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Climate Change and CERCLA Remedies: Adaption Strategies for Contaminated Sediment Sites

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I. INTRODUCTION

The actual and projected manifestations of climate change, including sea level rise, stronger rainstorms, more severe storm events, inland storm surges, and associated flooding, pose a host of adaptation challenges. The effective management of hazardous waste sites under the new environmental conditions occasioned by climate change presents one such adaptation challenge, though this challenge is easily overlooked in the rush to protect highly visible and obviously vulnerable infrastructure and populations such as coastal communities. Many hazardous waste sites have been remediated, or are proposed to be remediated, relying in whole or in part on engineering and institutional controls meant to prevent or limit exposure to contaminants. These remedies include caps over contaminated sediment or soil, deed

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restrictions, barrier walls and others controls, all of which can allow the contaminants to remain onsite indefinitely.

However, the traditional design of these engineering and institutional controls affords protection from historical and predicted environmental conditions that may not reflect real-world conditions generated by climate change, either already present or anticipated. This raises both backward-looking considerations for sites already remediated using engineering and/or institutional controls, and forward-looking considerations with respect to the selection of remedies at sites undergoing cleanup. Could climate change-related storms, flooding, or other events compromise engineering and/or institutional controls and cause new releases of and exposure to contaminants? If so, can or should further work be required at these sites to reduce this risk? In remedy selection, how should regulators take into account the effects of climate change when assessing the protectiveness of remedies, especially remedies incorporating engineering and/or institutional controls?

This article considers these questions in the context of a particular type of contaminated site—sites with contaminated sediments subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[1] Although climate change may impact a variety of waste sites in different ways,[2] even those without sediment contamination, this article focuses on sediment sites so as to frame a more manageable inquiry susceptible to in-depth treatment. The following section, Part II, identifies the vulnerability of contaminated sediment sites to climate change. The section describes sediment contamination, regulatory approaches to remediating contaminated sediments, and how climate change may impact sediment remedies. Part III evaluates strategies for managing climate risks at closed, previously remediated sediment sites; these strategies include reopening consent decrees. Part IV considers how climate effects may impact the selection of remedies dependent on engineering or institutional controls at contaminated sediment sites. The article concludes that the U.S. Environmental Protection Agency (the EPA) should monitor sediment

1. Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. §§ 9601–9675 (2006). For an interesting argument that CERCLA provides authority to support climate mitigation (reductions in GHG emissions), see Curtis A. Moore, *Existing Authorities in the United States for Responding to Global Warming*, 40 ENVTL. L. REP. NEWS & ANALYSIS 10185 (2010).

2. For example, sea level rise may cause leaching from hazardous waste sites located on land. For a discussion of the risks posed to hazardous waste sites by sea level rise, see Timothy J. Flynn et al., *Implications of Sea Level Rise for Hazardous Waste Sites in Coastal Floodplains*, *in* GREENHOUSE GAS EFFECT AND SEA LEVEL RISE: A CHALLENGE FOR THIS GENERATION 206 (Michael C. Barth & James G. Titus eds., 1984), *available at* http://epa.gov/climatechange/effects/coastal/SLRChallenge.html; Edna Sussman et al., *Climate Change Adaptation: Fostering Progress through Law and Regulation*, 18 N.Y.U. ENVTL. L.J. 55, 116 (2010).

sites for climate-related damage, particularly after extreme weather events, and should require that future remedies be designed to withstand upper-bound, climate change-adjusted frequencies and severities of relevant climate events. Proposed approaches include more aggressive monitoring requirements that clearly require prompt assessment of sites after severe events, and agreements that contain modified reopener language that expressly addresses whether and when climate change-related weather events, projected or actual, will trigger a reopener.

II. IDENTIFYING VULNERABILITY TO CLIMATE EFFECTS

Contaminated sediment sites are uniquely vulnerable to the effects of climate change. This vulnerability stems from the persistent nature of sediment contamination coupled with contemporary remedies for preventing exposure and transport of contaminated sediments. An analysis of the regulatory and enforcement adaptations to climate change-related threats to contaminated sediment sites first requires a description of sediment contamination and the mechanisms under CERCLA for addressing that contamination, followed by a review of the potential impacts of climate change on sediment remedies.

A. Sediment Contamination and CERCLA

Contaminated sediment consists of "soils, sand, organic matter, or minerals that accumulate on the bottom of a water body and contain toxic or hazardous materials that may adversely affect human health or the environment."[3] Surface waters in the United States suffer from extensive sediment contamination. Sampling conducted as part of the National Sediment Quality Survey (NSQS) indicates that direct or indirect exposure to sediment at 73.1% of sampling stations included in the National Sediment Inventory database, which includes locations in U.S. rivers, lakes, oceans, and estuaries, could be connected to adverse effects to aquatic life and human health.[4] The EPA concludes that

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3. U.S. ENVTL. PROT. AGENCY, EPA'S CONTAMINATED SEDIMENT MANAGEMENT STRATEGY 1 (April 1998) [hereinafter EPA'S CONTAMINATED SEDIMENT MANAGEMENT STRATEGY]; *see also* Water Resources Development Act of 1992, Pub L. No. 102–580, § 503, 106 Stat. 4797 (defining contaminated sediments as "aquatic sediment which contains chemical substances in excess of appropriate geochemical, toxicological, or sediment quality criteria or measures; or is otherwise considered by the Administrator [of the EPA] to pose a threat to human health or the environment.").

4. U.S. ENVTL. PROT. AGENCY, THE INCIDENCE AND SEVERITY OF SEDIMENT CONTAMINATION IN SURFACE WATERS OF THE UNITED STATES xix (Nov. 2004) [hereinafter THE INCIDENCE AND SEVERITY OF SEDIMENT CONTAMINATION]. The National Sediment Inventory data is largely obtained from monitoring programs directed to areas suspected of contamination and thus likely overstates the extent of sediment contamination nationwide.

