BBL Ports and Harbors
Publications/Articles Abstracts

Gravelding, M.O., J. Lannie, and E. Schaper. 2001. "Multi-Component Stream Channel Remediation and Restoration Approach." In Proceedings of the ASCE 2001 Wetland Engineering and River Restoration Conference. Reno, Nevada.

As the number of soil and sediment remediation projects performed increase, so do the remedial approaches applied to the site-specific needs of these projects. This paper provides a discussion of a multi-component stream channel remediation and restoration approach applied to a site impacted by polychlorinated biphenyls (PCBs). Based on the complexity of the site's tributary system, considerable time and effort were expended, by the Tennessee Gas Pipeline Company, (the Company) and the New York State Department of Environmental Conservation (the Agency), to develop a "performance-based" approach for remediating the site in a way that would achieve the goal of protecting human health and the environment, meet applicable Standards, Criteria, and Guidance (SCGs), and avoid extensive disruption and/or damage to the natural tributary ecosystem caused by large-scale excavation. This multi-component alternative for soils and sediments in the tributary consisted of: combination of erosion protection and removal and disposal of potentially erodible material with relatively high PCB levels; installation of a sediment trap and sedimentation basin to reduce the amount of potentially PCB-containing sediments transporting off site; and site restoration that included installing erosion controls to prevent meandering of the stream and potential erosion of soils containing residual PCBs.

A key aspect to the soil/sediment removal component was the "performance-based" approach; hence, a removal "action level" was not defined, rather, the removal limits were based on on-site discussions with Agency representatives. The Company, in consultation with the Agency, proposed a remedy for the tributary system in a reach-by-reach manner, which targeted erodible soil removal and prevention of off-site migration of sediments via stream channel erosion and sedimentation control. This remedial approach, while allowing some PCBs to remain in-place, focused on preventing destruction of over 3 kilometers of a pristine tributary ecosystem while maximizing improvements to the ecosystem through targeted removal and restoration.

Ludwig, D.F. and T.J. Iannuzzi. 2002. Incremental chemical risks and damages in urban estuaries: spatial and historical ecosystem analysis. In Coastal and Estuarine Risk Assessment, eds. M. C. Newman, M. H. Roberts, Jr., and R. C. Hale. Washington, D.C.: Lewis Publishers.

Urbanized estuaries may be the most abused environments on Earth. After centuries of shoreline development, wetland "reclamation," watershed alteration, physical disturbances from such activities as dredging, shipping, mosquito control, and garbage disposal, biotic communities have endured substantial habitat loss and degradation. For more than 150 years, urban waterways have been subjected to varying degrees of chemical pollution from industrial and municipal sources. Over time, the habitats that support estuarine-dependent organisms in urban areas have decreased in size and become spatially fragmented. Water and sediment quality is so degraded (at least seasonally) in some urban systems that many organisms are excluded from portions of the estuary. Consequently, despite their adaptive flexibility, many estuarine-dependent organisms have been constrained to "patchy" use of the urban environment.

Our ability to evaluate incremental risks and damages from various chemical groups in urban waterways depends on many interrelated factors bridging a number of scientific disciplines. These include the ecology of the system, the form, mode of action, and toxicity of the chemicals, and the physiology of the organisms that may be sensitive to the effects of exposure (i.e., at risk). Effective chemical risk assessment should be accurate: it should neither underestimate nor overestimate risk. To begin the process of conducting an accurate chemical risk assessment, two key factors must be addressed. The first is the influence of nonchemical impacts to the system, or the "baseline" environmental conditions that would exist in the absence of the contamination. The second is the spatial extent of chemical concordance with the habitats that organisms use, given the fragmentation of the ecosystem. This overlap determines the potential for exposure. These factors can be addressed through a combination of site-specific historical/ecological research, and quantification of the findings using Geographic Information System (GIS) analyses.

