as to protect communities against inadvertent stigmatization.

Research Questions, Hypotheses, and Synthesis

This research began with the overarching research question: How will water sustainability needs and anticipated SLR affect the economic opportunities, ecosystems, and quality of life in the coming decades for populations in the coastal zone of the Mid-Atlantic region? An exploratory research team, with the help of workshop participants, has explored various facets of this question, seeking to identify significant hypotheses, approaches to creating new knowledge, and linkages among the various disciplinary approaches.

Scientific Questions

The first set of scientific questions identified by the research team focused on: (a) defining the scope of the problem of joint risks; and (b) framing the problem in a manner that allowed for integrated research. Four groups of key questions were collected in preliminary research. (* indicates questions posed to the workshop participants.)

Surface and Ground Water Impacts of SLR

1. How will SLR affect developed, undeveloped, and agricultural land in the mid-Atlantic region?*
2. What are the dominant mechanisms and time scales of salinization and flushing of soils and groundwater due to storm surges and SLR?*
3. What hydrogeologic factors most affect salinization and freshening of coastal water?*
4. How will rising sea level affect contaminated soils located near tidal rivers and coastlines?
5. What will be the effect on marshes, including the implications of widespread marsh decline that reduces natural contaminant buffering?
6. What will be the human and policy response to these changes, and what new water management challenges will emerge?

The Science of Contamination and Engineering Solutions

7. How are metals transported within and from urban-legacy contaminated sites?*
8. What is the fate of these metals?*
9. What contaminants are most important to study?*
10. What are the best methods for modeling the risks associated with these processes, especially with respect to site and contaminant characteristics?*
11. What technologies are available to resolve or adapt to previously immobile contaminants?*
12. How will the resulting site quality vary with available technologies?*
13. How much do these technologies cost, and how do they vary with quality outcomes?*
14. How much precision is available to quantify the quality expectations of doing nothing?*

15. What mitigation strategies are available for remediation of contaminated soils near tidal rivers, coastlines, and marshes?
16. From an engineering perspective, what solutions are available and what are the various environmental quality outcomes, coupled with associated costs?
17. How does this compare to the cost of doing nothing?

Risk Processing, Behavior, and Property Market Impacts

18. How does SLR affect household-level risk perception, behavior, and property values?*
19. How do contaminated sites and stigma affect household-level risk perception, behavior, and property values?*
20. Are there likely synergies in the risks that cause risk perception or property impacts below or above the additive levels?*
21. How does one best study how people trade off adaptation alternatives?*
22. How might socioeconomic status affect behavior, and how should studies be framed to assess preferences at different status levels?*
23. What value does the public have for different environmental benefits of mitigation technologies?
24. How does risk (the uncertainty of outcomes) affect received benefits?
25. How do these benefits vary spatially and across different socioeconomic groups? How can an economic choice experiment be designed to value the public's received benefits of the environmental changes associated with each engineering solution?
26. How does the benefit measure compare to the engineering cost measure?
27. How might a cost-effectiveness analysis show what would be the optimal solution given various remediation standards?

Policy Options and Synthetic, Integrated Hypotheses

28. What are the available policies related to SLR and contamination sites?*
29. What is known about at-risk populations and joint risks?*
30. How can governance systems be made more resilient to meet the needs of conflicting constituencies?*
31. How can the key environmental justice issues be best articulated and operationalized for integrated research?*
32. What are key knowledge gaps from the perspective of policy makers?*
33. How can hypotheses about the joint risks best be integrated?*
34. How can feedback pathways be built into research studies on these joint risks?*
35. What are the likely pitfalls and challenges to designing an integrated research project on joint risks?*
36. How are these behavioral and policy responses, in turn, likely to affect natural systems through feedback processes?
37. Will population densities change in the face of risks and benefits?
38. How can risk behavior be measured in the experimental economics laboratory?
39. What are the implications for built water systems?
40. How can governance systems be made more resilient, to meet diverse and often conflicting needs?

These four sets of scientific questions formed the basis of the workshop structure. The workshop participants offered disciplinary-based perspectives on these questions and then the discussion sought to react to and refine the questions. In addition, the research team sought to create hypotheses and an integrated research plan with which to examine the hypotheses.

Workshop Synthesis: What Do We Know and What Should We Study?

The workshop participants shared research results and perspectives from multiple disciplines. In general, these reactions were in terms of the research questions listed above. This section presents a synthesis of these discussions. The workshop discussion produced general agreement that, in coastal areas, the entire context of contaminated site definition, remediation, and policy will likely need to adjust to account for SLR risk. Specifically, how will contaminated sites be defined in light of SLR risk? New definitions and approaches may require new ranking criteria. Science will need to determine what contaminants are detrimentally affected by SLR, and to what extent. There is a need for much more evidence about the potential human and ecological impacts of these exposures.

Workshop participants suggested that initial research on joint risks ought to start in other U.S. states, such as Texas, New York, and Louisiana, which are likely to have experience with inundation of Superfund sites. Research questions identified for studies in these locations include: (1) Are some metabolites less harmful in oxidized conditions? (2) Are some metabolites less harmful under reduced conditions? (3) How does salinity complicate the analysis? and (4) Does bioavailability change with inundation?

Workshop participants also made specific suggestions about studying joint risks in Delaware, including recommendations about study sites. At a basic level, research is needed to determine the most problematic contaminants in Delaware. An interesting approach was suggested for collecting data on mobilization without having to replicate the potentially slow-moving process of transport. Instead, can transport processes be determined by looking at historic land use and marsh cores? Sites in Delaware were identified (such as Churchman's Marsh) and a set of pollutants was suggested: As, Pb, Cr, Hg, PCBs, and polycyclic aromatic hydrocarbons (PAHs). Combining observations with historical data on SLR and water salinity may yield insights.