"approximately 10 percent of the sediment underlying our nation's surface water is sufficiently contaminated with toxic pollutants to pose potential risks to fish and to humans and wildlife who eat fish,"[5] and that "sediment contamination exists at levels where associated adverse effects are probable . . . in some locations in every region of the country."[6] As of 2002, 2,800 fish advisories, covering "more than 544,000 river miles, 71 percent of the Nation's coastal waters, and more than 95,000 lakes" had been issued for contaminants often found in sediments.[7]

Sediment acts as a reservoir for contaminants, including many persistent pollutants that pose a variety of threats to water quality, aquatic life, and human health. Perhaps of most concern is that while chemical contaminants in the sediment may be directly toxic to aquatic life, the contaminants may also bioaccumulate in individual species and biomagnify up the food chain. Bioaccumulation involves the transport of dissolved contaminants in pore water to benthic invertebrate communities that live in the sediment. This process leads to biomagnification: when benthos are consumed by fish and shellfish, the persistent pollutants accumulate in tissues and are passed up the food chain, in increasing concentrations, to fish species and humans.[8] Furthermore, sediment contamination can alter benthic invertebrate communities or even destroy them, while known effects on fish species include fin rot, increased tumor frequency, and reproductive toxicity.[9] Human consumption of contaminated fish may cause cancer or child neurological and IQ impairment.[10] Studies suggest that individuals who consume seafood from areas with highly contaminated sediment face an estimated excess lifetime cancer risk from less than one in one hundred thousand to as great as two to five in one thousand.[11] In many places, regulators issue fish advisories cautioning individuals to limit the consumption of fish from contaminated water bodies.[12]

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5. EPA'S CONTAMINATED SEDIMENT MANAGEMENT STRATEGY, *supra* note 3, at 2.

6. THE INCIDENCE AND SEVERITY OF SEDIMENT CONTAMINATION, *supra* note 4, at 5-3.

7. *Id.* at 1-4.

8. *Id.* at 1-3 to -4.

9. *Id.*

10. EPA'S CONTAMINATED SEDIMENT MANAGEMENT STRATEGY, *supra* note 3, forward.

11. U.S. ENVTL. PROT. AGENCY, PROCEEDINGS OF EPA'S CONTAMINATED SEDIMENT MANAGEMENT STRATEGY FORUMS 2 (Sept. 1992) (citing testimony from Gerald Pollock, California Environmental Protection Agency), *available at* http://water.epa.gov/polwaste/sediments/cs/upload/csforum.pdf.

12. EPA's website allows individuals to search for advisories across the country. *Advisories Where You Live*, U.S. ENVTL. PROT. AGENCY, http://water.epa.gov/scitech/swguidance/fishshellfish/fishadvisories/states.cfm (last visited Jan. 5, 2012). Of note, not all fish advisories are occasioned by contaminated sediment; water pollution can also require the issuance of fish advisories.

Under CERCLA, parties are held strictly, jointly, and severally liable for the cleanup of hazardous substance releases.[13] Accordingly, CERCLA "provides one of the most comprehensive authorities available to the EPA to obtain sediment clean-up, reimbursement of the EPA clean-up costs, and compensation to natural resource trustees for damages to natural resources affected by contaminated sediments."[14] As of 2004, about three hundred sites, or about twenty percent of the sites on the Superfund National Priority List, included contaminated sediment.[15] Decisions about how to clean up these sediments have already been made at nearly half of those sites.[16]

The EPA publishes technical and policy guidance regarding the remediation of contaminated sediments sites. The most important of these publications is the Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (hereinafter the EPA Sediment Remediation Guidance).[17] The EPA Sediment Remediation Guidance recommends three potential methods of cleanup at a contaminated sediment site: monitored natural recovery (MNR), in-situ capping, and dredging and excavation.[18] Complex sediments sites may employ a combination of these remedies. Both MNR and capping leave contaminated sediments in place. Capping is a type of engineering control, and MNR and capping both usually employ institutional controls.[19] Because the MNR and capping remedies leave contaminated sediments in place, they are uniquely vulnerable to climate change related events and are of primary relevance to the present inquiry.

1. Monitored Natural Recovery

Monitored Natural Recovery "typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or

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13. CERCLA § 107, 42 U.S.C. § 9607 (2006).

14. EPA'S CONTAMINATED SEDIMENT MANAGEMENT STRATEGY, *supra* note 3, at 59.

15. THE INCIDENCE AND SEVERITY OF SEDIMENT CONTAMINATION, *supra* note 4, at 1-5.

16. *Id.*

17. *See generally* ENVTL. PROT. AGENCY, CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES (Dec. 2005) [hereinafter EPA SEDIMENT REMEDIATION GUIDANCE].

18. *Id.* at ii ("Due to the limited number of cleanup methods available for contaminated sediment, generally project managers should evaluate each of the three potential remedy approaches (sediment removal, capping, and MNR) at every sediment site.").

19. An institutional control "generally refers to non-engineering measures intended to affect human activities in such a way as to prevent or reduce exposure to hazardous substances." EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 3-22. Institutional controls at sediment sites include fish consumption advisories, commercial fishing bans, and waterway use restrictions. *Id.* at iii.

toxicity of contaminants in sediment."[20] Frequently this remedy means simply leaving a site untouched while monitoring the site to confirm the continuation of natural processes already reducing contaminants or exposure to contaminants, such as the deposit of clean sediment over contaminated sediment.

A key limitation of MNR is that "[w]hen MNR is based primarily on natural burial, there is some risk of buried contaminants being re-exposed or dispersed if the sediment bed is significantly disturbed by unexpectedly strong natural or man-made (anthropogenic) forces."[21] Moreover, the success of MNR in reducing risk at a given site frequently depends on sedimentation, or the physical process of new, uncontaminated sediment depositing and burying older, contaminated sediment.[22] Thus, a significant concern with respect to MNR remedies is that "[m]ajor events, such as severe floods or ice movements may scour the buried sediment, exposing contaminated sediment and releasing the contaminants into the water column."[23] The EPA advises regulators to "consider the potential influence of these processes on exposure rates and risk."[24]

2. In-Situ Capping

In-situ capping involves containing contaminated sediments in place and covering the contaminated sediments with a clean material, such as uncontaminated sediment or gravel, in a manner that will trap the contaminated sediments. In-situ capping is used to physically and chemically isolate contamination by sequestering, stabilizing, and preventing erosion of contaminated sediment. Capping as a remedy has one significant limitation because "sediment is still left in place in the aquatic environment where contaminants could be exposed or dispersed if the cap is significantly disturbed or if contaminants move through the cap in significant amounts."[25] If a major storm breaches the cap, pollutants may become widely dispersed, rendering a post-storm excavation infeasible. This limitation and potential consequence calls for caution when considering capping remedies for persistent pollutants.

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20. *Id.* at 4-1; *see also* ENVTL. SECURITY TECH. CERTIFICATION PROGRAM, TECHNICAL GUIDE: MONITORED NATURAL RECOVERY AT CONTAMINATED SEDIMENT SITES 1-3 (May 2009) [hereinafter MNR TECHNICAL GUIDE].

21. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 4-4.