Walter, B.R., D.P. Ostrye, E. M. Hathaway, S.P. Truchon, and J.W. Williams. . 1998. "The Use of Site Specific Sediment Toxicity Testing to Establish Sediment Action Criteria." Presentation at the 19th Annual Meeting of the Society of Environmental Toxicology and Chemistry, 15-19 November, Charlotte, North Carolina.
Metal contaminated groundwater at the Saco Municipal Landfill Superfund Site. in Saco, Maine was found to be discharging to a local stream (Sandy Brook). Studies found that naturally occurring metals (primarily arsenic, iron and manganese), were being leached from the underlying bedrock due to reducing conditions induced by the leachate discharge from the landfill. The leached metals discharged to Sandy Brook where changes in water chemistry resulted in the precipitation of the leached metals. Sediment sampling in the Brook and adjacent wetlands detected concentrations as high as 2,250 mg/kg arsenic-several hundreds times the 8.2 mg/kg ER-L for arsenic. A Sediment Removal Action was completed in wetlands immediately adjacent to the brook using a conservative interim cleanup concentration of 19 mg/kg arsenic. Approximately 200 yd3 of sediment were removed. However, it became evident that 19 mg/kg arsenic for the stream sediments was not attainable without significant disruptions to the existing aquatic ecosystem. Aside from a visible iron floc, the Brook did not appear to be adversely impacted, suggesting that site-specific factors may be limiting the potential toxic effects of arsenic. Acute and chronic laboratory sediment toxicity tests were conducted using the amphipod Hyalella azteca in conjunction with a baseline ecological risk assessment to determine environmentally acceptable endpoint concentrations. Preliminary acute toxicity data suggest that acceptable endpoint arsenic concentrations of 100 mg/kg or higher may be appropriate. Final results of the acute and chronic tests, available in mid-July will be discussed along with resulting site restoration strategy.

Wright, S.J., R.K. Mohan, M.P. Brown, and C.C. Kim, 2001. Filter design criteria for sediment caps in rivers and harbors. Journal of Coastal Research 17(2), 353-362.
Remediation of contaminated sediments in rivers and harbors by in-place capping is being increasingly considered at several sites along the United States and even worldwide. Currently, few design guidelines are available for use in designing such cap systems, especially the requirements for the filter layer. An in-depth review of the existing literature on filter design criteria is provided in the paper. In addition, details of the methodology and results of a physical model investigation undertaken for evaluating the various filter design options for in-place sediment caps in the Great Lakes are presented. Finally, design guidelines and nomograms are developed for application at contaminated river and harbor sites for filter design.

Costa, H.J. and N.E. Gensky. 2001. "Concentration or Composition? Defining PAH Background in Sediment." Platform presentation at the Society for Environmental Toxicology and Chemistry Annual Meeting, Baltimore, Maryland.
An essential step in assessing PAH-contaminated sediments is defining the PAH background. In most cases, PAH concentrations in sediments not influenced by site contamination are used to define background. The diverse nature of PAH sources and dynamics of PAHs in sediment systems can complicate the interpretation of PAH concentrations alone in defining a background for ecological assessment or site remediation. River systems with urban and industrial land-use upstream of a PAH-contaminated site further complicate defining PAH background for risk assessment or remediation purposes. The analysis of an expanded suite of alkylated PAHs, along with the conventional suite of priority pollutant PAHs provides a basis for characterizing compositional features, as well as concentration gradients for PAHs in sediments. Compositional features were used to define PAH background in sediments for the remedial investigation of a former manufactured gas plant (MGP) and a former creosote wood-treating facility. Statistical

analysis of background sediments in the vicinity of the former MGP site revealed two outliers upstream of the site. Thermal signatures of fluoranthene and pyrene in the PAH composition were evaluated and confirmed that the outliers were “background,” rather than site related. At the creosote site, compositional analyses enabled fingerprinting site-influenced samples at near-background concentrations. These distinctions were used to demonstrate the natural attenuation of creosote-derived PAH residues in creek sediments to near background concentrations and composition, with total PAH depletion exceeding 90 percent.

Iannuzzi, T.J., D.F. Ludwig, J.C. Kinnell, J.M. Wallin, W.H. Desvousges, and R.W. Dunford. 2002. *A Common Tragedy: History of an Urban River*. Amherst, MA: Amherst Scientific Publishers.

