American Bar Association
Section of Environment, Energy, and Resources

Developing Long-Term Sustainable Management Strategies for Complex Contaminated Sediment Projects

Anne Fitzpatrick
AECOM Environment
Seattle, WA

17th Section Fall Meeting
Baltimore, MD
September 23-26, 2009

ABSTRACT

The effectiveness of remediation at sediment megasites has been actively debated over the years. Sediment megasites are complex, large in scale and scope, and generally located in urban environments. Defining alternatives and risk-based cleanup goals that can be achieved in an urban environment creates controversy between maintaining an economically viable environment for site operators/land owners and establishing realistic risk reduction goals that can be met cost effectively in a relevant time frame. Improvements in dredging and capping operations, project controls, and characterization efforts have allowed many projects to meet short-term performance goals after active remediation. Where sediment residuals are above target concentrations after dredging, a six-inch sand cover may address them. Achieving long-term risk reduction goals, however, especially for bioaccumulative chemicals, is more difficult. Few projects have met their predicted goals to date. For some, insufficient time has passed to verify observed trends, but for many, significant reduction in fish/shellfish tissue concentrations or surface-weighted average sediment concentrations is indeterminate because of uncertainties in quantifying recovery rates, source control, and recontamination. Tabulated case study results are provided.

This paper stresses the importance of adaptive management, source control, incentives for early actions, and real world and achievable goals for remediation. What do these concepts mean in a practical sense? This paper presents a practical cleanup approach for managing sediment sites that considers these four factors, ideally in a step-wise manner that links science to management decisions, and goals; then concludes with ideas for a holistic, sustainable approach to restoring our urban waterways.

I. Trends over the Past Fifteen Years

EPA is tracking progress at over 75 sediment sites nationwide where the remedy involves removing more than 10,000 cubic yards of sediment or remediating more than 5 acres using any combination of technologies.[1] Eleven of these sites are on the National Priority List (NPL) and are categorized as megasites (> $50 million cleanup costs expected).[2] Three others are also megasites, but are not on the NPL.

Often, remediation of megasites involves choosing between a "big dig" and a "combined remedy". Big digs remove all contaminated sediment above a defined concentration, elevation, or stratigraphic horizon. Combined remedies involve a combination of dredging, containment (capping), enhanced natural recovery (ENR), and monitored natural recovery (MNR). Recently, projects are trending toward combining technologies to achieve cleanup goals (Figure 1) and EPA's current policy is that combination remedies may be the most effective way to manage risks, especially at large sites.[3] Fewer projects rely solely on dredging due to the sometimes enormous sediment volumes; limited availability of suitable disposal sites; large spatial extent; environmental impacts associated with removal—resuspension, releases, and residuals; immense coordination between different parties; questionable ability of dredging to achieve performance standards; and often decades-long project durations.

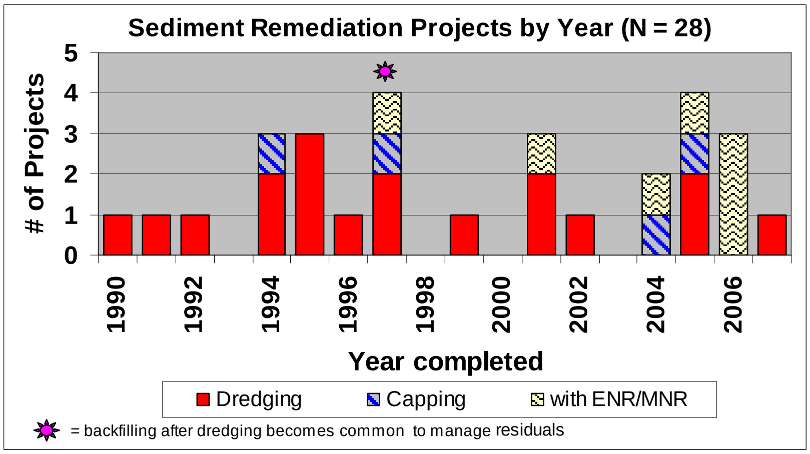

Figure 1. Sediment remediation projects have been increasing over the past 12 years, with more using combined remedies

EPA considers the five National Contingency Plan balancing criteria when selecting a remedial alternative, but incorporating more passive remedial technologies into an alternative largely hinges on two variables: the system's recovery potential and the acceptable restoration time. Recovery potential depends on a site's natural hydrodynamics, vessel scour, sediment transport and stability, contaminant fate and transport, and functional uses, all subject to the limits and expectations of source control efforts (controlling sources of pollutant discharges such as stormwater drains and atmospheric deposition). The need for upland source control will be site-

---

[1] A list of these sites is available at: http://www.epa.gov/superfund/health/conmedia/sediment/sites.htm

[2] NRC 2007. *Sediment Dredging at Superfund Megasites, Assessing the Effectiveness.* National Research Council, of the National Academy of Sciences. ISBN 13: 978-0-309-10977-2. The National Academies Press, Washington D.C. pp. 294. The sites include: New Bedford Harbor, MA; Hudson River PCBs, NY; Marathon Battery Corps, NY; Onadaga Lake, NY; Triana/Tennessee River, AL; Sheboygan Harbor and River, WI; Velsicol Chemical, MI; Bayou Bonfouca, LA; Milltown Reservoir, MT; Silver box Creek Butte Area, MT; Commencement Bay, WA; plus GE Housatonic River, MA; Lower Fox River, WI; Manistique River/Harbor Area, MI. NRC also lists many additional Tier 1 and 2 sites that are large and controversial.