22. *Id.*; *see also* MNR TECHNICAL GUIDE, *supra* note 20, at 1-11 tbl.1-5 (identifying as one line of evidence in evaluating whether a site is appropriate for MNR the "[d]etermin[ation] if sedimentation is occurring and if newly-deposited sediments will remain in place.").

23. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 4-6.

24. *Id.*

25. *Id.* at iv; *see also id.* at 5-3.

Thus, a key goal of capping is finding a location that can "ensure that hydraulic forces do not erode and resuspend the underlying contaminated sediment."[26] To this end, caps are frequently armored or used at depth that can minimize the impacts of wave action or other hydraulic stresses. Caps are more likely to succeed in low-energy environments: the EPA suggests that project managers "should consider . . . storm-induced waves and other episodic events" when evaluating and designing caps.[27] The agency also advises project managers to consider whether nearby stormwater outfalls may impact cap integrity, and base the design of a cap's erosion protection features on "the magnitude and probability of occurrence of relatively extreme erosive forces estimated at the capping site," generally a one-hundred-year storm.[28]

3. Remedy Selection

The EPA Sediment Remediation Guidance also provides instruction on evaluating and selecting appropriate remedies at contaminated sediment sites.[29] During the remedy selection process, a number of considerations arise that are particularly relevant for understanding how climate change may impact the selection and effectiveness of sediment remedies. Two of the most relevant considerations in remedy evaluation and selection with respect to climate change are site characterization and risk assessment.

a) Site Characterization

An initial step in selecting a remedy at a site is site characterization, or the preparation of a conceptual site model.[30] Site characterization is used to identify "present and future exposure pathways, evaluate[] their significance as routes of exposure, and provide[] sufficient knowledge of

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26. STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, SERDP AND ESTCP EXPERT PANEL WORKSHOP ON RESEARCH AND DEVELOPMENT NEEDS FOR THE IN SITU MANAGEMENT OF CONTAMINATED SEDIMENTS 35 (Oct. 2004).

27. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 5-4. Some caps may also provide in situ treatment of contaminants; erosion is also very important with respect to evaluation of in situ treatment. STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, *supra* note 26, at 12 ("Several in situ treatment technologies are based on the amendment of sorptive or reactive particles to the sediments. The potential loss of the amendments through resuspension and transport could be a major concern. There is need for improved understanding of the fate and transport processes of amendment materials, especially over the long term.").

28. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 5-6, 5-9.

29. For an overview of remedy selection considerations see generally *id.* at ch. 7. There are many factors involved in remedy selection, including, for example, anticipated future land uses and the presence of sensitive environments. *See id.* at 7-5 highlight 7-2. The discussion here focuses on those factors most likely to be influenced by climate change.

30. *Id.* at 2-7 to -12; *see also* STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, *supra* note 26, at 14 (describing this process as "[d]eveloping working hypotheses for site behavior.").

the system to allow design of effective remedial measures."[31] Successful site characterization facilitates remedial decisions that are both technically informed and risk based.[32] A key aspect of site characterization, and also a driver of risk, is whether and how contaminated sediments move, or can be expected to move, in ways that may cause or increase exposure to ecological or human receptors.[33]

Even without the complications presented by climate change, site characterization is very complex, in part because of the difficulty in understanding sediment mobility and contaminant fate and transport.[34] Some causes of sediment or contaminant movement include floods, scour, seiches (sustained winds causing oscillations in lake elevation), and storm-generated waves and currents.[35] Site characterization also requires knowledge of site hydraulics and hydrodynamics. Hydraulic and hydrodynamic information can be characterized in a "system flow balance," a calculation generated by analyzing a variety of factors, including precipitation data and a range of flow conditions.[36] The flow conditions considered in the creation of the system flow balance range from dry weather conditions to wet weather conditions that may cause over-bank flooding.[37] In addition to flow conditions, an understanding of the balance of solids in the system is also necessary for site characterization. Many of the same possible conditions factor into the understanding of solids in the system: "As with flow monitoring, it is critical to gather data under both low-flow conditions and high-flow or flooding conditions in order to capture transport of solids under normal

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31. STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, *supra* note 26, at 14.

32. *Id.*

33. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at ii ("An important part of the remedial investigation at many sediment sites is a site-specific assessment of whether movement of contaminated sediment (surface and subsurface) or of contaminants alone is occurring or may occur at scales and rates that will significantly change their contribution to risk. For example, is significant sedimentation of cleaner sediment burying contaminated sediment, and, if so, how quickly, and is erosion likely to re-expose those contaminants in the future?").

34. STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, *supra* note 26, at 22, 30 (identifying the development of "site characterization tools to measure the rates of important sediment chemical/physical/biological *processes* affecting the fate and transport of contaminants" as a high priority research need and conceding that "our ability to determine cohesive sediment stability at a given location is quite uncertain . . . . [I]t is . . . difficult to anticipate how much sediment will be eroded due to hydrodynamic forcing of specified intensity and duration.").

35. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-24 highlight 2-8 (referencing "[f]loods generated by rainfall or snow-melt induced runoff from land surfaces[,] [i]ce thaw and ice dam-induced scour[,] [s]eiches (oscillation of lake elevation caused by sustained winds) . . . [,] and [s]torm-generated waves and currents (e.g., hurricanes, Pacific cyclones, nor'easters).").

36. STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, *supra* note 26, at 18.

37. *Id.*

conditions and more turbid conditions under which resuspension of bed sediments may occur."[38]

Understanding sediment bed stability frequently integrates modeling studies with empirical studies that use site-specific observation to evaluate whether sediments have remained stable during past high-energy events.[39] Site-specific data may help predict whether sediments can remain stable when subjected to an unprecedented event.[40] Sediment transport models attempt to "quantitatively predict the impacts of catastrophic events on the sediment bed" and "predict the location and depth of bed scour due to a flood or a rare storm, sediment advection to and from a site, and associated contaminant burial or dispersal."[41]

The EPA Sediment Remediation Guidance outlines the data needed for site characterization—including temperature, flood frequencies, event-driven hydrographs and current velocities, and ice cover and break-up patterns—and instructs that "[w]hen considering watershed characteristics, it is generally important to consider both current and future watershed conditions."[42] The guidance further emphasizes the importance of a site-specific assessment of the "frequencies and intensities of expected routine and extreme events that mobilize sediment."[43] The EPA advises that regulators or those conducting analyses at sediment sites examine historical records, including meteorological and flow records, to understand the frequency of extreme events and the intensity of these extreme hydrodynamic forces at a site.[44]

b) Risk Assessment, Evaluating Alternatives and Remedy Selection

Decision making regarding remedial action at Superfund sites requires a risk assessment of human and ecological risks, including an "assessment and prediction of the transport and fate of contaminated sediments and the associated chemical bioaccumulation . . . ."[45] The National Contingency Plan (NCP) identifies nine criteria for evaluating remedies, including, *inter alia*, whether the remedy protects human health and the environment, complies with applicable regulatory limits

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38. *Id.*

39. *Id.* at 29.