The rise and fall, and rise again of an American river is the theme of' A Common Tragedy: History of An Urban River: This work traces historical events along a waterway in one of our nation's most congested metropolitan centers. The authors investigate the delicate dance between man and environment from pre- history through the events of today. In many instances, the magnitude of some of these events could not be fully recognized until a historical survey such as this laid them out for the modern reader.

This “Passaic River” study is scholarly with scores of charts, lists, chronologies, footnotes, and a rich bibliography for the specialist. Still, the text “flows” for the average reader as well. From the earliest geological and historical descriptions the reader is transported through time to the beginning of reconstitution of a "dead" or the "second worst polluted river in America" into a re-covering and rediscovered asset. Newark and the more than three hundred communities that line the Passaic's shores have benefited and taken from it for generations, and are beginning to look at the River as a major resource in their 21st century redevelopment. Lessons taken from the waterfront revivals of other major cities such as Baltimore and San Antonio are being heeded. The cycle of life emerging from water may well be reenacted on the Passaic River today.

The Native American, Dutch, English, and later the Connecticut Puritans found the Passaic River essential to 17th and 18th century progress. The 19th and 20th century manufacturers, travelers, and sports persons used the River it for their own individual goals. In the wake of these activities the Passaic River nearly died and was forgotten. Still, life is returning to the River and with new energy.

Topics included in this Passaic River compendium include its geological and historical past; the role of the Dutch, English, and American developers; the changes in shoreline and wetlands over three centuries; and the role of industrialization an urban- ism. All phases of recreation have been visited and the final question asked-have we learned from past mistakes? This is recommended reading for admirers of rivers in general and the Passaic in particular.

Mohan, R.K., R.D. D’Hollander, A.N. Johnson, P.S. Brozowski, K.T. D’Ambrossio, and J. Jerome. Remediation of contaminated marine sediments by in-place containment: A case study of Rahway River, New Jersey. Marine Env. Engg. 5: 1-34.

Abstract: Sediment in the Rahway River, New Jersey, has been affected by historical discharge of chemicals from numerous industries located along its banks. This paper presents an environmentally effective and economical technique for remediating the contaminated marine sediments near the Warners Plant section of the Rahway River. The remedial design consisted of sheetpiling the coast and backfilling with select fill material, and installation of an engineered in-place containment system. The containment system consisted of a base geotextile layer, a sand isolation layer, a geotextile filter layer, and a water column by several order of magnitude. Details of the design assumptions, considerations, methodology, and results are presented in this paper.

Wallin, J.M, T.J. Iannuzzi, D.F. Ludwig, and D.E. Rabbe. 2000. "Historical Injury Assessment for Chemicals in Sediments of the Lower Passaic River, New Jersey." Presentation at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, 12-16 November, Nashville, Tennessee.

An injury assessment was conducted for surface and buried contaminants in sediments of the tidal portion of the Passaic River. The injury determination was based on radio-dated sediment chemistry data from sediment core samples collected throughout the 1990s. Historical timelines for sediment chemistry in the river date back into the early 20th century. Historical concentrations of chemicals, including a variety of metals and organic compounds, were estimated for each decade. Injuries were assessed based on the ability of sediments to support a benthic community with "normal" diversity and abundance for northeastern estuaries. To do this, the chemical data for each decade were compared to available benchmark sediment quality values for chemicals that are known to depress benthic populations. From this comparison, injury threshold exceedances were calculated. Subsequently, a spatial analysis of the injury threshold exceedances in the river was performed to estimate area of injured sediments. The results of this assessment suggest that the ability of Passaic River sediments to support benthic invertebrate populations was severely depressed in the early part of the 20th century, primarily due to several metals and polycyclic aromatic hydrocarbons. Conditions have improved somewhat since the 1950s, although benthic populations remain depressed in this river due to a variety of habitat and water/sediment quality factors.

Mohan, R.K., D.C. Urso, and P.R. Steele. 1999. Optimization of dredged material placement needs using the sub-channel placement concept. Journal of Dredging Engineering 1(1): 11-25.