[3] EPA 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. EPA-540-R-05-012. OSWER 9355.0-85.

specific but may include: containment or treatment of wastewater or groundwater discharges, isolation or containment of upland soils or hotspot sediments, pollutant load reductions from point and non-point runoff discharges, and implementation of best management practices. Restoration time refers to how long it will take to achieve the desired goal or remedial action objective (RAO). Typically, restoration times range from 0 to 30 years after active remediation has been completed, but these are dependent on the system's ability to recover naturally and reach some equilibrium or steady-state condition.

Removal-Focused Remedies. Dredging may be a good option for sites where contaminated sediment exists above permitted vessel depths (e.g., berthing areas, navigation channels). Dredging may also be preferred when the RAOs are easily achieved through removal (i.e., benthic toxicity, direct contact with sediment), when hotspot areas are orders of magnitude above protective levels and can be acting as a secondary source of contamination to surrounding sediments, or when maintenance monitoring is not preferred. However, short-term impacts to the water column, biota tissues, and surrounding communities via increased removal/truck/rail transport activities are expected from a large remediation effort. Several studies have shown that elevated fish and benthic tissue concentrations will occur through the duration of the dredging project due to resuspension and releases of contaminants and will remain elevated for 1 to 3 years after dredging (higher TSS and suspended chemical concentrations).

Combined Remedies. The high cost, environmental impacts, and lengthy time required to implement large-scale dredging projects, in conjunction with the uncertainty of achieving the desired risk reduction goals, favor a combined remedy approach. If the site can physically accommodate capping, it is less labor and energy intensive, less disruptive to habitat and biota, and generally more cost-effective than dredging alone. MNR is the least disruptive technology available, as it does not involve construction, infrastructure, or active material management to achieve the project goals. However, a substantial stakeholder communication is often associated with these combined remedies since a common public misperception is that risk reduction is best achieved with removal (i.e., dredging) technologies.

II. What Works and Doesn't Work – Achieving Project Goals

Empirical evidence from sediment remediation undertaken to date shows that short-term cleanup goals can be met immediately after dredging (assuming adequate residuals management), but that long-term risk reduction goals (linked to RAOs) are often not being achieved, at least not yet. This is especially critical since many of the megasite RAO concerns are related to bioaccumulative constituent risk reduction, which may take decades to evaluate effectively.

To evaluate the effectiveness of remedies, we need to explore the successes of sediment projects on two time scales: immediately after active remedy completion and over time, ranging from > 1 to 30 years after remediation to verify achievement of RAOs. Periodic monitoring is typically conducted every five years as part of a long-term monitoring program. In addition to the time scales, different spatial scales may apply as well. Sediment toxicity effects, direct contact, and benthic health are usually evaluated as point data, while fish/benthic tissue concentrations and human health ingestion pathways are evaluated on a larger surface-weighted scale. Flexibility can be built into a compliance monitoring program by including two to three different criteria to evaluate effectiveness: (a) not-to-exceed point concentrations, (b) surface-weighted average sediment concentrations (SWACs) with a buffer around the results, or (c) a significance test to determine if one population (the site) is different from a reference population or upstream area. All three metrics could be included in a compliance program; however, collection of the larger datasets needed to perform the more complex spatial and population comparisons may be costly. Table 1 provides an array of short-term and long-term goals established for sediment projects, shows how the criteria have been applied (e.g., points or SWACs), indicates the expected time frame when goals should be met, and presents the results.

A. Short-term Performance Based Goals

Short-term performance-based goals are criteria that define the requirements for completing the active construction portion of a sediment remediation project. They define the scope and extent of contractor operations, before equipment demobilizes from a site or moves to another area. For dredging projects, short-term goals are typically either numeric chemical or physical criteria (e.g., concentrations, elevations) used to manage the lateral and vertical extent of sediment removal. Similarly, containment (capping) and ENR project goals define the spatial extent of coverage. In both cases, the numeric chemical criteria may be set at the long-term cleanup level so as to achieve the desired improvement in sediment quality immediately following construction. Alternatively, and in the context of a combined remedy, the short-term goals may comprise several action levels that allow different technology-specific actions to be undertaken depending on concentration and engineering feasibility, followed by passive remediation to eventually achieve the desired cleanup levels. Measurement endpoints typically include bathymetry surveys and surface sediment concentrations (expressed as points or SWACs).