A similar approach could be used for studying legacy As from poultry operations. Phosphate tends to be high in poultry farm soils. What is the influence of high phosphate on As mobility and toxicity? It was suggested that the many shallow drinking water wells in the poultry production areas of the state could be used for historical monitoring data.

Another suggested study site was the Southbridge area of Wilmington, Delaware. The area has sites with legacy pollution and frequent flooding. Moreover, the state of Delaware has been active in remediation in Southbridge. Workshop participants suggested that constructed wetlands or marshes could be used as study sites for hydrologic and chemical response, and this could be coupled with existing regulatory, governance, and community data. This is a living laboratory in the Wilmington area. Such a study would also allow for examination of social and policy questions, such as how do you most effectively bring information to the community?

Some workshop participants made observations from their various scientific and policy perspectives, which further rationalized the importance of this work. For instance, SLR risk changes the current remediation standards for contaminated sites. Cycling and redistribution of contaminants can affect project outcomes by negating positive effects. In addition, closed sites may have to be reopened in the future if SLR causes changes that increase risk. Participants argued that underground storage tanks have not received sufficient research and policy attention, and these may be the source of many problems in light of SLR because, with flooding, pipes can break and tanks can come to the surface. Similarly, participants recommended that increased attention be given to chemical storage areas, which are not currently regulated. If extreme events occur, these areas could be potential new sources and could create new Superfund sites. An example of this occurred on January 9, 2014, when crude 4-methylcyclohexanemethanol was released into the Elk River in West Virginia upstream of a main water intake.[5] The spill left approximately 300,000 residents without drinking water for at least four days.

One concern involves marshes. Although marshes are currently contaminant sinks, inundation of marshes could make them sources of contaminants. This suggests that policy may be used to protect marshes, not on the basis of current objectives such as pollutant sinks, flood buffering, and habitat, but instead to prevent marshes from becoming nonpoint sources of contaminants.

The workshop participants discussed integrated research approaches. They concluded that coupled modeling was needed. Coupled modeling is currently conducted in many integrated NSF research projects, especially with climate, groundwater, surface water, and agronomic models. It will be challenging to couple hydrologic and economic models at a sufficiently broad scale. Many economic-hydrologic coupled models involve micro-level behavior, so they do not control simultaneously for decisions on many dimensions, all of which might affect the production and reception of the joint risks. A further step in model coupling involves human health effects. Workshop participants recommended examining EPA's Epidemiology-RAGS-Superfund risk model (http://www.epa.gov/oswer/riskassessment/ragsa/).

Workshop participants suggested questions that policy makers should begin to debate. For example, joint risks are clearly a major threat that could consume a considerable share of future budgets. In light of this, how much should be spent in the present to study and solve the joint-risk problem? One strategy with a low budgetary cost is to end current policies that (A) cost money and (B) incentivize human activities that are detrimental. Workshop participants did not identify specific policies, but some popular press publications have suggested that subsidized flood insurance lowers the cost of building and owning housing in flood-prone areas.

Workshop participants also shared knowledge about what data in Delaware are currently available. The DNREC Site Investigation and Restoration Section has measured ecological risk and proximity to surface water for 800 sites with statuses ranging from new to closed. These data are in paper format. DNREC also has data on migration of PCBs from land and rivers to marshes. The data that determine state fish advisories are also available and include high resolution data with water, sediment, fish, and osprey bio data (2007). In addition, there is a recent Whole Basin Approach (previous DNREC initiative) updating toxic pollution. Monitoring data from Indian River groundwater, surface water, sediment, and fish tissue data indicated As is not routinely above limits. Finally, there is a draft report from 2013 on Metachem Hg methylation.