40. *Id.* at 30.

41. *Id.* at 30; *see also* EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-33 (providing as an example for the use of models "[p]redicting contaminant fate and transport . . . during episodic, high-energy events (i.e., tropical storm or low-frequency flood event).").

42. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-5, 2-18.

43. *Id.* at 2-25.

44. *Id.* at 2-25, 2-29.

45. U.S. ENVTL. PROT. AGENCY, EVALUATION OF THE STATE-OF-THE-ART CONTAMINATED SEDIMENT TRANSPORT AND FATE MODELING SYSTEM 1 (Sept. 2006).

for relevant chemicals, and can be expected to be effective in the long-term. The long-term issue particularly calls for an evaluation of the adequacy and reliability of controls to manage residual risk from contaminants that remain onsite.[46]

The EPA Sediment Remediation Guidance discusses the application of these criteria at sediment sites. With respect to evaluating protectiveness and assessing human health threats at a contaminated sediment site, the EPA specifically recommends consideration of secondary releases of contaminants from sediment as a result of stormwater runoff and flood events.[47] With respect to evaluating long-term effectiveness and residual risk for MNR and capping remedies, the EPA instructs that a primary consideration ought to be the stability of the sediment bed, or for MNR, "the chance that clean sediment overlying buried contaminants may be eroded to such an extent that unacceptable risk is created," and for caps, the "likelihood of cap erosion or disruption exposing contaminants."[48] The EPA has identified current and future sediment bed stability as a site condition conducive to the implementation of both MNR and capping remedies.[49] When comparing different remedies at a site, the EPA instructs regulators to consider disruption from natural causes, identifying specifically "floods and ice scour," including "the 100-year flood and other events with a similar probability of occurrence."[50] The one-hundred-year flood is a flooding event with a one percent probability of occurring or being exceeded in any year. The EPA instructs that project managers should evaluate the impacts on sediment and contaminant movement of a one-hundred-year flood and "other events or forces [such as hurricanes] with a similar probability of occurrence (i.e., 0.01 in a year)."[51]

B. Potential Climate Impacts on Sediment Remedies

As described above, assessing the risk posed by contaminated sediment sites, and achieving effective remediation of such sites, requires an understanding of the likelihood that contaminated sediment will be disturbed or disbursed and thus expose humans and the environment to those contaminants. Myriad guidance documents recognize that floods, extreme weather events (high winds, hurricanes,

46. 40 C.F.R. § 300.430(e)(9) (2011); *see also* EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 3-5 to -6.

47. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-12 highlight 2-5.

48. *Id.* at 3-16.

49. *Id.* at 4-3, 5-2 (stating with respect to caps that "[h]ydrodynamic conditions (e.g., floods, ice scour) are not likely to compromise cap or can be accommodated in design.").

50. *Id.* at ii.

51. *Id.* at 2-29.

and storms), and stormwater and other runoff are the types of phenomena likely to cause erosion and potentially disperse contaminated sediment.[52] These events present particular concern because they can move large amounts of sediment;[53] "[u]nder certain conditions, such as high winds, strong currents, or changes in ambient chemistry, accumulated contaminants are released, resuspended, or dispersed in the water."[54] The EPA expressly suggests project managers consider the intensity of extreme hydrodynamic forces at a site; this is because "[t]he intensity of a force will be a significant determinant of its possible impact on the proposed remedy."[55]

It is significant to note that floods, extreme weather events like high winds, intense hurricanes, and storms, and unusual and unpredictable stormwater and spring runoff are not only phenomena likely to give rise to erosion and dispersal of contaminated sediment, but are also among the most commonly predicted effects of climate change.[56] With climate change, storms, particularly in coastal areas, will likely be more intense.[57] Sea levels are projected to rise, with estimates as high as three to six feet during the next century.[58] Heavy downpours that once occurred every twenty years may occur every four to fifteen years; and those heavy downpours will likely become ten to twenty percent

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52. Of note, floods can have a negative effect by damaging caps and spreading contaminated sediment, and also a positive effect by depositing additional clean sediment over contaminated sediment. Similarly, "in some situations, the large scale rainstorms associated with hurricanes may greatly impact sediment loading to the water body through erosion of watershed soils, but have little effect on stability of the in-water sediment bed itself." EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-23 to -26.

53. *Id.* at 2-29.

54. OFFICE OF OCEAN RES. CONSERVATION & ASSESSMENT, SEDIMENT TOXICITY IN U.S. COASTAL WATERS (1998); *see also* STRATEGIC ENVTL. RESEARCH & DEV. PROGRAM, *supra* note 26, at 8 ("To understand and model the processes controlling contaminant transport from sediments to the water column, and from contaminated areas to lesser or non-polluted sites, it is necessary to quantitatively evaluate particle and associated contaminant resuspension and deposition along with likely mechanisms promoting transport. Wind-wave, tidal, and fluvial forces all generate physical energy in estuarine and coastal areas that can resuspend and redistribute contaminated sediments.").

55. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-29.

56. U.S. GLOBAL CHANGE RESEARCH PROGRAM, GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 9–10 (2009) ("Likely future changes for the United States and surrounding coastal waters include more intense hurricanes with related increases in wind, rain, and storm surges . . . . [S]ea-level rise will increase risks of erosion, storm surge damage, and flooding for coastal communities . . . . Reduced snowpack and earlier snow melt will alter the timing and amount of water supplies.").

57. *Id.* at 32 ("Heavy downpours that are now 1-in-20-year occurrences are projected to occur about every 4 to 15 years by the end of this century, depending on location, and the intensity of heavy downpours is also expected to increase. The 1-in-20-year heavy downpour is expected to be between 10 and 25 percent heavier by the end of the century than it is now.").