Table 1 presents short-term performance goals and outcomes for 25 full-scale sediment remediation projects implemented in the U.S. since 1990. A total of 21 projects met their short-term goals. But six of these sites only met their goals after six inches of cap material was applied to manage dredge residuals or manage problems encountered with bedrock. At three of the 21 sites, all of which had a dredging component, the remediated footprint became recontaminated within a year after construction. The remaining projects did not meet their goals for a variety of reasons: presence of bedrock or substantial debris, sloughing from sidewalls, dredge residuals, or presence of contamination deeper than was expected. With years of case study precedent behind us, we can compensate for these types of adverse physical site conditions and limitations by designing more flexible compliance criteria (e.g., only remove material to within six inches of bedrock), and/or backfilling with a thin layer of sand.

B. Long-term Remedial Action Objectives and Goals

The RAOs for a project define, in narrative form, the long-term benefits a sediment cleanup remedy is expected to achieve. RAOs usually specify a reduction in risk to humans and the environment. Typical measurement endpoints are chemical concentrations in surface sediment, surface water, porewater, tissue, and/or biota toxicity, attainment of which may culminate in site delisting, cessation of monitoring requirements, or a change in status for fish/shellfish consumption advisories. A long-term objective for many projects is to protect human health relative to fish and shellfish consumption exposure pathways, with an assumption that tissue residue concentrations in these food items will be reduced at some point in time following a remedial response action. However, these metrics are very difficult to measure and evaluate.

Overall, the success rate for achieving RAOs is low. Mass removal via dredging clearly does not always equate to a concomitant level of risk reduction. Of the projects in Table 1, six met or partially met their stated long-term objectives. In three of the six cases, fish/shellfish consumption advisories were rescinded in the project area. One of the six sites was delisted from regulatory status and was no longer required to monitor. Results for the remaining 19 projects are varied, with 2 to 15 years of recovery since cessation of active remediation. Some projects observed a reduction in fish/shellfish tissue concentrations, but the statistical significance of these trends are unconfirmed. While a reduction in fish/shellfish tissue concentrations is meaningful as a measure of risk reduction, the relationship between tissue and sediment concentrations is not well understood. Therefore achieving sediment concentration goals may not result in the anticipated reduction in risk to human health. Three projects in Table 1 have either not met their target cleanup goals or have become recontaminated after remediation.

Table 1. Short-term Performance Based Goals and Long-term Cleanup Objectives for Sediment Projects

Project	NPL Site ?	Remedial Action		Short-term Performance Based Goals				Long-term RAO Goals	
		Dredged Volume (cy)	Year Dredging Completed	Type of Target Goal	Risk Driver Chemical	Performance Goal	Target Achieved	Project-defined RAOs and Cleanup Goals	RAO Achieved
Triana/Tennessee River, AL	Y	cap; source control	1988	chemical	DDT	Not defined	Y	reduce DDT in water and fish (5 ppm ww) in 10 yrs	Bass = Y Others = N
Black River, OH	N	60,000	1990	horizon	PAHs	---	Y	reduce toxicity to fish	Y*
Commencement Bay, Sitcum Waterway, WA	Y	425,000	1994	depth	metals	SQOs	Y	remove all cont. seds	Y**
Sangamo-Weston MNR Site, SC	Y	MNR	1994	chemical	PCBs	1 ppm	Y	reduce chemicals in fish after 12 yrs (2 ppm in tissue, FDA)	P
Waukegan Harbor/Outboard Marine, IL	Y	38,300	1994	chemical	PCBs	50 ppm	N, not immed.	reduce PCBs in fish	P*
Bayou Bonfouca, LA	Y	169,000	1995	depth/ chemical	PAHs	1,300 ppm	Y, with backfill	reduce contact and tissue levels, HH	Y*
Marathon Battery, NY	Y	100,200	1995	chemical	cadmium	100 ppm 10 ppm	Y	reduce bio impacts	Varied
GM Foundry, Massena, NY (pilot)	N	27,000	1996	chemical	PCBs	1 ppm	Y (83%), backfill	manage hotspots; reduce PCBs in fish	P
Ford Outfall/ River Raisin, MI	Y	28,500	1997	horizon	PCBs	10 ppm	80%, P	reduce PCBs in fish	Varied
United Heckathorn Site, CA	Y	110,000	1997	chemical	DDT	590 ppb	Y, with backfill, but recontaminated	reduce human and aquatic risk in SW and tissue	P
Wykcoff/West Eagle Harbor, WA	Y	3,650; cap, ENR	1997	chemical	mercury	5 ppm 2.1 ppm	Y	reduce toxicity to biota 0.59 ppm in 10 years	P
Manistique River, MI	Y	72,000	1999	chemical	PCBs	10 ppm	N	reduce PCBs in fish	Varied
Ketchikan Pulp Co. AK	Y	8700; ENR 30 ac MNR 50 ac	2001	physical	ammonia; 2-methyl phenol	Not defined	Y	reduce toxicity in biota improve benthic communities (SQS) (no chemical goal)	Cap = Y MNR = N
Newport Naval Complex, RI	N	34,000	2001	chemical	copper = nickel = chrysene = PCBs =	in Porewater in Porewater 1.7 ppm 3.63 ppm	P, met except in bedrock areas	reduce toxicity to biota; reduce chemicals in fish	Sed = Y Fish = N
Reynolds Metals , St. Lawrence River, NY	N	86,000	2001	chemical	PCBs = PAHs =	1 ppm 10 ppm	P; PCBs = Y after ENR cap; PAHs = N	reduce PCBs in fish	N