[5] http://en.wikipedia.org/wiki/2014_Elk_River_chemical_spill

Conclusions and Recommendations for Synthetic Research Study

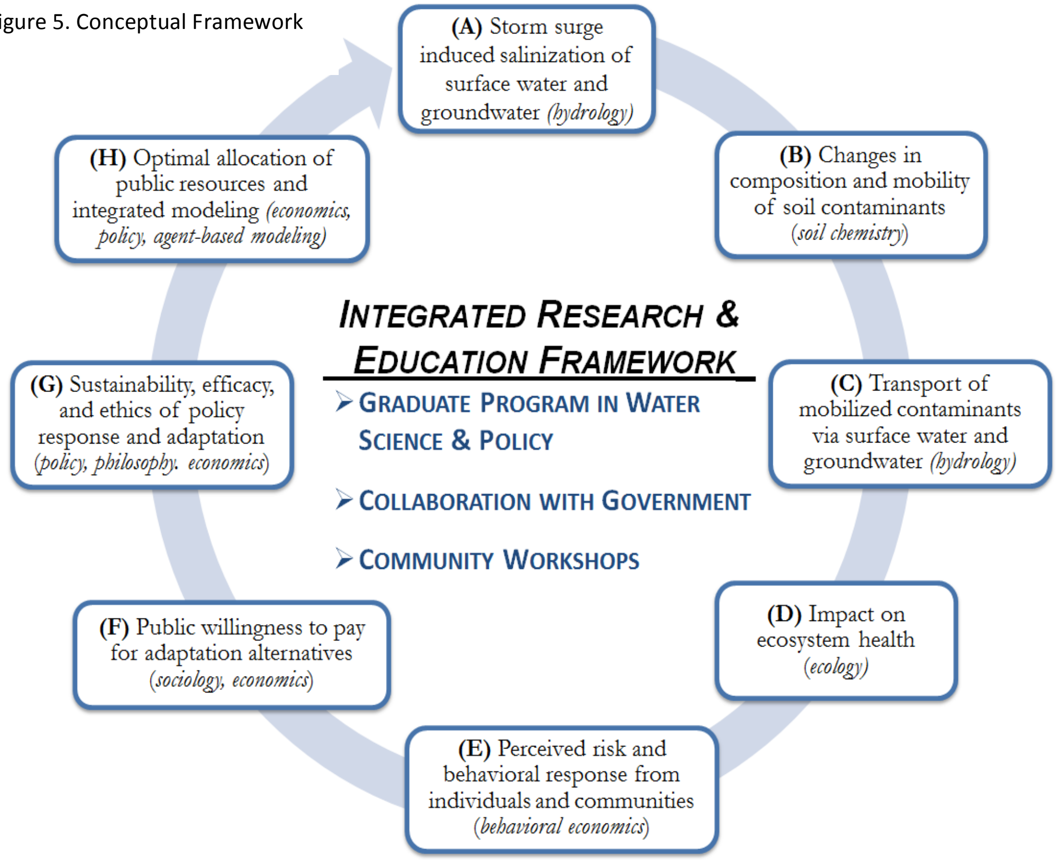
The research team concludes that the joint risks of SLR and contaminated sites pose a new set of risks for the health and well-being of residents and the economic activity in vulnerable areas. This is because seawater-related changes in hydrology and chemistry in contaminated soils may cause widespread release of currently immobilized constituents. Of particular concern are mobility and transport of heavy metal(loids) such as As, Cr, Cu, Ni, and Zn. Although scientific evidence exists, the problem of joint risks is poorly understood, has not affected policy design, and will likely increase in the future. Current policy action may avoid very high future costs.

Proposed Approach 1: An Integrated Study of the Effect of Storm Surges and Anticipated Sea-Level Rise on Contaminated Site Risk in Coastal Communities

The research team derived a model (Figure 5) to represent what is needed for an integrated research study of joint risks, which was submitted in 2013 as a proposal titled, "An Integrated Study of the Effect of Storm Surges and Anticipated Sea-Level Rise on Contaminated Site Risk in Coastal Communities." As shown in Figure 5, the proposed integrated research and education framework will examine the feedbacks between human and natural systems. The proposed research is more than just a set of studies related to the same topic, but instead the studies are linked to each other through multiple interactions. Thus, the results of each of the eight research themes will inform the other project themes. This proposed research is also innovative in that it is closely integrated and coordinated with the state of Delaware's efforts to deal with storm surges, SLR, and contaminated sites. Following the framework of Figure 5, the specific research questions for each theme are as follows:

A. What are the dominant mechanisms and time scales of salinization of soils and groundwater due to storm surges and SLR?
B. What is the impact of storm surges and resulting flooding on the cycling, mobility, and speciation of As and Cr in contaminated soils?
C. How are metals transported from contaminated sites and what is the fate of these metals?
D. What are the effects of these newly mobilized toxins on tidal marshes and wetlands?
E. How do these toxins affect the risk perception and behavior of individuals and communities?
F. How do the risks affect people's quality of life? How do people trade off adaptation alternatives? How are the risks perceived by households likely to affect property values? How does the public's willingness to pay to adapt vary in terms of geographic location and social circumstances?
G. How should policy responses to contamination issues resulting from storm surge and SLR be structured to be socially just?
H. What is the optimal allocation of limited public resources to various adaptation alternatives? What are the various benefits and costs associated with predictive outcomes based on integrated, complexity-science models that incorporate key results from all themes?

Figure 5. Conceptual Framework



Source: NSF Grant Proposal, Coastal SEES (Track 2): An Integrated Study of the Effect of Storm Surges and Anticipated Sea Level Rise on Contaminated Site Risk in Coastal Communities. Messer (PI), Sparks, Michael, Duke, Kirby (Co-PI)

Proposed Approach 2: Socioeconomic Research on Public Preferences for Contaminant Adaptation and the Optimal Allocation of Public Resources

One of the most significant impacts of contaminated sites and mobilization centers on how people process risk. Do people understand the associated risks? How do the risks affect the quality of their lives? How do the risks impact property values? How is health affected? How do received risks vary in terms of location, socioeconomic status, etc.? These questions will be investigated using an economic research method: the choice experiment.

Although some of the impacts result in monetary costs affecting people's lives (such as property values and health care costs), a considerable amount of the impacts affect received costs indirectly or fall entirely beyond the boundary of the pricing system. For instance, indirect evidence from hedonic research shows that contamination is a disamenity that reduces neighboring property values. However, impacts on wildlife or poorly understood risks affect the quality of people's lives, but they are almost completely censored in market data. Even more significant, market behavior cannot be used to infer how a heretofore-unimplemented adaptation or mitigation policy will affect people's welfare. For these reasons, a direct valuation technique must be used to measure economic impacts.

Choice experiments are the state-of-the-art public survey technique to measure welfare impacts associated with nonuse values or untested policies. The economic benefits of each facet of an environmental improvement (or degradation) can be isolated using mixed logit regression analysis. As sketched above, this exploratory research may identify a set of engineering solutions to mitigate contamination risk (each implementable at varying levels or intensities), as well as status quo alternatives (doing nothing), averting options (self-protection solutions such as buying bottled water), and abandonment options (such as relocation).

