## EXECUTIVE SUMMARY


Most contaminated sediment sites are characterized by generally low levels of contamination and large areas to be remediated, rendering *ex situ* approaches, including dredging and disposal economically challenging. *In situ* remedial approaches face the burden of demonstrating clear advantages over dredging and disposal in terms of criteria such as minimizing short-term risks (e.g. due to releases during remediation), technical feasibility, long term effectiveness, and cost. Nevertheless, the advantage of *in situ* sediment treatment is that it has the potential for overall protectiveness and permanence, while satisfying the regulatory preference for reduction of toxicity, mobility, or volume through treatment. There is also great potential for reduction in cost, relative to dredging and disposal, by eliminating the need for sediment removal as well as *ex situ* sediment dewatering, treatment, and solids disposal.

Risk-based decision making for selection of *in situ* technologies is contingent on a basin-wide prioritization and site-specific ranking of risk. Since sediments and contaminant sources are hydrodynamically linked, the criteria have to be balanced with the capabilities and maturity of the available technologies. A proposed technology opportunity matrix is shown in the summary table, as adopted from EPA. The table matches up the currently available technologies and their characteristics with application domains exhibiting different energetics (from high to low): river, banks, levies, flood plain.

**Sediment capping technology** is the least expensive way to manage effectively the risks to human health and to the surrounding ecological systems. Sediment caps are typically just 1 to 3 foot layers of sand or soil sometimes with an armoring layer. More recently, caps are being amended with coal or activated carbon to reduce bioavailability. Most sediment caps can be installed for 30K –100K per acre, depending on cost of material. The technology is becoming increasingly accepted by regulators and the public in hydrogeological regimes with limited potential for scouring (e.g. due to storm events, ice scour, or ship wakes and propeller wash), and where navigational stipulations are not limiting. The main uncertainty is that capping still requires a long-term monitoring strategy, unless it can be proven that the contaminants are destroyed in situ or retained permanently in place. There are sites where capping by conventional means may provide insufficient risk reduction or where ambiguities in cap performance goals or implementation feasibility have not provided sufficient confidence in a capping solution. Workshop participants clearly identified the need for fundamental research to develop active capping solutions to improve risk reduction, develop performance assessment measures, and eliminate uncertainty associated with high hydrodynamic environments. Improved characterization of the biogeochemical environment and the physical integrity of an emplaced cap were important research needs. Whereas conventional (sand) caps have been demonstrated at the field scale, reactive caps which include contaminant stabilization technology are at the pilot demonstration stage for quiescent riverine environments. Laboratory tests are needed to match the sediment and soil properties (soil grain size, compaction characteristic, friction properties of all material layers, shear strength and hydraulic conductivity) with the proper type of cap components.

| Technology | Development Status | Residuals Produced | O&M or Capital Intensive | Availability | System Reliability and Maintainability | Cleanup Time | Overall Cost | Halogenated SVOC | Hydrogeological Application Domain |
|---|---|---|---|---|---|---|---|---|---|
| **Containment** | | | | | | | | | |
| Capping<br>For Upland Disposal<br>- Asphalt/Concrete Cap<br>- RCRA Subtitle C Cap<br>- RCRA Subtitle D Cap | F | L, V | Cap | ■ | ■ | Δ | ■ | ○ | River<br>Levy |
| In Situ Sediment Caps<br>- Sand and armor caps for aqueous sediment<br>- Soil cover for flood plains | F | N | Cap | ■ | ♦, ✳ | ■ | ✳ | ○ | River<br>Floodp<br>lain |
| Landfill Cap Alternatives<br>- Water Harvesting<br>- Vegetative Cover | F | L, V | Cap | ■ | ■ | Δ | ■ | ○ | Flood<br>plain |
| Sequestration<br>( using coke or activated carbon) | P | N | N | ○ | ○ | Δ | ○,<br>✳ | ○ | Banks,<br>Flood<br>plain |
| **In-situ Biological Treatment** | | | | | | | | | |
| Bioremediation<br>- Aerobic<br>- Anaerobic | F | N | O&M | ■ | ○,✳ | ○ | ■ | ♦ | Flood<br>plain<br>River<br>sedime<br>nt |
| Phytoremediation<br>-Enhanced Rhizosphere Biodegradation<br>- Phyto-accumulation<br>- Phyto degradation<br>- Phyto stabilization | F | L, S | N | ○ | Δ | Δ | ■ | ♦ | Banks<br>Flood<br>plain<br>Levy |
| **Ex-situ Treatment** | | | | | | | | | |
| Biopiles | F | V | N | ■ | ■ | ○ | ■ | ♦ | All |
| Composting | F | N | N | ■ | ■ | ○ | ■ | ♦ | All |
| Land Farming | F | N | N | ■ | ■ | ○ | ■ | ○ | All |
| **Other Treatment** | | | | | | | | | |
| Excavation, and Off-Site Disposal | F | NA | N | ■ | ■ | ■ | ♦ | ○ | All |