		Remedial Action		Short-term Performance Based Goals				Long-term RAO Goals	
Project	NPL Site ?	Dredged Volume (cy)	Year Dredging Completed	Type of Target Goal	Risk Driver Chemical	Performance Goal	Target Achieved	Project-defined RAOs and Cleanup Goals	RAO Achieved
Grand Calumet River, IN	N	786,000	2002	elevation	PCBs, metals, PAHs	Remove all non-native sediment	N	reduce chemicals in fish	Fish = N
PSNS, Bremerton Naval Complex, WA	N	225,000; w/ MNR	2004	chemical	PCBs	12 ppm oc 6 ppm oc ENR	Y, but increased 1 yr later	reduce PCBs in fish (0.023 mg/kg ww tissue in 10 years)	N
Lockheed and Todd Shipyard, Harbor Island OU, WA	Y	70,000; 220,000	2004, 2005	chemical	various	SQS	Y, with backfill	SQS in 10 years (toxicity)	P
Puget Sound Resources, WA	Y	10,000; cap 22 ac	2005	chemical	PAHs, dioxins, PCBs	CSL	Y	SQS in 10 years (toxicity)	N
Commencement Bay, Head of Hylebos, WA	Y	404,000	2006	chemical	PCBs	0.45 ppm	Y, in all but one area, ENR cap	MNR in 10 yrs 0.30 ppm pts 0.15 ppm SWAC	ND
Commencement Bay, Thea Foss Waterway WA	Y	422,535; cap, ENR	2006	chemical	PAHs, metals	SQOs	Y, but recontam. at head	SQOs	P
St. Louis River/ Interlake Duluth Tar, MN	Y	190,000; cap 28 ac	2006	chemical	PAHs, metals, PCBs	13.7 ppm PAHs	Y, with backfill (assumed)	reduce PCBs in fish	ND
Ashtabula River, OH	Y	70,000	2007	chemical	PCB	50 ppm (hotspots) 3.1 ppm	Y	reduce chemicals in sediment and fish, HH	ND
Lower Fox River OU1, WI	Y	370,000; cap 110 ac cover 150 ac	2008 ***	chemical	PCBs	1 ppm pt 0.25 ppm SWAC	P, Pts = Y SWAC = N	reduce PCBs in fish and surface water in 10 and 30 yrs	ND
New Bedford Harbor, MA	Y	14,000 (hotspot); 80,000; cap 20 ac	1995 2004-2008 ***	chemical	PCBs	4,000 ppm; 10 ppm	Y	reduce PCBs in fish	ND

Ac = acres; CSL = cleanup screening level established in Washington State; ENR = enhanced natural recovery; Hg = mercury; HH = human health; N = no; NC = no change; ND = not data available yet, too soon for long-term monitoring results; NV = No value available for review; oc = organic carbon; OU = operable unit; P = progress towards goal, partially met; PAH = polycyclic aromatic hydrocarbons; PCB = polychlorinated biphenyls; ppm = parts per million; PSNS = Puget Sound Naval Shipyard; SED = sediment; SW = stormwater; SQOs = sediment quality objectives established for entire Commencement Bay Superfund Site; SQS = sediment quality standards established in Washington State; SWAC = spatially-weighted average concentration; Varied = either sediment or some tissue species are still elevated; ww = wet weight; Y = yes

* = Fish advisories rescinded (although data not reviewed); ** = site delisted, and no further monitoring required; *** = more dredging planned

Five projects need more data and time to evaluate risk reduction. Depuration rates[4] for PCBs and other contaminants in fish/shellfish tissue require 1 to 7 years (depending upon the species), therefore many projects require more time and monitoring to observe consistent downward trends in tissue concentrations, assuming adequate source control.[5] Numerous sources of uncertainty make it difficult to assess the long-term effectiveness of sediment remediation efforts. EPA[6] guidance recognizes this uncertainty and states “at many sites, especially, but not

---

[4] The rate at which organisms rid their bodies of contaminants.

[5] Thomann, R.V. and J.P. Connelly, 1984. Model of PCB in the Lake Michigan lake trout food chain. *Environ. Sci. Tech.* 18: 65-71.