The research proposed will design the choice experiment in three steps. First, working with the scientists on the team, the social science researchers must develop a set of (1) understandable impacts from contaminated sites and mobilization; and (2) potential solutions to adapt or mitigate these issues. Second, a set of focus groups in the targeted regions will be conducted to investigate how people process these risks and the language they use to describe the impacts. The team proposes to study various communities, including one in a low-income urban area (also low-lying with legacy contamination), a more rural area with natural, agricultural, and residential land uses (also low-lying with and without legacy contamination), and a moderate-high income area (also not low-lying and without legacy contamination).

The outcomes of the focus groups then affect the third step, which is to construct the attributes and levels. Although the three-step research process will identify the final set of attributes, the research team proposes a sample draft of attributes with some possible levels:

1. Soil contamination (varying from zero risk to high risk, expressed in ppm)
2. Policy label (contaminated, legacy, brownfield, and Superfund)
3. Policy options on adaptation (abandonment through buyouts, abandonment with full relocation costs, soil replacement)
4. Policy options on adaptation
5. Water quality measures
6. Policy options for surge protection
7. Proximity to site
8. Visual cues instead of scientific contamination measures ("When it rains, the runoff is yellow")
9. Health impact information measures

Proposed Approach 3: Integrated Hypothesis on Adaptation to Joint Risks with Land Use Change

The best science should affect the policy created. However, this section proposes an innovative investigation (posed by authors Duke and Michael) of how a seemingly optimal policy can lead to a perverse outcome, if feedback effects are not considered. Specifically, SLR and contaminated sites policy responses are likely to alter natural system functionality, but this functionality will in turn likely be affected by human response to the new environment through feedback processes.

The current land use choices of residents and businesses reflect perceptions and risk processing of the status quo. This status quo, as the research report has shown, poorly recognizes the joint risks of SLR and contaminated sites, though the status quo decisions likely have better risk processing of the independent risks of SLR and contaminated sites. As joint risks become more well known, one expects land use decisions to begin to shift so that land prices will fall in areas with greater joint risk.

If public policies are implemented to address these risks (for example, as more funding becomes available for remediation and protection against SLR), the land use decisions made by the public will change from the status quo. Specifically, people will need to pursue fewer averting expenditures, as the joint-risk policies offer greater public protection. Most importantly for this proposed research, the private and public decisions about abandonment will change from the status quo. Because recognition of joint risks will increase aggregate risk, one hypothesizes that more public and private decisions will favor the abandonment and retreat from contaminated sites.

At a broader scale, consider that widespread changes in hydrology and chemistry surrounding contaminated soils from industrial sites may cause widespread release of currently immobilized constituents. Public response to the released toxic material will force coastal population retreat inland from the coastal area. How will population migrations change the coastal ecosystem, such as coastal marshes and fish? How is general SLR influenced by alteration in the coastal ecosystem due to coastal land use change?

The economic hypothesis of abandonment, which arose from scientific hypotheses on contamination, will then potentially feed back upon the chemistry of the contaminated soils surrounding abandoned sites. This may lead to a potential perverse incentive from policy. If SLR is seen to be so severe as to warrant abandonment, then some urban contaminated sites might be more likely to be affected by SLR than if they were not abandoned. This accelerated SLR impact will further drive the contaminated site mobility. Land use change (private through averting efforts and public initiatives) can actually exacerbate the problem relative to a status quo of no formal action. An integrated research project would examine the impact on contaminant mobilization of abandonment *relative* to options such as armoring. This in turn could lead to policy that does not promote abandonment, but instead emphasizes remediation.

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Appendix 1: Workshop Program

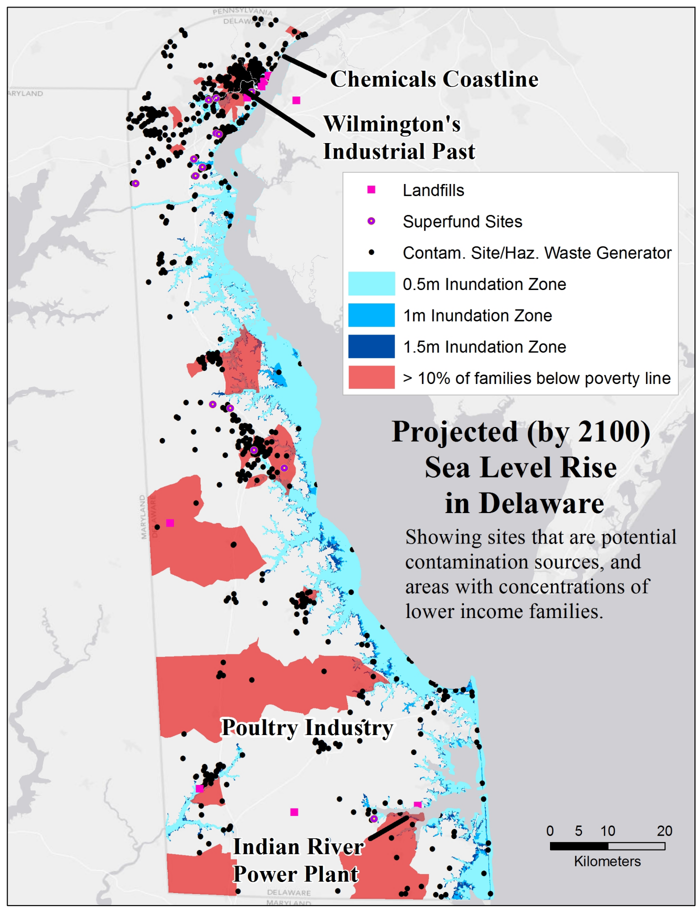
Workshop on Sea Level Rise and Contaminated Sites

November 22, 2013
8:00 a.m. to 5:00 p.m.
(Mini-continental breakfast starting at 7:30 a.m.)
102 DBI (Delaware Biotechnology Institute)
15 Innovation Way • Newark, DE 19711
University of Delaware

A National Science Foundation sponsored workshop that seeks to understand the joint risks posed by sea level rise and contaminated sites. The workshop will assemble a set of prominent and topically diverse scholars, policy makers, and other experts to accomplish two goals:

Goal 1: To share interdisciplinary knowledge and learn about approaches to studying these joint risks.