In order to provide optimal placement of contaminated dredged material from the New York and New Jersey shipping channels and berths, the Port Authority of New York a& New Jersey (PA) conducted a study of the Sub-channel Placement Cell (SPC) concept. Areas studied included the Howland Hook Marine Terminal, the Port Jersey Channel, the Brooklyn Marine Terminal, South Elizabeth Channel, Elizabeth Pierhead Channel, Port Newark Pierhead Channel and Port Newark Channel. The study evaluated the feasibility and cost of providing dredged material storage capacity below the channel depth for dredged material at these sites as well as creating cells suitable for trapping the contaminated sediments. It was found that SPC's could be used at select locations along the New York and New Jersey Harbor to provide cost effective and environmentally attractive placement of dredged material.

Mohan, R.K., and Steele, P.R. 1999. Implementing effective remedial dredging projects. Engineering News Record 68(12): 14.

When sediment contamination poses a severe threat to the environment, restoration by sediment removal may be warranted. In recent years, there has been some debate on this topic. On one side, some responsible parties argue that sediment removal is expensive and ineffective. On the other side, regulators often maintain that sediments must be dredged for public safety. While each view may have merit in different instances, there are some simple rules of thumb for determining when to implement a remedial dredging program and how to make it effective.

Mohan, R.K. 2000. Modeling the physical & chemical stability of underwater caps in rivers and harbors. In Handbook of Coastal Engineering., ed. J.B. Herbich. New York: Mc-Graw Hill, Inc.

Rapid, largely underregulated industrialization of the past has caused contamination of rivers, waterways, and harbors all over the world. Regardless of the source of contamination (industrial discharges, storm sewers, wastewater, landfill runoff and leachate), they severely impair the ecological and recreational functions of the affected water body. Typically, the released contaminants adhere to the finest fraction of the suspended sediments in the water column and get deposited in relatively quiescent areas of the water body. Once in place, contaminated sediments can exert a significant oxygen demand, support a poor diversity of benthic organisms, and adversely affect local (overlying) and downstream water quality. Removal of the contaminated sediments can be expensive because a high degree of efficiency and reliability is required in such operations. Subaqueous capping is an attractive, nonintrusive and cost-effective method of remediating contaminated sediments in rivers and harbors where draft restriction is not a major concern. The same physiochemical properties and hydraulic conditions that favored the initial adsorption to the deposition of the contaminated sediments typically favor successful containment by capping. Since capping is an in-situ technique, it can often be accomplished at approximately 20 to 30% of the cost of a remedial dredging project.

Successful design of an underwater cap requires the proper application of hydraulic (armor and filter equations), chemical (diffusive and advective/dispersive transport equations), and geotechnical (settlement and stability equations) engineering principles. An underwater cap should be able to withstand the worst design case physical and chemical events at the site in order to ensure sufficient protectiveness and isolation of the contaminants from the surrounding environment. The major physical destabilizing forces include extreme water flows, storm waves, and tidal currents. Molecular diffusion, groundwater-induced advection, hydrodynamic dispersion, and pore water flux due to consolidation are the major chemical destabilizing forces. A base sand isolation layer provides protection from chemical events and an armor/filter layer (usually riprap and gravel/cobbles) provides protection from physical forces. Bioturbation (sediment processing by benthic organisms) is another major destabilizing force causing mixing of the water/sediment interface, thereby releasing contaminants to the water column. Therefore, the design thickness of the cap should account for physical and chemical isolation, as well as bioturbation. Since the likelihood and type of organisms that may colonize the cap would vary from site to site, a site-specific survey of benthic organisms is often required. This could also be estimated by chemical and isotopic analysis of thinly sectioned sediment cores for sediment mixing depths.

Since the early 1980s, several pilot-scale and full-scale projects have been conducted to evaluate the effectiveness of capping under a variety of site conditions [Kikegawa (1983); Strugis and Gunnison (1985); Palermo (1991); Sumeri et al. (1991); Wang et al. (1991); Fredette et al. (1992); Zeeman (1993); Averett and Francingues (1994); Nelson et al. (1994); Randall et al. (1994); Thibodeaux et al. (1994); GeoEngineers (1995); Wright and Kim (1995); Environment Canada (1996); Ling et al. (1996); Hull et al. (1998); Laboyrie and Flach (1998); Li et al. (1998); Lillycrop and Clausner (1998); Shaw et al. (1998); and Mohan et al. (1999a)]. While these studies established the validity of the environmental isolation provided by the capping process, design of underwater caps is still a complicated process requiring specialized skills in hydraulic, chemical, and geotechnical engineering aspects. This chapter outlines the theoretical considerations for modeling the physical and chemical stability of underwater caps in river and harbor environments, and presents a generic setup of a cap evaluation model (CAPSSABL). In addition, the various factors directly affecting the long-term stability of underwater caps in the marine environment are identified through and example application of the model in a project case study.