58. Martin Vermeer & Stefan Rahmstorf, *Global Sea Level Linked to Global Temperature*, 106 PROC. NAT'L ACAD. SCI. U.S.A. 21527, 21531 (2009).

heavier.[59] As a result of increased downpours, the frequency and intensity of floods are also likely to increase. For example, "[a] 100 year flood could occur in the New York Metropolitan Region every 43–80 years by the 2020s, 19–68 years by the 2050s, and 4–60 years by the 2080s."[60]

Climate change will likely increase the incidence of those phenomena recognized to cause erosion and dispersal of sediments, particularly in coastal areas, and could therefore undermine the effectiveness of remedies that rely on engineering and institutional controls, such as MNR and capping.[61] Some of these phenomena may also complicate the implementation of other sediment remedies; for example, extreme weather events could exacerbate the risk of resuspension of contaminated sediments during dredging. In Wisconsin, concern has been expressed over lower water levels that may lead to a need for increased navigational dredging; there the dredging could resuspend contaminated sediments.[62]

Notably, however, climate change effects are intensely regional and differ between different types of waterways. Climate change effects are uncertain at local levels, and the impact of such effects is very site specific, depending upon the chemicals involved, the remedy employed, and other factors. In some areas drought may reduce river flows, increase sedimentation, and thereby increase the viability of using institutional and engineering controls to control contaminated sediments. A storm event that leads to a net deposit of clean sediments at a site may further bury contaminated sediments.[63] In some contexts, dispersion of

59. U.S. GLOBAL CHANGE RESEARCH PROGRAM, *supra* note 56.

60. N.Y. STATE BAR ASS'N, TAKING ACTION IN NEW YORK ON CLIMATE CHANGE 6 n.22 (Jan. 2009) (citing COLUMBIA UNIV. CTR. FOR CLIMATE SYS. RESEARCH, METRO EAST COAST REGIONAL ASSESSMENT xi (2001)), *available at* http://www.nysba.org/globalwarmingtaskforcereport/; *see also Climate Impacts in New York City: Sea Level Rise and Coastal Floods*, NAT'L AERONAUTICS & SPACE ADMIN., http://icp.giss.nasa.gov/research/ppa/2002/impacts/results.html (last visited Jan. 6, 2012) (reporting that in New York City "weaker storms will be able to produce the equivalent of the '100-year storm' of today. In addition, there will be an increase in the number of '100-year storms' relative to the year 2000.").

61. Rising water temperatures may also increase the release of contaminants from sediments. THE UNION OF CONCERNED SCIENTISTS & THE ECOLOGICAL SOC'Y OF AM., CONFRONTING CLIMATE CHANGE IN THE GREAT LAKES REGION 21, 54 (2003) ("Lower oxygen and warmer temperatures also promote greater microbial decomposition and subsequent release of nutrients and contaminants from bottom sediments.").

62. WIS. INITIATIVE ON CLIMATE CHANGE IMPACTS, WISCONSIN'S CHANGING CLIMATE: IMPACTS AND ADAPTATION 114 (2011) ("If water levels are lower on average and require additional dredging, buried toxic sediments may be exposed and re-suspended in the water. Lower water levels, more intense rainfall events or a combination of these conditions could also increase stream scouring and erosion, leading to more sedimentation downstream in Great Lakes bays and rivers, potentially exposing these areas to re-suspended pollutants.").

63. MNR TECHNICAL GUIDE, *supra* note 20, at 3-12.

sediments may support MNR.[64] Although climate change may provide some narrow benefits for site remediation, the core predicted impacts of climate change broadly suggest greater erosion risks, particularly in coastal areas. Ultimately, climate effects, whatever they may entail in a given region or location, should be taken into account when assessing CERCLA remedies.

Serious sediment contamination appears to be concentrated in coastal areas where climate effects may be most pronounced. The NSQS identified areas of probable concern (APCs) where further study of the effects and sources of sediment contamination and the possibilities of risk reduction may be warranted due to more frequent exposure of benthic organisms and resident fish to contaminated sediment. A national map showing the location of APCs reveals that they are clustered in four main areas: the Washington coast, the California coast, the Great Lakes region, and the East coast from approximately the Chesapeake Bay north to Massachusetts, including the Hudson River valley.[65] Sites where the EPA issued a Record of Decision or Action Memo describing a sediment remedy that would address at least ten thousand cubic yards of contaminated sediment similarly included a large number of sites in those four areas.[66] Additionally, a significant number of U.S. coastal waters show sediment toxicity.[67]

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64. *Id.* at 1-8, 1-8 tbl.1-4.

65. THE INCIDENCE AND SEVERITY OF SEDIMENT CONTAMINATION, *supra* note 4, at xxii fig.3; *see also id.* at 5-3. ("A number of specific areas in the United States had large numbers of sampling stations where associated adverse effects are probable. Puget Sound, Elliot Bay, Hudson River, the Pacific Ocean (near Santa Monica and San Diego), Willamette River, Sinclair Inlet, Mississippi River, Big Creek (Grays Harbor), and Duwamish Waterway were among those locations.").

66. *Id.* at 3-13 to -20, figs.3-6 & 3-7.

67. OFFICE OF OCEAN RES. CONSERVATION & ASSESSMENT, *supra* note 54, at 14, fig.8 (1998) (showing that eleven percent of estuarine areas surveyed nationwide demonstrated whole sediment toxicity to amphipods).

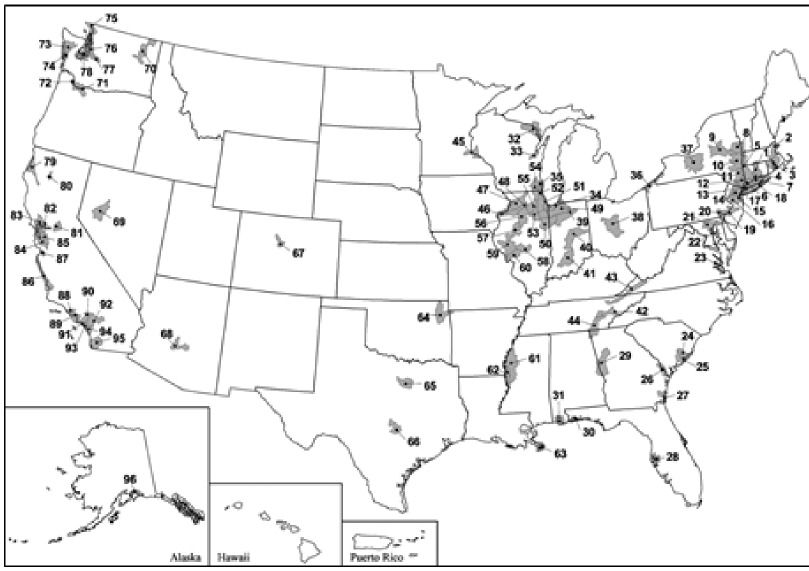

Figure 1: Locations of Areas of Probable Concern (APC) listed in the NSQS.[68]