[6] EPA 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. EPA-540-R-05-012. OSWER 9355.0-85.

exclusively those with bioaccumulative contaminants, the attainment of sediment cleanup levels may not coincide with the attainment of remedial action objectives. For example, this may be due to the length of time needed for fish or the benthic community to recover."

III. Moving Forward, Adaptive Management Considerations

The risks driving many sediment remediation projects are often the bioaccumulative compounds such as PCBs, dioxins, and metals. The current paradigm is to establish low risk-based cleanup goals that are protective of human health (via fish/shellfish tissue consumption) in the hope that they will be reached eventually. In the Pacific Northwest, these levels are driven by tribal issues and higher consumption rates, often to levels below background. Food-web modeling may predict that these conservative levels can be reached, but in reality, empirical monitoring data often do not approach these levels. This paradigm assumes that a lowering of fish/shellfish tissue concentrations can be accurately predicted by unraveling the interactions between fish, surface water, and sediment. This approach requires considerable data collection and modeling, and is at times uncertain. Lastly, it is apparent that this paradigm has proceeded too long without considering technical practicability.

A recent evaluation of dredging projects published by the NRC in 2007 concluded that substantial uncertainties exist in cleaning up large, complex, sediment megasites. Uncertainties stem from the dynamic structure and complexity of aquatic systems arising from sediment transport properties, ongoing source contributions, timing and likely effectiveness of upland source control efforts, background conditions, and the relationship between sediment concentrations and tissue concentrations. The record is littered with failed or only partially successful remedies; this is likely a testament to the lack of appreciation for this collective uncertainty. Given these uncertainties and lessons learned, adaptive management should be used at these complex sites. Adaptive management considerations include:

1. Establish attainable and protective cleanup levels that consider bioavailability, sediment stability, background, and recontamination potential.
2. Address the worst contamination first, starting upstream (or upgradient) and moving downstream (or downgradient). This allows the remedy to be adjusted based on monitoring data and changed conditions.
3. Create incentives for parties to go first. This requires an iterative approach to cleanup that provides incentives to parties for completing remedial actions at priority areas first.
4. Recognize the importance of source control efforts within the Superfund program or other state-led programs, but consider their limitations when developing achievable cleanup goals.

A. Establish Realistic Cleanup Levels

In setting realistic cleanup levels, the first task is to understand the controlling factors that influence sediment recovery. This is commonly established in the RI/FS as a conceptual site model (CSM) (Figure 2). The CSM illustrates the physical, chemical, and biological processes that affect contaminant fate and transport within the complexity of an active system. Figure 2 shows that dredge residuals, lateral inputs, atmospheric deposition, sediment scour/transport, tidal cycles and presence of a saltwater wedge, ongoing sedimentation, depth of contaminated sediment, and bioavailability all affect how much risk can be reduced and a system's ability to recover.

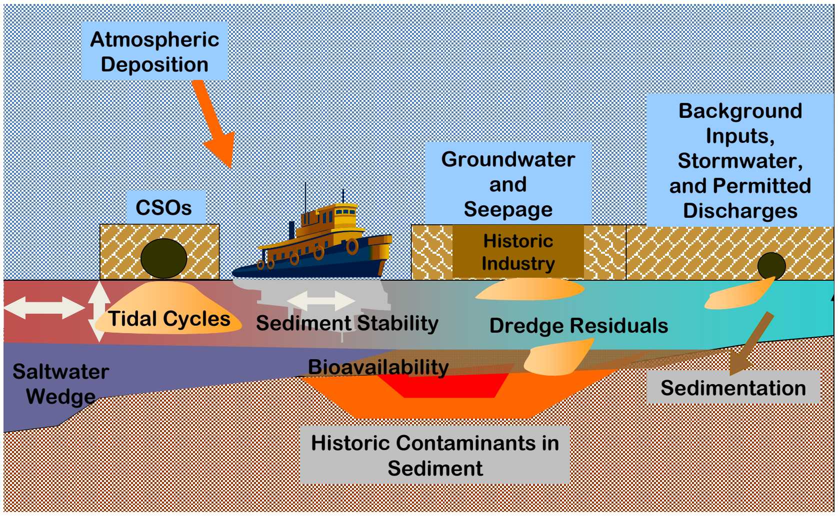

Figure 2. Site Conditions and Mechanisms that Affect Surface Sediment Recovery and Recontamination Potential

The CSM also highlights the gaps in our understanding, especially regarding recontamination potential. The RI/FS should address the two primary mechanisms for recontamination—sediment exposure and source control. All surface sediments actively move to some extent in the top few centimeters of the sediment bed. During routine events (regular storms, tides, ice movement, transiting vessels), fine-grained sediments may be temporarily resuspended then quickly redeposited, often in the same or similar location. These areas are fairly stable. Sediment exposure refers to the uncovering of deeper, buried contaminated sediments by episodic events that expose, redistribute, and disperse deeper sediments. These processes can be evaluated through scour/deposition modeling, bioturbation studies, vessel traffic studies, and empirical chemical trends in surface sediment and cores.