Legend: F = Full; L = Liquid; O & M = Operation and maintenance; P = Pilot; S = Solid; V = Vapor; N = None. Technology Rating: ■ = Better; ○ = Average; Δ = Worse; ♦ = Contaminant specific; ✳ = Hydrology specific

The deployment and consideration of ***in situ*** **amendment technologies** requires substantial upfront and post-implementation monitoring and are highly dependent on site-specific characteristics. Considering the early stage and level of maturity of these technologies, the data gaps recognize the future needs for systems-level approaches to their development, scaled demonstration, and evaluation of performance characteristics. This requirement implies that proper operational and scaling constraints relevant to deployment should be adhered to for quantification of site- and technology-specific parameter uncertainties on the performance endpoints and economics. This issue is particularly pertinent considering the regulatory criteria for long-term effectiveness and permanence of any technology to protect human and ecosystem health and the current preference for dredging in remedial decision-making. Estimates per technology demonstration at the pilot scale are on the order of $0.75 to 1.5 M.

- **Sequestration** is a newly developed technology, which does not produce residuals. This method is used in conjunction with caps to reduce bioavailability of contaminants, but will not chemically destroy the contaminant. The costs of the technology depends on the type, concentration and the characteristics of the contaminant, type of sequestering material used, and the volume of the soil to be treated. In general, the most sequestering materials used (coke, sand, soil, activated carbon) are relatively inexpensive (coke is $100/ton). However, the process has to be evaluated at the lab and field pilot scale before implementation.
- **Bioremediation** technologies have been developed and demonstrated (most at the pilot scale) for soils, sludges, and contaminated groundwater, at moderate levels of contamination (ppb-ppm range). Bioremediation treatments generally require addition of inexpensive nutrients and they do not produce residuals, but may accumulate degradation products. The need for addition of non-indigenous species needs to be evaluated in light of the capability to stimulate the activity of indigenous microorganisms. The treatment of contaminated soil and contaminated water can be performed at the same time, however, the technology efficiency is dependent on biogeochemical characteristics of the environment to be treated. Based on the site-specific characteristics, the length of time needed for treatment varies from 6 months to 5 years. Due to the inherent variation in soil characteristic or aquifer properties, bioremediation lacks uniformity and the process is more difficult to monitor. The typical cost for enhanced bioremediation is on the order of $30 to $100 per cubic meter of soil, depending on the soil type and chemistry, type and quantity of amendments used, and type and extent of contamination.
- **Phytoremediation** represents a group of technologies, which have been demonstrated for volatile organic compounds.. The type of plant used is determined by the type and concentration of contaminant and by the soil characteristics. This technology is limited by the depth reached by the roots of the plants, contaminant concentration and bioavailability, soil characteristics, transport phenomena, and transfer of the contaminants from soil to air. Estimates for phytoremediation of inorganics in soil to a depth of 50 cm was $60,000 to $100,000 per acre, which is well below the figure needed for excavating and landfilling the same soil volume ($400,000 to $1,700,000). There are no good estimates for organic contaminants in sediments. Based on the above elements, the phytoremediation will probably most suited for areas that need soil stabilization in addition to bioremediation, such as banks, levies and flood plain.

By way of comparison to capping and *in situ* technologies, a number of *ex situ* technologies are presented in the technology matrix. These technologies are amenable to in situ implementation as well.