Goal 2: To set a research agenda by evaluating integrated hypotheses and framing scientific problems.



Sponsored by the National Science Foundation Award Number 1204672, "Water Sustainability in Coastal Environments: Exploratory Research for an Integrated Study of the Effect of Anticipated Sea Level Rise on Contaminated Site Risk." Duke (PI), Messer (co-PI), Michael (co-PI), Sparks (co-PI), Jeanette Miller, Amy Slocum, Jenny Egan

See http://sites.udel.edu/wsc/
Map created by Andrew Homsey

Registration and Mini-Continental Breakfast (7:30 a.m. – 8:00 a.m.)
Delaware Biotechnology Institute, room 102

Welcome

8:00 – 8:05	Don Sparks, Director of Delaware Environmental Institute & S. Hallock du Pont Chair in Soil and Environmental Chemistry, University of Delaware *Welcoming Remarks*

The Joint Problem of Sea Level Rise and Contaminated Sites: An Introduction

8:05 – 8:15	Josh Duke, Professor of Applied Economics and Statistics, University of Delaware, and PI of the NSF workshop grant *Introduction to the Problem & Objectives of the Workshop*

Keynote Speaker I

8:15 – 8:50	Joel Eisen, Professor of Law and Austin Owen Research Fellow, University of Richmond School of Law *Stigmatized Sites and Urban Brownfield Redevelopment: Legal, Economic, and Policy Issues*

Working Session I
Surface and Ground Water Impacts of Sea Level Rise

Holly Michael, Moderator

Questions driving this session: How will SLR affect developed, undeveloped, and agricultural land in the mid-Atlantic region? What are the dominant mechanisms and timescales of salinization of soils and groundwater due to storm surges and SLR? What hydrogeologic factors most affect salinization and freshening of coastal water?

8:50 – 9:05	James Kirby, Edward C. Davis Professor of Civil and Environmental Engineering, University of Delaware *Understanding of Processes of Surface Water Dynamics Causing Storm Surge Flooding*
9:05 – 9:20	Adam Langley, Assistant Professor of Biology, Villanova University *How Sea Level Rise Affects Tidal Marshes and Wetlands*
9:20 – 9:35	Holly Michael, Unidel Fraser Russell Chair for the Environment and Assistant Professor of Geological Sciences, University of Delaware *Understanding of Processes of Groundwater Flow and Salt Transport in the Subsurface*
9:35 – 9:55	Group discussion and clarification questions

Break (9:55 - 10:10)

Working Session II
The Science of Contamination and Engineering Solutions

Don Sparks, Moderator

Questions driving this session: How are metals transported within and from urban-legacy contaminated sites? What is the fate of these metals? What contaminants are most important to study? What are the best methods for modeling the risks associated with these processes, especially with respect to site and contaminant characteristics? What technologies are available to resolve or adapt to previously immobile contaminants? How will the resulting site quality vary with available technologies? How much do these technologies cost, and how do they vary with quality outcomes? How much precision is available to quantify the quality expectations of doing nothing?

10:10 – 10:25	Don Sparks, Director of Delaware Environmental Institute & S. Hallock du Pont Chair in Soil and Environmental Chemistry, University of Delaware *Assessment of Metal Cycling and Speciation in Delaware Contaminated Soils*
10:25 – 10:40	Jeff Bross, Chairman, Duffield Associates Inc. *The Impact of Sea Level Rise on Metals Remediation Strategies*
10:40 – 11:00	Group discussion and clarification questions

Working Session III
Risk Processing, Behavior, and Property Market Impacts

Kent Messer, Moderator

Questions driving this session: How does SLR affect household-level risk perception, behavior, and property values? How do contaminated sites and stigma affect household-level risk perception, behavior, and property values? Are there likely synergies in the risks that cause risk perception or property impacts below or above the additive levels? How does one best study how people trade-off adaptation alternatives? How might socio-economic status affect behavior and how should studies be framed to assess preferences at different status levels?

11:00 – 11:15	Patrick Walsh, U.S. Environmental Protection Agency *Adaptation, Sea Level Rise, and Property Prices in the Chesapeake Bay Watershed*
11:15 – 11:30	Kent Messer, Unidel Howard Cosgrove Chair for the Environment and Associate Professor of Applied Economics and Statistics, University of Delaware *Investigations of the Behavioral Response to Contamination Risk*
11:30 – 11:50	Group discussion and clarification questions

Keynote Speaker II and Lunch (11:50 – 1:20)

12:30 – 1:20	Marian Young, President, Brightfields, Inc. *Historical Issues of Contamination in Delaware*

Working Session IV
Policy Options and Synthetic, Integrated Hypotheses

Josh Duke, Moderator

Questions driving this session: What are the available policies related to SLR and contamination sites? What is known about at-risk populations and joint risks? How can governance systems be made more resilient to meet the needs of conflicting constituencies? How can the key environmental justice issues be best articulated and operationalized for integrated research? What are key knowledge gaps from the perspective of policy makers? How can hypotheses about the joint risks best be integrated? How can feedback pathways be built into research studies on these joint risks? What are the likely pitfalls and challenges to designing an integrated research project on joint risks?