Source control can be evaluated through outfall sampling, near-field modeling, shoreline surveys, and watershed inventory of chemical inputs. It may not be practical to ensure "source control is complete" before starting remedial actions, which can have practical limitations on target levels (short-term remedial action levels) and how low sediment concentrations can be achieved. Collection of more data does not eliminate uncertainty; therefore, sediment cleanup levels could be expressed as a range to account for remaining uncertainty. Municipalities and local industries are prioritizing where to spend their limited funds. Efforts in controlling urban runoff may take years, and is confounded by the increased contributions of PAHs and phthalates, in particular, into urban watersheds from continuing urbanization.[7] Therefore, we need to redefine "how clean is clean".

The solution is to recognize these limitations and establish realistic goals that are similar to anthropogenic, urban, or light urban background chemical concentrations, not just risk-based levels. This is a departure from many state regulations that dictate a remedy cannot be considered final until natural background concentrations are reached. Washington State, in particular, recognizes these limitations and is beginning to consider approaches for managing urban sediments.[8] Other state regulated programs, such as the Massachusetts Contingency Plan, recognize that the urban river systems in the Commonwealth of Massachusetts are not pristine, and that establishing anthropogenic background or reference conditions ("local conditions") may

---

[7] Van Metre, P.C. and B.J. Mahler, 2005. Trends in hydrophobic organic contaminants in urban and reference lake sediments across the United States, 1970–2001. *Env. Sci. Tech* (39): 5567 – 5574.

[8] SMARM 2009. Sediment Management Annual Review Meeting held in Seattle WA. Sponsored by USACE, Washington Department of Natural Resources, US EPA, and Washington State Department of Ecology. May 6.

be a critical part of urban river assessment efforts. EPA guidance[9] recognizes these limitations and states "It is especially important to consider both background levels of contamination and what has been achieved at similar sites elsewhere so that achievable cleanup levels are developed."

B. Sequence Cleanup Using a Worst-First Approach

Remedial alternatives that rely primarily on dredging to achieve risk-based goals have practical limitations due to sediment resuspension and recontamination. Further, time frames for completing source control and sediment cleanup may span decades at megasites. These characteristics suggest that an iterative, phased approach can yield valuable site-specific feedback from monitoring and allow informed adaptation of the remedy, including contingency actions as needed. Conceptually, it makes sense to take a "worst first" approach. An example would be:

1. Identify high priority areas, generally upstream or upgradient of the site, for a first phase of active remediation (tier 1). Depending on circumstances, priority might be given to beaches and other public access areas with direct contact risks, impaired habitat, areas of high benthic toxicity, and hotspots where surface sediment concentrations are several times higher than surrounding areas.

2. Identify interim goals to be achieved following active remediation for use as benchmarks for progress toward final cleanup goals (or RAOs). Base interim goals on current knowledge and predictive modeling.

3. In parallel, plan and implement source control to keep pace with cleanup, focusing on worst-first contributors to sediment and surface water contamination.

4. Integrate five-year reviews of monitoring data into a comprehensive review of remedy progress, fish/shellfish consumption advisories, source control status, and overall waterway health. Allow flexible response to monitoring information: contingency remedies for recontaminated areas; conversion to containment, partial dredge/cap, or ENR (instead of complete dredging) based on physical conditions and operational needs for tier 2 areas.

The goal is to move projects toward remediation faster by accepting higher levels of uncertainty during the FS and design phase. Fewer rounds of data would be collected during the RI/FS or early actions. After remediation of tier 1 areas, a site-wide monitoring effort may be needed to re-establish baseline conditions, following the concepts of adaptive management. The burden of site-wide monitoring can be costly and labor intensive; so, data quality objectives should be clearly defined to help focus data collection efforts.

C. Provide Incentives to Parties to Go First

Only a certain number of acres/cubic yards can be remediated in a given construction season (e.g., short work windows/acceptable fish windows, winter ice-over conditions, ongoing vessel traffic and operations, equipment limitations). Therefore, encouraging potentially responsible parties to take action sooner than later is an important consideration for large sediment remediation projects that may take a decade or more to complete. Some megasites have four or more participating parties conducting the RI/FS (Passaic River, New Jersey; Newtown

---

[9] EPA 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. EPA-540-R-05-012. OSWER 9355.0-85.