In light of the sediment contamination present in U.S. coastal regions, climate change raises unique concerns with respect to management of contaminated sediment sites. Movement of sediment at a previously remediated site as a result of an extreme weather event could damage a cap and disperse contaminants. Unanticipated and unprecedented conditions could undermine the accuracy of models used to predict sediment mobility, fate, and transport. In fact, the EPA recognizes that uncertainty in models often stems, in part, from assumptions about future conditions like rainfall, land use, or upstream contaminant sources.[69]

As of 2004, MNR had already been selected in whole or in part as the remedy at one dozen CERCLA sites; caps had been selected, in whole or in part, as the remedy at fifteen CERCLA sites.[70] As of September 2005, the EPA had selected a remedy at sixty Tier 1 sediment sites—sites where the remedy includes dredging or excavation of at least ten thousand cubic yards or capping or MNR of at least five acres.[71] However, many more sites are subject to investigation and evaluation, and incorporating climate data into the decision processes at those sites

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68. THE INCIDENCE AND SEVERITY OF SEDIMENT CONTAMINATION, *supra* note 4, at xxii fig.3.

69. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-41.

70. *Id.* at 4-3, 5-1.

71. *See Data on Superfund Sediment Sites*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/superfund/health/conmedia/sediment/data.htm (last visited Jan. 6, 2012).

may avoid wasting resources by revisiting remedies. At a minimum, the predicted effects of climate change increase uncertainties in the modeling the effects of future storms at contaminated sediment sites. The potential for climate change to interfere with sediment remedies thus presents both backward- and forward-looking concerns.

III. BACKWARD-LOOKING CONSIDERATIONS: MANAGING CLOSED SITES

The universe of contaminated sediment sites that employ MNR or capping and have already been remediated and closed is relatively small.[72] However, the risk posed by climate change at some of these sites may be significant. Flooding or an extreme weather event could re-expose and/or disburse buried contaminated sediment. Not only could cleaning up after such an event prove expensive and difficult, but contaminated sediments could pose serious threats to human health and the environment, particularly if the exposure or dispersal initially goes undetected. Managing these closed sites to reduce climate risks presents two related but distinct considerations. First, with respect to detecting remedy failure, efforts should be made to closely monitor these sites to ensure that remedies continue to perform adequately. Monitoring should be prompt, especially after extreme weather events. Second, with respect to avoiding remedy failure, the EPA should review implemented and in-process MNR and capping remedies to confirm that they continue to adequately control risk. If not, potentially responsible parties (PRPs) and the EPA will need to discuss an appropriate response, including the possibility of reopening a governing consent decree to require additional work.

A. Monitoring

Many contaminated sediment sites employing MNR or capping were likely remediated pursuant to a settlement agreement between PRPs and the EPA.[73] Requirements to periodically monitor the remedy are built into most, if not all, of these agreements. Under CERCLA, where a remedy leaves hazardous substances in place in excess of certain levels, periodic five-year reviews can be conducted.[74] In fact, the EPA Sediment

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72. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 4-3, 5-1 (identifying twenty-seven sites as of 2004 where MNR and/or capping was selected as all or part of the remedy).

73. Where PRPs can be identified, the strict, joint, and several liability structure of CERCLA, as well as its contribution provisions, historically created a strong incentive for PRPs to settle. Stefanie Gitler, Note, *Settling the Tradeoffs Between Voluntary Cleanup of Contaminated Sites and Cooperation with the Government Under CERCLA*, 35 ECOLOGY L.Q. 337, 360 (2008) (noting that strong incentives to settle historically made settlement the "norm," but analyzing how recent interpretations of CERCLA's liability provisions have altered settlement incentives).

74. CERCLA § 121(e), 42 U.S.C. § 9621(c) (2006).

Remediation Guidance specifies that such reviews should generally be required for most sites remediated using MNR or capping.[75] The EPA's Model Remedial Design/Remedial Action Consent Decree places the responsibility on settling defendants to conduct any studies and investigations requested by the EPA so as to permit the EPA to review whether the remedial action "is protective of human health and the environment at least every five years as required by Section 121(c) of CERCLA, 42 U.S.C. § 9621(c), and any applicable regulations."[76] Moreover, most consent decrees incorporate by reference an operation and maintenance plan that identifies the activities required to maintain the effectiveness of the remedy and commits PRPs to carry them out.[77] If monitoring reveals that a remedy has failed or fails to meet performance standards, the EPA typically retains authority to require that the PRPs address the failure by repairing the remedy, such as repairing a cap or conducting additional cleanup. The additional cleanup could come by enforcing the decree itself (notably, most MNR sites will likely not yet have received a certification of completion), the operation and maintenance plan, and/or reopening the consent decree.[78]

Accordingly, the EPA usually has the authority to require monitoring of contaminated sediment sites with MNR or capping remedies so as to detect climate-related remedy failure and require repairs or additional cleanup where remedies fail.

The possibility alone that climate change could cause remedy failure at some of these sites should encourage the EPA to work with PRPs to ensure that there is robust monitoring and, importantly, that mechanisms are in place to quickly assess sites after extreme weather events. The emphasis on monitoring and assessment is consistent with the EPA's existing sediment remediation guidance with respect to MNR:

> For areas that may be subject to sediment disruption, the project manager should conduct more extensive monitoring when specified disruptive events (e.g., storms or flow stages of a specified recurrence interval or magnitude) occur to evaluate whether buried contaminated sediment has been disturbed or transported and the extent of contaminant release contaminants [sic] and increased exposure.[79]

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75. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 7-8.

76. U.S. Envtl. Prot. Agency, Model RD/RA Consent Decree ¶ 17 (Oct. 2009) [hereinafter Model RD/RA Consent Decree].

77. *Id.* at ¶ 4.

78. *Id.* at ¶¶ 18–21, 96–97.

79. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 8-13.

With respect to caps, the guidance calls for "extensive monitoring" of "areas that may be subject to cap disruption . . . when specified disruptive events (e.g., storms, flow stages, or earthquakes of a specified recurrence interval or magnitude) occur," to determine whether the cap was disturbed, and whether any such disturbance caused a significant release of contaminants and increased risk.[80] The EPA's sample cap monitoring protocol even includes "Severe Event Response" as a monitoring phase and suggests the use of sub-bottom profiles, sediment profile cameras, and cores after major storms.[81]

B. Identifying and Improving At-Risk Remedies

Monitoring for remedy failure does not reduce the risk of failure or its potentially costly and dangerous consequences. The EPA could take a more aggressive approach and review existing contaminated sediment remedies that employ MNR or capping. Such a review could determine if any of these remedies present unacceptable risks to human health and the environment in light of projected climate change effects. If they do, the EPA could require PRPs to augment the remedy in order to reduce those unacceptable risks.[82] While such a review may prove prudent and necessary, undertaking the task now presents three distinct difficulties.