Mohan, R.K. 2001. Design & construction of coastal wetlands using dredged material. In Handbook of Dredging Engineering, ed. J.B. Herbich. New York: Mc-Graw Hill, Inc.
Wetlands are dynamic ecosystems that exist in the nearshore regions and generally consist of the following categories: leveed, pothole, floodplain, freshwater, riparian, depressional, alpine, salt and brackish water, mountain meadow, permafrost, and rainforests (Hayes, et al., 2000; SCS, 1992). Depending on their type, wetlands serve several functions such as wildlife habitat, fish and shellfish production, food production, flood storage, flood conveyance, storm surge buffer, erosion/sedimentation control, shoreline/stream bank stabilization, water quality improvement, groundwater discharge/recharge, rare, threatened or endangered species habitat, historic, cultural and archeological value, aesthetic quality, recreation, timber production, water supply, and education and research.

In the past century, vast acres of wetlands were lost because of human activities. Use of dredged material from ports and harbors to create and/or restore wetlands in the coastal region has been considered a beneficial and environmental reuse (Landin, 1984, 1988, 1997; Landin, et al., 1990; Mohan and Palermo, 1998; Palermo, 1992; U.S. CE, 1978a-d, 1986; U.S. EPA, 1991).

This chapter will present technical methodologies, construction aspects, and project lessons learned based on case studies of select projects around the country.

Truchon, S.P., T.J. Iannuzzi, J.A. Rothrock, and D.F. Ludwig. 1999. "Quantification of Habitat Use to Determine Exposure Risks to Aquatic Organisms in a Riverine System." Presentation at the 20th Annual Meeting of the Society of Environmental Toxicology, 14-18 November, Philadelphia, Pennsylvania.
In large aquatic systems, exposure of fish and other organisms to chemicals in sediments is disproportional between species and locations within the system. While the uptake of chemicals from sediments is a function of multiple factors, (i.e., sediment characteristics, food sources, and organism physiology), exposure on a spatial scale is a function of where key habitats are located with respect to the location of the contaminated sediments. Thus, the mass of contaminants in the sediment column is less important than where the mass is physically located in relationship to where a species forages and nests, or where a food web predominates. By characterizing habitats (and chemistry) as part of the risk assessment process, risk management and remedial planning can be focused on those discrete areas of a system that represent the largest potential for biological exposure to substantial levels of chemicals. Subsequently, discrete sediment deposits can be identified and evaluated during the risk management process in an attempt to maximize risk reduction, minimize disruption to the ecosystem, reduce implementation time, and lower remediation costs. As an example, a habitat-based food web characterization was developed as part of an ecological risk assessment performed for the Lower Fox River. A series of habitat scoring criteria were developed in an attempt to weight the different factors that determine the importance of riverine features that influence habitat selection and use by fish. By quantifying and characterizing habitats and food web distributions, areas of preferential exposure were identified and quantified for a variety of species. This information was used in the construction of a numerical bioaccumulation model that is being used to evaluate remedial alternatives for the river.

Hattersley, M., M. Shivell, and A.S. Fowler. 2000. "GIS - An Effective Tool for Management of Sediment Sites." Poster Presentation for the Sediment Management Seminar, Tampa, Florida.
A Geographic Information System (GIS) is an instrument used to compile large amounts of geographic data and manipulate it into a usable form. Environmental management is a major application of GIS because many different, yet interrelated, data sets need to be analyzed simultaneously. For sediment issues, the most common application is for creating maps showing relationships between data collected at various sample locations. The example presented here shows how GIS can be used to organize and analyze a variety of spatial data.

GIS can be used to perform geoprocessing, such as overlaying one map theme on top of another. It can also perform spatial functions such as unions and intersections of data sets. This allows for the identification of spatial data components easily and accurately. Spatial modeling, or the "What if?" scenarios, can be explored using GIS.