1:30 – 1:50	Susan Love, Director of the Sea Level Rise Advisory committee for the Delaware Department of Natural Resources and Environmental Control *Preparing for Sea Level Rise: Development of an Adaptation Strategy for Delaware and the Social Dimensions of Risk*
1:50 – 2:10	Group discussion and clarification questions
2:10 – 3:15	Breakout Sections by Discipline 1. Water/Hydrology Group: Josh Duke and Holly Michael, moderators 2. Contaminants Group: Kent Messer and Don Sparks, moderators

Coffee Break (3:15 - 3:30)

3:30 – 5:00	Group discussion of integrated hypotheses and report out of breakout sections; Josh Duke, moderator

Conclusion (5:00)

Workshop by invitation, 40 participants, program has 11 speakers

Workshop Synopsis: An exploratory-research team at the University of Delaware will hold an NSF-sponsored water sustainability climate (WSC) workshop on November 22, 2013, at the Delaware Biotechnology Institute. State agency policy makers, university researchers, and other experts will gather to discuss how water sustainability needs are impacted by the joint impacts of contaminated sites and anticipated sea level rise. An overview of the available scientific evidence from hydrology, biogeochemistry, civil engineering, economics, social science, and policy response to the risk will be presented. The workshop results focus on the discussion of a set of hypotheses that will enable understanding the joint risk, which could help further develop optimal adaptation strategies.

Grant Abstract: WSC Category 1 Water Sustainability in Coastal Environments: Exploratory Research for an Integrated Study of the Effect of Anticipated Sea Level Rise on Contaminated Site Risk
This research seeks to understand the chemistry and hydrology of contaminant transport within the context of anticipated sea level rise, the engineering solutions available, and the way humans process the risks. The projected interaction of sea level rise and contaminated sites is a poorly understood problem, but a significant one, positioned at the interface of natural science and social science. The scientific problem is complex, given factors such as the chemical effects of salinity, pH, redox, the physical effects of changes in hydraulic gradients, rising water tables, marsh drowning, new areas inundated by storm surges, and the risk that currently-immobilized constituents may be released. Economic choice experiments and laboratory experiments provide a way to incorporate this complexity and to understand how humans may respond.

An exploratory team at the University of Delaware is investigating how water sustainability needs are impacted by the joint impacts of contaminated sites and anticipated sea level rise. Concerns about climate change and sea level rise extend beyond traditional issues of human adaptation, such as reinforcing buildings and roads, building water barriers, health impacts of climate change, changing agricultural land use, and insurance issues. Alterations in hydrology and chemistry of contaminated soils in urban areas, industrial sites, and waste disposal sites, as the result of sea level rise, could enhance the release and mobility of contaminants, threatening drinking water supplies and food sources. The project analyzes how the joint risk of sea level rise and contamination may affect the economic opportunities, ecosystems, water quality, and quality of life in the coming decades for coastal zone populations. The research ultimately seeks to compare the benefits and costs of different remediation alternatives, resulting in direct policy advice. The policy implications of this research may include a different prioritization of technological solutions for remediation, including options for abandonment, containment, and human adaptation. This advice depends on the human processing of perceived risks, and the distributional patterns of received benefits and costs across different populations. Understanding how the public responds to risk, including research on responses when the risk is communicated in different ways, will provide insights toward improving risk management.

Key Personnel: Josh Duke (PI), Don Sparks (co-PI), Holly Michael (co-PI), Kent Messer (co-PI), Jeannette Miller, Amy Slocum

Appendix 2: Survey on Resident Perceptions by Co-PI Messer and His Colleagues

Co-PI Messer extended the WSC project by surveying residents of Southbridge, Delaware, a low-income minority community at the confluence of the challenges of both sea level rise and legacy industrial contamination. Co-PI Messer worked in Walker Jones, a graduate student in the Department of Applied Economics and Statistics, and Dr. Victor Perez, an Assistant Professor in Sociology to develop and administer a survey of Southbridge residents. This work started in the spring of 2014 with the majority of the effort occurring in June and July, 2014. Data analysis will continue in August and September, 2014.

Survey of Southbridge Residents

To assess community knowledge, risk perceptions, and ethical concerns, a survey was developed in May and June 2014 by a team of sociologists and behavioral economists. This survey entitled the "Southbridge Health and Environmental Concern Survey" was administered to community residents on Saturday, July 19, 2014. This particular day was selected because it was the second day of "Southbridge Weekend," an annual celebration within the neighborhood that attracts hundreds of residents. During this weekend, a free carnival event was held at Elbert playground in the heart of the Southbridge community. At this event, many vendors and community organizations set up exposition tables to be frequented by the attendants of the carnival.

Recruitment of respondents was executed on site, with a $2 bill serving as the incentive for participation in the survey. The survey took 10 to 15 minutes to complete. The survey had been approved by the Institutional Review Board of the University of Delaware and all respondents reported being over the age of 18 years old. The survey was administered at a tent rented by the research team. There were four survey administrators on site who are all qualified to conduct human subjects research and two additional assistants from the Center for Experimental & Applied Economics aided with the logistics on that day.

Recruitment was done by intercepting community members participating in day's event and asking whether they would voluntarily complete the survey. Upon successful recruitment, respondents were given a paper copy of the survey with an ID entered at the top and asked to fill it out in the presence of an administrator. Administrators stayed in close proximity to respondents as some participants had trouble reading or understanding the survey. Basic demographic data were collected at the beginning. These questions served to identify the age, race, sex, education, and labor status, and income of the respondents in question. These questions were pertinent in order to identify which segment of the population was being surveyed specifically.