Creek, New York; Portland Harbor, Oregon; Lower Duwamish Waterway, Washington; and Lower Fox River, Wisconsin), and additional parties may be expected to help pay for remediation. Individual parties are often reluctant to take action until forced to do so. Right now, EPA provides no incentives to encourage parties to go first. To create a win-win situation, EPA should consider adopting a remedial action plan that provides incentives for action. The following example assumes phased remedial action levels (RALs)[10] that decrease with time following issuance of the ROD. In this hypothetical example, the relative concentration order of RALs is RAL1 > RAL2 > RAL3 > the cleanup level and RAL3 is designed to achieve a spatially-weighted cleanup level sometime after active remediation:

1. Years 1 to 5: Prioritize remediation of hotspots defined as areas where the concentration exceeds RAL1 (e.g., 65 mg/kg-oc PCBs, the Washington State cleanup screening level, for example) by removal or capping, if viable. Assume the remediated area eventually reaches equilibrium with surrounding sediment as other areas are remediated; assume the cleanup level is met in 20 years. A thin-layer sand cap may be used as a physical bed marker to distinguish between the remediated surface and newly deposited material.

2. Years 5 to 10: Require active remediation of moderate contamination defined as areas where the concentration exceeds RAL2 (e.g., 32 mg/kg-oc PCBs, or half the Washington State CSL, for example). Removal may be preferred, but capping or ENR is acceptable with compliance monitoring every five years. Assume the remediated area eventually reaches equilibrium as other areas are remediated; assume the cleanup level is met in 10 years.

3. More than 10 years: Require active remediation of remaining areas where the concentration exceeds RAL3 (e.g., 12 mg/kg-oc PCBs, the Washington State Sediment Quality Standard, for example) with minimal or no allowance or consideration made for natural recovery.

In this example, parties are encouraged to address hotspots of contamination (i.e., where surface risks are highest and recovery potential is lowest). Incentives come in the form of reduced monitoring, and an acknowledgement that natural recovery processes will be ongoing and are capable of achieving the desired risk reduction goals in the long term. An additional encouragement for fast action could come in the form of a release from further liability with a pay-out option toward future monitoring and contingency actions. The last parties at the table would be responsible for implementing this monitoring program.

This approach assumes that remediated areas will be recontaminated to some degree and that the level of recontamination will decrease with time as more areas are remediated.[11] No further action would be required in the remediated areas as long as concentrations are not above equilibrium levels. Lateral and upland source control efforts are completed in parallel to ensure that recontamination is not above ambient site conditions. Equilibrium can be defined as the asymptotic point in a concentration curve, where concentrations no longer decrease after repeated monitoring events. This concept is similar to many state groundwater cleanup programs that use

---

[10] Remedial Action Level (RAL) is the concentration above which a remedial action must be taken. It can also serve as the post-remedy verification compliance concentration for a remediated area. RALs are usually point-based concentrations.

[11] AECOM 2009. *Draft Feasibility Study, Lower Duwamish Waterway, Seattle, Washington.* Prepared for Port of Seattle, City of Seattle, King County, and the Boeing Company. Submitted to EPA and the Washington State Department of Ecology. Prepared by AECOM Environment, Seattle, Washington. April 24, 2009.

a trend analysis to determine when concentrations have reached a steady-state, and monitoring is no longer required.

D. The Role of Source Control

Sources of chemicals to surface sediments are often numerous and linked to both natural and anthropogenic inputs and pathways (Figure 2). Given sufficient time, chemical concentrations in surface sediments are expected to trend toward a steady-state condition reflecting the influences of continued source contributions and *in situ* biogeochemical processes. Predicting final (i.e., long-term) concentrations in remediated sediments is fraught with uncertainty stemming from a combination of measurement imprecision, changes in population/land use, and limited understanding of source control effectiveness. For example, source inputs may decrease over time as source control efforts continue,[12] or may increase as populations grow and land use becomes more urbanized.[13] [14] Regardless, source control is essential for slowing and limiting the degree to which sediment may become recontaminated.

Source control is generally recognized as "those efforts taken to eliminate or reduce, to the extent practicable, the release of contaminants from direct and indirect continuing sources to the water body under investigation."[15] Source releases have impacts on both water and sediment quality. EPA guidance states that significant upland sources should be controlled to the greatest extent practicable before a sediment remedy is implemented. In practice, many sediment cleanup projects have proceeded before or during source control implementation. Recent presentations and panel discussions[16] confirm that some sites are being recontaminated above conservative cleanup goals (i.e., Thea Foss Waterway, Washington; Duwamish/Diagonal CSO, Washington) and that the causes are localized recontamination attributable to uncontrolled stormwater and CSO discharges.[17] These projects are not necessarily failures. Instead, expectations for cleanup should be set at equilibrium concentrations that are achievable in the short-term while source control efforts catch-up. In concept, goals could be more narrative, or expressed as a range, that account for uncertainties and complications of managing multiple, ongoing, upland source inputs to surface sediments. Longer-term sediment goals could be expected only after programmatic levels of source control are complete.