GIS can incorporate both raster and vector data. This allows for the incorporation of imagery (aerial photography and satellite imagery) and standard digital map formats. High quality map formats are becoming readily available from both public and private sources. Output from surface water and sediment transport modeling computer programs can also be incorporated into GIS to develop floodplain extents and chemical isopleths.

GIS is a technology that can be used to make better decisions faster. By examining multiple data sets together, relationships between variables can be discovered. Maps and reports can be quickly developed to aid in communication and with the advancement of Internet Map Servers GIS can be interfaced via the World Wide Web from nearly any location imaginable.

Brown, M.P., 1999. The Role of Natural Attenuation/Recovery Processes in Managing Contaminated Sediments. Presentation at the *Sediment Management Work Group*.

Executive Summary

When considering how to reduce human health and ecological risks posed by contaminated sediments within an aquatic ecosystem, it is important to recognize the considerable capacity of natural processes continuously at work within the system to reduce those risks. Technically referred to as natural attenuation, this approach to sediment remediation relies on the powerful natural processes that are inherent within all aquatic systems to reduce COC bioavailability and potential transport. The natural attenuation of aquatic systems is driven most often by quantifiable physical mechanisms such as the mixing and in-place burial of contaminated sediments with progressively cleaner solids delivered by the watershed. This natural sedimentation process can effectively reduce the physical availability of COCs for potential transport downstream and similarly reduce the biological availability of COCs for potential exposure to human and ecological receptors. Other potentially significant mechanisms include chemical processes such as adsorption and redox reactions and the complex biological processes involved in biodegradation.

Despite today's apparent emphasis on applying active remedial technologies in managing contaminated sediment, there is ample evidence that natural attenuation can be applied as an effective remedial alternative or to enhance the protectiveness of other alternatives selected for aquatic sites. While the regulatory community and public tend to view the natural recovery of sediments as a no action alternative, this paper discusses the capacity for natural attenuation processes combined with performance monitoring to be a protective, feasible, and cost-effective alternative that should be considered and fully evaluated against other potential remedies. Unique to natural attenuation as a remedial alternative is its ability to reduce the mobility, toxicity, and potential exposure of COCs through inherent physical, chemical, and biological processes without the need for intervention typified by technologies such as sediment capping or dredging. Although natural processes are known to be active in all aquatic ecosystems, full recognition of the power of these natural forces in healing those systems and reducing human and ecological exposure is lacking. In recognizing that natural attenuation is increasingly relied on for addressing environmentally persistent COCs in soil and groundwater, the use of monitored natural attenuation can and must play a wider role in contaminated sediment management. To that end, this paper
concludes by offering several recommendations, which are summarized below.

- *The natural attenuation alternative can be a protective remedy; it is not a no action alternative.* Currently, natural attenuation is reducing risks posed by contaminated sediments to some degree at virtually all contaminated sediment sites. The natural attenuation alternative which, as a risk management tool necessarily includes monitoring and appropriate institutional controls, can be a protective and preferred approach to managing contaminated sediment site risks.

  The policy-level recognition of the natural attenuation alternative as an effective remedy needs to be communicated to regulatory personnel in the field. In doing so, the key applicable principles of the USEPA guidance on using monitored natural attenuation for soils and groundwater can and should be adopted and promoted. The USEPA and other federal and state agencies have recognized the applicability of natural attenuation at the policy level, but actual selection and application of the alternative is lacking.

  The role of natural attenuation in addressing environmentally-persistent COCs in soil and groundwater is well documented and is increasingly relied on as one component of a site's overall remedial package. In addition, the USEPA has formally selected natural attenuation as a whole or partial remedy at several sediment sites. Fundamentally, it must be recognized that natural attenuation is an intrinsic set of processes that operate continuously within all aquatic ecosystems. Given that premise, natural attenuation is necessarily already relied on before, during, and after other more intrusive remedies. However, additional effort is needed in the site assessment phases of remedial planning

to discern what portion of overall recovery gains (or reversals) are attributable to natural processes versus source control, intrusive remedial action, and other actions.