The next topic addressed was residential status respective to the community of Southbridge in particular. The goal of this was to ascertain how many of the respondents actually reside in

Southbridge, the amount of time they have lived there, as well as if they own a home there. The idea behind this was to see if residency in Southbridge has an effect on overall health and environmental concern. Throughout the rest of the survey, there were questions that used a three-point scale to gauge the respondents' level of concern about various possible threats. Respondents were asked to label their level of concern towards the potential effects that certain pollutants could have on their everyday life within the community. Specifically, respondents were urged to disclose their concern for how certain metals, gases, and particulate matter could potentially affect air quality, drinking water, locally grown food, plant life, local fishing, and soil quality.

A similar three-point scale was applied in the next segment of the survey, which addressed health concerns tied to pollution. Participants were asked to disclose concern regarding potentially harmful outcomes of exposure to pollution. Cancer, birth defects, genetic diseases, asthma, headaches, and fatigue were included in this segment as well as the potential damage to the nervous, reproductive, and urinary systems. The final segment of the concern scale culminated in the segment addressing overall exposure to pollutants in Southbridge (including air, soil, and both environmental and drinking waters). In particular, this portion of the survey addressed the uncertainty of past, present, and future pollution exposure.

The final part of the survey sought to identify each respondent's feelings towards the sea level rise and pollution mitigation. Questions were asked to ascertain the overall knowledge of these issues and whether the residents of Southbridge feel these topics are of high priority socially and economically. For instance, questions asked if the respondent would be willing to pay higher taxes in order to help improve pollution, flooding, sea level rise impacts, as well as the overall environment of Southbridge. Questions were also posed about the desire for residents of other communities to help pay for these mitigation and adaptation responses to these issues.

After completion of the survey, an envelope containing a $2 bill along with the informed consent for the study was given out to each respondent. The survey collection was more successful than anticipate as all 49 surveys that were brought to the event were completed in less than three hours. The data from the paper survey are being digitized and will be reported by Co-PI Messer and his colleagues.

Sample Survey Questions

Here is a selection of Survey questions from the survey conducted by Co-PI Messer and colleagues.

Here is a list of specific types of environmental issues that pollution can contribute to. On a scale from not at all concerned to greatly concerned, regarding Southbridge, how concerned are you about the effects of toxic pollution on: (please X your level of concern for all seven issues)

	Not at all concerned	**Concerned**	**Greatly concerned**	**Prefer not to answer**	**Don't know**
Air quality					
Drinking water					
Other waters (river, streams, groundwater etc.)					
Locally grown food					
Plant life and trees					
Local fishing					
Soil quality					

The following is a list of toxic pollutants that may be affecting Southbridge. On a scale from not at all concerned to greatly concerned, how concerned are you about the impact of the following pollutants on the air, soil, and both environmental and drinking waters in the community? (please X your level of concern for all three pollutants)

	Not at all concerned	**Concerned**	**Greatly concerned**	**Prefer not to answer**	**Don't know**
Metals (chromium, lead, arsenic, etc.)					
Gases (ammonia, ozone, sulfur, etc.)					
Particulate matter (dust and airborne particles)					

The following items are potentially harmful outcomes of exposure to pollution. On a scale from not at all concerned to greatly concerned, how concerned are you about the following as a result of environmental pollution in Southbridge (for yourself or any other): (please X your level of concern for all nine outcomes)

	Not at all concerned	**Concerned**	**Greatly concerned**	**Prefer not to answer**	**Don't know**
Cancer					
Birth defects in local children					
Genetic or hereditary diseases					
Damage to the reproductive system					
Damage to the nervous system and brain					
Damage to the urinary system					
Asthma					
Headaches					
Fatigue					

Here is a list of concerns regarding exposure to pollution in Southbridge (including air, soil, and both environmental and drinking waters). On a scale from not at all concerned to greatly concerned, how would you describe your level of concern regarding: (please X your level of concern for all seven)

	Not at all concerned	**Concerned**	**Greatly concerned**	**Prefer not to answer**	**Don't know**
Your past exposure					
Your present exposure					
Your future exposure					
Not knowing what you are being exposed to					
Not knowing how exposure affects your health					
Health problems resulting from exposure					

Using a **scale ranging from none of it to all of it**, regarding Southbridge, **how much of the soil, air, and water do you think is polluted**? (please X the amount for all four)

	None of it is polluted	**Very little of it is polluted**	**A moderate amount of it is polluted**	**A great deal of it is polluted**	**All of it is polluted**	**Prefer not to answer**	**Don't know**
Soil							
Air							
Drinking water							
Environmental waters							

1. How much do you know about sea level rise?
a. Nothing at all
b. A little
c. A moderate amount
d. A great deal
e. Prefer not to answer
f. Don't know

2. How serious of a problem do you think sea level rise is for the community of Southbridge?
a. Not at all serious
b. A little serious
c. Somewhat serious
d. Very serious
e. Extremely serious
f. Prefer not to answer
g. Don't know

3. How serious of a problem do you think flooding is for the community of Southbridge?
a. Not at all serious
b. A little serious
c. Somewhat serious
d. Very serious
e. Extremely serious
f. Prefer not to answer
g. Don't know

4. By answering yes or no, please tell us if you would pay higher taxes to improve the *pollution* in Southbridge?
a. Yes
b. No
c. Prefer not to answer
d. Don't know