First, a comprehensive review of sites would be time consuming, expensive, and perhaps a relatively low priority. Adapting effectively to climate change presents numerous challenges; the breadth of these challenges makes it important to prioritize resources appropriately. The priority of undertaking a large-scale review of contaminated sediment sites is arguably reduced by the relatively small number of affected sites and further discounted by the likelihood of serious disturbance at any given site and the reality that the EPA retains the authority to require monitoring to detect and efforts to fix remedy failure.

Second, current local and regional climate change projections do not provide sufficiently accurate predictions as to the effects of climate change at any specific location. Thus, any contemporary review of the threat to a specific site posed by climate change would necessarily include a wide range of projections and significant uncertainty. A delay in site-specific remedy review could allow climate modeling to improve and allow greater accuracy in climate impact predictions at a site and may lead to more agreement about appropriate actions in response to climate threats.

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80. *Id.* at 8-16.

81. *Id.* at 8-15 highlight 8-4.

82. *See* Sussman et al., *supra* note 2 ("For cleanups that are already complete, regulators may reopen cleanups and revise remedies based on changed conditions.").

A third and related difficulty for sites certified as closed is the ambiguity as to whether the EPA could successfully reopen a consent decree and require additional work based on existing estimates of increased climate change risks, particularly in light of the present uncertainty of localized climate change projections. The covenants negotiated by PRPs generally include releases from liability as part of the consideration for the cleanup or payment of cleanup of a site. These releases or covenants are typically subject to a reopener, required by statute, that preserves the EPA's authority to sue the PRP under CERCLA for future releases, or threats of such releases, where they "arise[] from conditions which are unknown at the time the President certifies . . . that remedial action has been completed at the facility concerned."[83] Thus, under most consent decrees, the EPA reserves the authority to hold a PRP liable under CERCLA for some releases, or threats of release, notwithstanding the decree's covenant not to sue. The EPA's Model CERCLA RD/RA Consent Decree, for example, includes the following standard reopeners:

> [T]he United States reserves . . . the right to institute proceedings in this action or in a new action or to issue an administrative order, seeking to compel Settling Defendants . . . to perform further response actions relating to the Site and/or to pay the United States for additional costs of response if, (a) subsequent to Certification of Completion of the Remedial Action, (i) conditions at the Site, previously unknown to EPA, are discovered, or (ii) information, previously unknown to EPA, is received, in whole or in part, and (b) EPA determines that these previously unknown conditions or this information together with other relevant information indicate that the Remedial Action is not protective of human health or the environment.[84]

To reopen a consent decree based on increased climate risk, the EPA will need to argue two primary points: (1) projections of local climate impacts constitute new conditions or new information sufficient to trigger the reopening of settlement agreements, and (2) the remedy in place no longer protects human health and the environment. With respect to the first argument, the EPA will need to show the projected effects or risks of climate change were unknown at the time of the Certification of Completion of the Remedial Action, or were not set forth in the Record

83. CERCLA § 122(f)(6)(A), 42 U.S.C. § 9622(f)(6)(A) (2006). The EPA is further authorized to include exceptions to covenants that would allow for future enforcement action at a site as "necessary and appropriate to assure protection of public health, welfare, and the environment." § 122(f)(6)(C).

84. Model RD/RA Consent Decree, *supra* note 77, at ¶ 97.

of Decision or other documents.[85] This inquiry must be done on a case-by-case basis, and it seems likely that the EPA will not have much difficulty satisfying this prerequisite. Although many MNR and capping remedies at contaminated sediment sites are relatively recent, localized climate effect projections are rapidly evolving. While materials prepared in support of a remedy at all sites would have included projections of one-hundred-year flood events and future storm events, such figures based on historical records would have failed to incorporate climate change: those projections are arguably distinct.

It might be a more difficult task, however, for the EPA to show that "the Remedial Action is not protective of human health or the environment."[86] Reopener provisions serve to retain the government's authority to require additional work as necessary to protect public health and the environment.[87] As set forth in its own guidance and confirmed in consent decrees, the EPA has already conceded and accepted at least a one percent annual risk of remedy failure by selecting the one-hundred-year storm event or one-hundred-year flood as part of its design criteria. The EPA would thus need to distinguish between those acceptable risks and the increase in the risk of remedy failure as a result of possible climate effects. How much of an increase in risk would it take to make a remedy no longer protective? Would it be sufficient if data suggests that one-hundred-year floods would occur twice as often—every 50 yearsthereby doubling the annual risk of remedy failure? The issue presents the significant question of how much of a shift in climate conditions must occur before it is considered a threat to the remedy's protection of human health or the environment. The EPA would not only need to develop a benchmark for that climate change value, but it would likely need to defend that benchmark against challenges by PRPs and public interest environmental groups.

It is unusual, but not unprecedented, for environmental agencies to reopen closed waste sites to address newly identified risks. New York State, for example, has reopened many sites to address the previously

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85. *Id.* at ¶ 98. In addition to the ROD, the risk information would necessarily not be in the administrative record supporting the Record of Decision, the post-ROD administrative record, or in any information received by the EPA pursuant to the requirements of this Consent Decree prior to Certification of Completion of the Remedial Action.

86. *Id.* at ¶ 97.

87. *See* Superfund Program; Covenants Not To Sue, 52 Fed. Reg. 28,038, 28,041 (Envtl. Prot. Agency July 27, 1987) (emphasizing that "[c]ongressional concern that remedial action might fail to protect public health and the environment . . . extended to any situation in the future at the site which is judged to present a threat to public health and the environment," and, in providing illustrations of conditions warranting use of a reopener, explaining that a reopener for remedy failure is warranted where "health effects studies reveal that the health-based performance levels relied upon in the ROD are not protective of public health or the environment . . . .").

unrecognized threat posed by vapor intrusion, where volatile chemicals in contaminated groundwater or soil infiltrate the indoor air of overlying or adjacent buildings.[88] The EPA is still finalizing its vapor intrusion guidance.[89] The actions by states such as New York suggest that environmental agencies are prepared to respond as new risks are identified even at closed sites.

IV. GOING FORWARD: TAKING CLIMATE CHANGE INTO ACCOUNT WHEN FASHIONING REMEDIES

The EPA continues to review, approve, and manage MNR and capping remedies at contaminated sediment sites. The analysis above suggests that the EPA should move quickly and aggressively to incorporate the projected effects of climate change into its decision processes so as to avoid approving remedies that cannot withstand future environmental conditions. The analysis that follows identifies a few ways climate risk may be relevant to, and be incorporated into, remedy selection.