IV. Next Steps: A Sustainable Remediation Approach

While dredging is an important technology, when combined with other technologies (capping, ENR, MNR), remediation goals can be achieved in a more sustainable, adaptable manner. However, we still do not fully understand all the relationships that affect how and when we can achieve long-term RAOs, such as lowering chemical concentrations in fish/shellfish tissue

---

[12] Ecology 2005. *Temporal Monitoring of Puget Sound Sediments: Results of Puget Sound Ambient Monitoring Program 1988 – 2005.* Prepared by V. Patridge, K. Welch, S. Aasen, and M. Dutch. Washington State Department of Ecology, Environmental Assessment Program. Publication No. 05-03-016. June 2005.

[13] Hart Crowser, Washington State Department of Ecology, EPA 2007. Puget Sound Partnership. *Control of Toxic Chemicals in Puget Sound. Phase 1: Initial Estimates of Loadings.* Publication Number 07-10-079. October.

[14] Van Metre, P.C., B.J. Mahler, and E. T. Furlong, 2000. Urban Sprawl leaves its PAH signature. *Env. Sci. Tech* (34): 4064 – 4070.

[15] EPA 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency. EPA-540-R-05-012, OSWER 9355.0-85. December 2005.

[16] Battelle 2009. *Panel: Strategies for Sustainable Sediment Management*. Fifth International Conference on Remediation of Contaminated Sediments, February 2–5, 2009. Jacksonville, FL.

[17] Wenning, R.J., D.B. Mathur, D.J. Paustenbach, M.J. Stephenson, S. Folwarkow, and W.J. Luksemburg, 1999. Polychlorinated Dibenzo-p-dioxins and dibenzofurans in stormwater outfalls adjacent to urban areas and petroleum refineries in San Francisco Bay, California. *Arch. Environ. Contam. Toxicol.* (37): 290–301. 1999.

to protect human health via consumption. Adaptive remedial solutions recognize the challenges of ongoing impacts from increased urbanization, source control effectiveness, and equilibrium conditions. Solutions must be protective, but it may be time to broaden our focus from managing chemical risks to providing sustainable remedies that help support economic activity, social welfare, and habitat enhancement.

In our experience, mass removal of large amounts of sediment to achieve a specific target concentration has historically been viewed by stakeholders as the surest way to significantly reduce risks associated with sediment-contaminated water bodies and restore their uses. However, numerous case histories (Table 1) suggest that reliance on active remediation that is focused on chemical stressors only, as the primary means to heal systems affected by multiple stressors, is not achieving the desired results. This narrow focus may squander the opportunity to leverage approaches other than dredging and capping to achieve a much broader set of improvements benefiting human health, the environment, and neighboring communities at these complex sites.

While chemical stressors clearly contribute to the decline in health of urban rivers, it is critical to recognize that urbanization over the past 100 to 200 years has also resulted in the loss of habitat, palustrine wetland complexes, safe passage for fish, and shoreline access for communities, as well as increased urban runoff, nutrient loading, and invasive species. This suggests looking beyond the traditional confines of sediment cleanup within Superfund to create a sustainable framework for evaluating and remediating complex sediment sites. A more holistic view of waterway (or river, lake, estuary) cleanup would consider a broader set of environmental, social, and economic factors, and ask “if we are going to spend extraordinary amounts of money, can we ensure that we do some good?” For some sites, removal of contaminated sediment may indeed be the appropriate management decision; whereas at other sites, factors such as water quality, ecological health, aesthetics, access, and recreational opportunities may warrant focused improvement strategies. In fact, if a remedy does not achieve tangible improvements in the overall ecological health and functionality of an impaired water body following active remediation, then we have not made the best use of our increasingly limited resources.

Adopting a holistic approach to improving the quality of our nation’s impaired rivers and water bodies should look to achieve visible and measurable improvements associated with a broader set of objectives for success than those currently prescribed in Superfund. An effective combined remedy should balance the environment with social and economic considerations to create sustainable solutions. This could involve using less resource intensive approaches such as MNR and reactive caps along with focused sediment removal. In addition, it could leverage public-private partnerships to enhance shoreline and water dependent uses such as creating urban parks; educational centers; recreational corridors for walking, biking, sitting, and overlook viewpoints; habitat areas; fish passage corridors; shoreline vegetation and shading; boat launches; economic development opportunities; and navigational depths for commercial and recreational vessels. For example, EPA’s Great Lakes National Program Office is currently seeking partners on waterfront revitalization projects that involve remediating contaminated sediment in Great Lakes Areas of Concern as part of its Great Lakes Legacy Act Program. This type of holistic framework can provide a greater return on investment and more benefits to both the environment and society than traditional sediment remediation strategies have historically achieved.

Acronyms:
CSL = cleanup screening level; CSM = conceptual site model; CSO = combined sewer overflow; ENR = enhanced natural recovery; mg/kg-oc = milligrams per kilogram organic carbon (carbon normalized); MNR = monitored natural recovery; NPL = National Priority List; PCBs = polychlorinated biphenyls; RAL = remedial action level; RAO = remedial action objective; RI/FS = remedial investigation/feasibility study; ROD = record of decision; SWAC = surface-weighted average concentrations; TSS = total suspended solids