- **Biopiles** represent a fully developed and commercially available technology that has been applied successfully to nonhalogenated volatile organic compounds (VOC) and fuel hydrocarbons. The technology was also applied to some halogenated VOCs and semi-volatile OCs with varying effectiveness. This technology produces vapors (biogas) during contaminant treatment, therefore a thorough characterization of the site and type of contaminant is needed to identify the potential safety issues and identify the best design to minimize these issues. Laboratory and pilot tests are also needed to characterize the amendment mixtures and microbial populations that best promote the remediation process, potential toxic degradation products, and effectiveness of the process (i.e., the lowest contaminant concentration achievable), degradation rates and factors that will affect it. This is a simple technology, with few requirements for personnel to operate and maintain it. It does not require a capital investment. A few factors determine the final cost for this treatment: type of contaminant, air emission control needs, pre and post-treatment needs. However, the typical figures are from $130 to $260 per cubic meter.
- **Composting** technology is fully developed and commercially available. It has been applied successfully to soils and lagoon sediments contaminated with biodegradable organic compounds. This technology does not produce vapors as by-products of the biotreatment, however contaminant concentration and soil characteristics need to be determined before the correct composting process is selected. The equipment required for the treatment is fairly simple which makes the process economical. However, the final cost will vary depending on the type of contaminant, the amount of soil to be treated, the type of amendments required, the type of technology employed. For a total soil volume of 20,000 cubic yards, the estimated costs for windrow composting is approximately $190/cubic yard, $236/cubic yard for static pile composting and $290/cubic yard for composting in mechanically agitated vessels.
- **Land farming** is a fully developed and commercially available technology that has been proven in the treatment of heavier organic hydrocarbons in petroleum, diesel fuels, oil fuels, oily sludges, wood-preserving wastes (PCP and creosote), coke wastes, and some pesticides. This technology does not produce vapor residuals, but requires pretreatment of volatile contaminants to avoid their release into the atmosphere. Landfarming requires a large amount of space and its effectiveness depends on the atmospheric conditions (temperature and precipitations) which vary the amount of time needed for complete remediation and affects the reliability of the process. The remediation efficiency and the cost of the technology is affected by the type of contaminant treated and its concentration, depth of contamination, presence of organic volatiles and inorganic contaminants, surface geological features (e.g., topography and vegetative cover), subsurface geological and hydrogeological features, temperature, precipitation, wind velocity and direction, water availability, soil type and texture, waste loading rates, soil moisture and aeration content, soil organic matter content, cation exchange capacity, water-holding capacity, nutrient content, pH, atmospheric temperature, permeability, and microorganisms (degradative populations present at site). The cost for the ex situ treatment and placement of soil on a prepared liner are $100 per cubic meter.

Throughout the workshop, the need for comprehensive site characterization with respect to physical, chemical, and biological processes affecting contaminant fate, transport, and exposure became apparent, as did the importance of understanding these processes when selecting, implementing, and assessing the performance of an *in situ* management approach. The ultimate goal is to define a set of environmental conditions for which technologies are appropriate. In addition, guidance will be required to aid in cost-effective and environmentally sound decision-making about *in situ* management approaches for contaminated sediments. Regulatory acceptance for incorporating these technologies in site management and exposure mitigation is dependent on research, including in the following areas:

1. Investigative and analysis tools for baseline characterization and technology effectiveness assessment (e.g. bioassays for pre/post remedial assessment, uncertainty modeling)
2. Delivery platforms for *in situ* amendments (e.g. novel geotextiles, mixing systems)
3. Technology scaling to appropriate test sites (e.g. capping in impoundments, phytoremediation along river banks, bioremediation on exposed floodplain soils)
4. Investigate opportunities for technology integration (e.g. bioremediation with capping)

Statutory criteria and the precautionary principle have sustained a long-standing preference for dredging in remedial decision-making for contaminated sediments. Cleanup criteria in particular have been difficult tests for *in situ* remedies to satisfy. In addition to complying with applicable rules and regulations, remedial actions must be protective of human health and the environment and meet additional “balancing” criteria for remedial selection, which include long-term effectiveness and permanence; and reduction of toxicity, mobility, or volume through treatment. A U.S. EPA technical guidance document that is currently in preparation is expected to recommend that *in situ* remedies be considered for low level wastes, but that close scrutiny be applied to consideration of these remedies in cases presenting high potential risk and uncertainty.