- *Empirical evidence and model projections should be used to evaluate the effectiveness of natural attenuation in reducing risks.* Site data that identify the mechanisms and rates of ongoing natural attenuation are critical to establishing the feasibility of the natural attenuation alternative. These data are needed not only to establish the basic proof that attenuation is occurring but to calibrate and optimally to verify fate and transport models that predict future bioavailable COC concentrations. Empirical information such as sediment deposition rates, sediment mixing layer thickness, and time series data documenting changes in COC bioavailability or toxicity over time are important. Multiple lines of such empirical evidence should be sought. Organizing site data into a mathematical model that can predict how the system will change over time is an important extension of the basic understanding of the processes that are reducing risk at a site. Deterministic modeling may be the only practical way to address such issues as assessing the reliability of natural attenuation processes to continue to reduce risks under conditions other than those which have been observed (e.g., rare extreme hydrologic events) or to address the combined effectiveness of source controls and natural attenuation.

- *The natural attenuation alternative should be evaluated in comparison to other action alternatives for sediments on the basis of effectiveness, implementability, and costs.* Defining a reasonable time frame for natural attenuation to meet remediation objectives is a site-specific process that weighs among other factors the extent of current risks and impacts to resources, availability, and reliability of institutional controls to manage risks; uncertainties associated with predicted time frame; and the implementability, effectiveness, and costs of other alternatives. For example, levels of risk reduction produced by intrusive technologies may not be achieved significantly sooner than allowing ongoing natural recovery processes to proceed uninterrupted. This is especially true when many years are required to fully design, permit, and construct large-scale capping or removal remedies, including the potential need to design and permit a proper disposal facility. Again, even after such remediation is complete, natural recovery processes would be relied on to attenuate remaining risks posed by the residual materials left behind by intrusive technologies.

  Comparative evaluation of remedial alternatives is necessary. Simple pass/fail decision criteria for natural attenuation that have been suggested (e.g., surface sediment COC levels within a factor of two of remedial objectives as suggested by Templeton et al. 1993) that implicitly assume capping or dredging alternatives to be more effective should be avoided.

- *Where irreconcilable differences of opinion exist regarding the time frame or reliability of natural recovery, performance-based natural attenuation should be selected along with a contingent remedy.* A contingent remedy would be an alternative such as containment or dredging that would be implemented at a specified future date (e.g., the five-year review of a Record of Decision) if a natural attenuation remedy fails to meet appropriate performance standards. Considering the potential consequences of being wrong in making a determination that natural attenuation is not performing (i.e., the high financial cost as well as social and environmental costs associated with implementation of active sediment remediation), the decision maker should be highly confident that natural attenuation is not working and that other remedial options will significantly reduce risk before deciding to abandon the natural recovery option. Consequently, some lower confidence limit on performance measurements such as fish contaminant trend monitoring data would be appropriate for use for triggering decisions to implement the contingent remedy. Performance standards should include at a minimum those that relate directly or indirectly to the expected rate of risk reduction needed to achieve risk-based remedial objectives for the site. Development of the performance standards should minimally address the lines of empirical evidence that supported the original decision. In general, promoting contingent remedies might help bring to closure to the different opinions regarding sediment remedies that are rooted in different expectations regarding the effectiveness, implementability, and costs of sediment remediation technologies.

- *The social and environmental benefits of the natural attenuation alternative may outweigh those perceived to flow from intrusive technologies.* The final word on natural attenuation in sediments is the need for risk managers to come to realize that natural systems have a substantial capacity to attenuate and recover from the presence of contaminants. Conversely, experience with remedial dredging highlights the fact that technology, while powerful, is not necessarily as effective as the nonintrusive natural processes. In making a final determination on this pivotal question, the overall social and environmental benefits and costs must be evaluated. If empirical and predictive lines of evidence indicate that natural attenuation can achieve risk reduction goals within a time frame similar to technological approaches, the benefits of avoiding habitat destruction, avoiding the technical and administrative limitations of construction and landfilling, and avoiding the sometimes extremely high social cost of paying for technological intervention may indeed clearly signal that natural attenuation is the most appropriate remedy for many of the nation’s contaminated sediment sites.