5. By answering yes or no, please tell us if you would pay higher taxes to improve the *flooding* in Southbridge?
a. Yes
b. No
c. Prefer not to answer
d. Don't know

6. By answering yes or no, please tell us if you would pay higher taxes to improve the *potential impacts of sea level rise* in Southbridge?
a. Yes
b. No
c. Prefer not to answer
d. Don't know

7. Do you want others (e.g., other DE residents) to pay higher taxes to improve the environment in Southbridge?
a. Yes
b. No
c. Prefer not to answer
d. Don't know

8. In your opinion, how prevalent are health problems caused by environmental pollution in Southbridge (e.g., cancer, asthma, kidney disease, etc.)?
a. No health problems due to pollution
b. Very few health problems due to pollution
c. A moderate amount of health problems due to pollution
d. A large amount of health problems due to pollution
e. Prefer not to answer
f. Don't know

9. Overall, how would you rate your own personal health?
a. Poor
b. Fair
c. Good
d. Very good
e. Excellent
f. Prefer not to answer
g. Not sure/Don't know

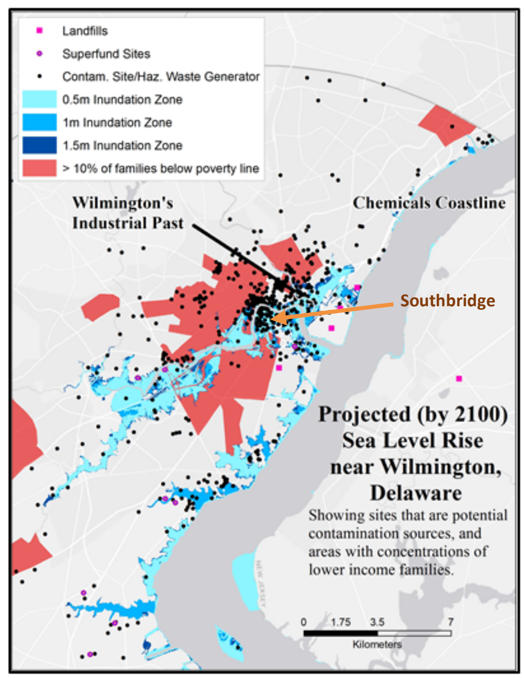
Appendix 3: Preliminary Survey Results by Co-PI Messer and Colleagues

Social Science Research Location – Southbridge community of Wilmington, Delaware

Kent Messer and colleagues (Victor Perez, Robyn Mello, Walker Jones)

In addition to identifying physical locations to study the joint risk of sea level rise and environmental contaminants from a natural science perspective, the WSC team worked to identify locations for studying the human responses to these new joint risks. In particular, the team was interested in developing good relations with members of low-income urban areas in the southern part of Wilmington, Delaware, which are also low-lying with legacy industrial contamination. Initial outreach efforts began in 2013. The first objective was getting to know the community leaders and listening to the concerns of the residents. Formal data collection began in 2014 and is anticipated to grow as our relations with the community continue to grow.

As seen in figure to the right, the community of Southbridge (shown with the orange arrow) in south Wilmington is surrounded by brownfield sites the line the banks of the Christina River, which creates a horseshoe around the community. Wilmington was the second largest center for tannery processing on the East Coast of the USA in the late 1800s and early 1900s. Once there were over 100 tannery operations clustered in an area along the Christina River; these now constitute 53 brownfield sites. Arsenic and chromium were widely used as part of the tanning process and are now common soil pollutants in soils along waterways in Wilmington, such as Southbridge.



Source: A. Homsey, Delaware Water Resources Center

As part of the assessment of the community as a research location, a team of researchers connected to Dr. Victor Perez, Dr. Kent Messer, and the Center for Experimental & Applied Economics administered a survey to fifty participants at the annual "Southbridge Weekend" neighborhood festival in July 2014. Respondents to this survey were on average 45.9 years old, 89.4% were black, 66.7% had not attended college, 46.8% were unemployed, and 58.5% reported annual household earning of less than $25,000.

	Concern about Overall Pollution	**Concern about Heavy Metals in the Water**
Concerned	58.1%	30.8%
Greatly Concerned	39.5%	51.3%
Total Combined (Concerned and Greatly Concerned)	97.7%	82.1%

As shown in the table above, respondents reported a high level of concern about environmental pollution in Southbridge as 97.7% reported being either "concerned" or "greatly concerned" about the overall pollution in the community. A similar level of concern was expressed about heavy metals (chromium, lead, and arsenic) being in local waters, as 82.1% of the respondents reported being either "concerned" or "greatly concerned".

Interestingly, 78.9% of the respondents reported knowing "little" or "nothing at all" about sea level rise. However, when asked about how serious they thought the problem of flooding was to the community of Southbridge, 77.5% responded that it was either "very serious" or "extremely serious". This high level of concern about flooding is likely due to the fact that flooding in Southbridge is a common occurrence as even small rains (~1-2") can lead to Wilmington's sewer system to send several inches of water throughout the community flooding many basements and forcing residents to walk through the standing water. This problem is most acute in Southbridge as it is one of the lowest lying communities in the city and has a very high water table as it is close to the Christina River which is also effected by tides.

In summary, the community of Southbridge appears to be an excellent location for studying the social dimensions of the joint risks posed by sea level rise and environmental contamination. Because of their geographic, social, political, and industrial histories, urban areas such as the Southbridge likely have different concerns and risk attitudes for adaptation alternatives than other more affluent communities that may be located in areas with less environmental pollution and less vulnerability to flooding. Conducting social science research in Southbridge and comparing the results to responses from residents in communities in other locations in the US and the world will likely lead to promising future research.