As briefly explained above, the NCP identifies nine criteria for evaluating remedies. Climate effects are directly relevant to the application of at least three of these criteria at contaminated sediment sites: whether the remedy protects human health and the environment, whether the remedy complies with applicable regulatory limits for relevant chemicals, and whether the remedy demonstrates long-term effectiveness, particularly with respect to the adequacy and reliability of controls to manage residual risk from contaminants that remain onsite.[90] In its sediment remediation guidance, the EPA provides specific examples showing how these criteria are applied in the evaluation of remedies at sediment sites. When comparing alternatives for cleaning up a sediment site, it is essential to assess the risk of re-exposure or redistribution of contaminated sediment posed by each alternative remedy.[91] To that end, a scientific analysis of sediment stability is an important aspect of remedy selection, and is an important tool for comparing alternative remedies.[92]

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88. Press Release, N.Y. State Dep't of Envtl. Conservation, DEC Reports: NY's Vapor Program Called the Most "Proactive" (Mar. 9, 2009), *available at* http://www.dec.ny.gov/press/52443.html.

89. Public Comment on the Development of Final Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Contaminated Groundwater and Soils (Subsurface Vapor Intrusion Guidance), 76 Fed. Reg. 14,660 (Envtl. Prot. Agency Mar. 17, 2011).

90. 40 C.F.R. § 300.430(e)(9) (2011); *see also* EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 3-5 to -6.

91. EPA SEDIMENT REMEDIATION GUIDANCE, *supra* note 17, at 2-32.

92. *Id.* at 7-17.

The EPA specifically instructs that "[i]n evaluating whether to leave buried contaminated sediments in place, project managers should include an analysis of several factors, including . . . the potential for erosion due to natural . . . forces."[93] One salient consideration in evaluating the long-term effectiveness of either a capping or MNR remedy is the inability to control physical disturbance from natural forces.[94] In comparing net risk reduction between alternative remedies, the EPA expressly identifies the effects that erosion may have on contaminant exposure as an aspect of potentially continuing or increasing risk.[95]

The EPA also specifies when sites are conducive to MNR or capping remedies. Sites may be conductive to these remedies where, for example, hydrodynamic conditions, such as floods or ice scour, are not likely to compromise natural recovery or capping, or where remedy design can accommodate such hydrodynamic conditions.[96] The EPA identifies "an accurate assessment of sediment mobility and contaminant fate and transport [as] one of the most important factors in identifying areas suitable for [MNR], in-situ caps, or near-water confined disposal facilities (CDFs)."[97]

Projected climate effects may change forecasts of future storm events and floods, the timing and extent of stormwater and spring runoff, and associated sediment stability, scour, and erosion. Thus, climate change may significantly affect whether and when site conditions support MNR or capping remedies. Climate change may alter the residual risks applicable to MNR or capped sites, and the risk reduction that those remedies afford. All of these changes and effects should be weighed when considering those remedies alongside dredging and excavation.

Still, as noted above, local climate projections remain uncertain. Incorporating this information into the decision-making process may prove difficult. This uncertainty, though, should not prevent the consideration of climate effects. Sediment sites present a number of difficult scientific and technical questions,[98] and the EPA's sediment remediation guidance directly addresses how uncertainty should be

93. *Id.* at 7-3.

94. *Id.* at 7-8.

95. *Id.* at 7-14.

96. *Id.* at 7-6.

97. *Id.* at ii.

98. Climate change is not, of course, the only source of uncertainty with respect to understanding sediment movement. Historical records may not, for example, reflect how "residential or commercial development in a watershed may significantly increase the impervious area and subsequently increase the frequency and intensity of routine flood events." *Id.* at 2-27.

managed both generally and with respect to remedy selection. When analyzing sediment transport at a site, the EPA suggests that if information about extreme events from historical records is insufficient, or the historical record is too short to be useful, "project managers should consider obtaining technical assistance to model a range of potential events to estimate effects on sediment movement and transport."[99]

The EPA also identifies methods to consider ways to manage climate variability in modeling sediment mobility at sites. Sensitivity analyses can be conducted and bounding calculations used to produce a conservative model outcome.[100] With respect to uncertainty and remedy selection, the EPA instructs as follows:

> For some complex sediment sites, there may be a high degree of uncertainty about the predicted effectiveness of various remedial alternatives. Where this is the case, it is especially important to identify and factor that uncertainty into site decisions. Project managers are encouraged to consider a range of probable effectiveness scenarios that includes both optimistic and non-ideal site conditions and remedy performance.[101]

Finally, the EPA endorses an adaptive management approach to provide more reliable information to support decisions at sediment sites, including "reevaluating site assumptions as new information is gathered . . . [as an] important component of updating the conceptual site model."[102]

Thus, although neither CERCLA nor the EPA's guidance specifically references climate change, those authorities can be read to compel the consideration of climate effects. Climate effects may also be relevant to the EPA's remedy design and consent decree negotiation at contaminated sediment sites where MNR or capping are used. It would be prudent for the EPA to require that remedies be designed to withstand upper-bound, climate change-adjusted frequencies and severities of relevant climate events. For example, caps could be made deeper or thicker. Additionally, the EPA should require aggressive monitoring requirements that mandate prompt assessment of sites after severe events, and the EPA should modify reopener language to expressly address whether and when climate change-related weather events, projected or actual, will trigger a reopener.

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99. *Id.* at 2-30.

100. *See generally id.* at 2-40 to -41.

101. *Id.* at 7-3; *see also id.* at 7-17.

102. *Id.* at 2-22.

V. CONCLUSION

This article relies on a relatively simple premise: some of the most commonly predicted impacts of climate change, including floods, sea level rise, more intense storm events, changes in runoff and river flows, may produce conditions already widely recognized as having the potential to jeopardize institutional and engineering controls at some contaminated sediment sites. This premise suggests a few considerations for how to manage contaminated sediment sites. Looking forward, regulators and the regulated community should take care to understand and address potential climate change impacts as they choose and implement remedies at such sites. With respect to sites that have already been remediated, the potential impacts of climate change underscore the importance of more rigorous site monitoring. The possible effects of climate change also suggest that in the longer term, changing conditions may warrant reevaluating the continued effectiveness of contaminated sediment site remedies. Finally, the potential significance of climate impacts for contaminated sediment sites suggests, more generally, the need to better understand the impacts of climate change at other CERCLA sites dealing with other types of contaminated media.