Water Quality Aspects of Dredged Sediment Management

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Abstract

About 500 million yd^3 of sediment are dredged annually to maintain navigation depth in the US's approximately 25,000 miles of navigable waterways. Sediments in some of these waterways are contaminated with potential pollutants (e.g., heavy metals, organics including pesticides, PCBs, nutrients) from municipal, industrial, and agricultural sources. Because of this contamination there is concern about the potential water quality impacts that could be caused by the dredging and disposal of these sediments. In the 1970s the US Congress authorized the US Army Corps of Engineers to conduct a $30 million, five-year Dredged Material Research Program (DMRP) to evaluate, with laboratory and field studies, the potential water quality impacts associated with dredged sediment management and to develop protocols for evaluating sediments for their potential to cause adverse impacts upon disposal. Those studies showed that open-water disposal of dredged sediment would not be expected to be adverse to water quality, aquatic organisms or other beneficial uses of waterbodies. However, on-land, so-called "confined" disposal of dredged sediments could lead to water quality impacts to surface and groundwaters due to the release of heavy metals and some other pollutants. The DMRP studies and subsequent studies also reaffirmed that the concentration of contaminants in sediments does not predict the potential for contaminant release from sediments during or after disposal. More recent attempts to develop numeric, co-occurrence-based sediment quality criteria are also technically unsupportable and unreliable for screening, evaluation, or regulatory purposes.

Key Words
contaminated sediment, dredging, sediment, water quality, US waterways, sediment criteria

Introduction

The US has 25,000 miles of navigable waterways which include coastal waterways, such as the Intercoastal Waterway along the Eastern and Gulf Coasts; the major inland rivers, such as the Mississippi and Ohio; and major ports and harbors such as New York, Galveston, Houston, Los Angeles, San Diego Bay, San Francisco Bay, Puget Sound, and those of the US-Canadian Great Lakes. The US Army Corps of Engineers (COE) is charged by the US Congress with maintaining the navigation depth of these waterways as they fill with sediment. Maintaining navigation depth is considered to be of national importance to minimize transportation costs of bulk materials. To accomplish this, the COE dredges, or issues permits for contractors to dredge,

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about 500 million yds^3/yr of sediment from major waterways as well as smaller harbors, marinas, ports and channels.

In the 1960s, it was beginning to be recognized that the sediments of some US waterways were highly contaminated with chemicals that have the potential to be pollutants – i.e., to impair the beneficial uses of waterbodies as domestic water supply sources or for aquatic life/fisheries. Since the conventional method of disposal of dredged sediment was to dump it in deeper open water, concern arose about the solubilization and desorption of chemical constituents that were associated with sediment particles, when sediments were dredged and then introduced into a watercolumn at a disposal site. In response to water quality impact concerns, the US Army Corps of Engineers developed a $30-million, five-year Dredged Material Research Program (DMRP) to investigate the water quality significance of potential pollutants in dredged sediments. As part of that program the authors conducted extensive laboratory and field studies to investigate the release of sediment-associated contaminants and their impacts associated with open-water disposal of dredged sediment (Lee et al., 1978; Jones and Lee, 1978; Lee and Jones-Lee 2000), results of which are summarized or referenced herein.

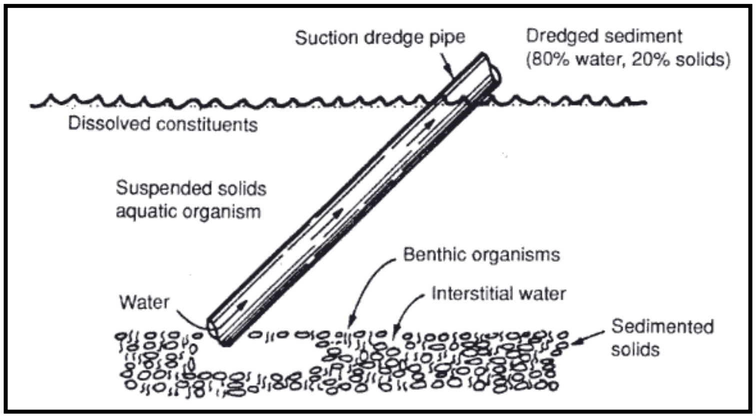
Impact of Type of Dredging/Disposal Operation

The development of an approach to evaluate and regulate potential water quality impacts of dredging and dredged sediment disposal requires an understanding of what transpires during such operations. In his *Handbook of Dredging Engineering*, Herbich (2000) described the various methods of dredging and dredged sediment disposal. Dredging is typically accomplished by either mechanical or hydraulic means.

Mechanical dredging/barge disposal. Mechanical dredging typically employs a clamshell or dragline bucket to remove sediments, which are then deposited onto a barge. Water introduced during dredging drains off the barge. After the barge is towed to the designated disposal site, the sediment is release and drops as a fairly cohesive mass to the bottom. Because there is limited mixing of the sediments being dredged with water, mechanical dredging results in limited opportunity for release of constituents from the sediments to the water. This limits the potential for sediment-associated contaminants to adversely impact water quality.

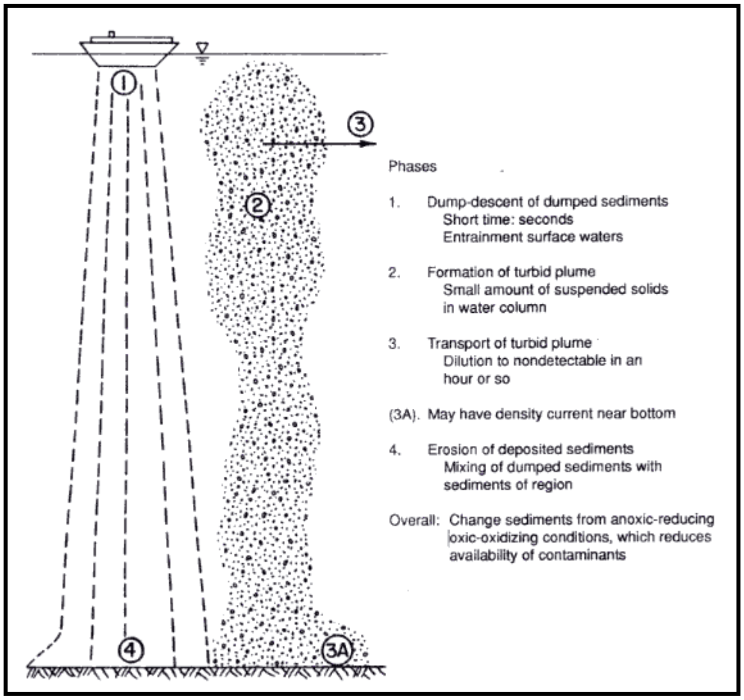
Hydraulic dredging. Hydraulic dredging involves sucking up the sediment as a slurry (Figure 1) and pumping it to an open-water or confined on-land disposal area or into the holding hoppers of a hopper dredge for transport to an open-water disposal site. The sediment:water ratio of the slurry is characteristically 1:4 by volume. The slurrying results in the mixing of the sediments with water, which tends to promote the release of constituents associated with the sediment and interstitial water into the slurry water. If hopper dredge is used, the excess water is typically allowed to drain off at the dredging site or during transport to the disposal site to optimize efficiency of sediment removal.

Figure 1. Diagrammatic Representation of Hydraulic Dredging



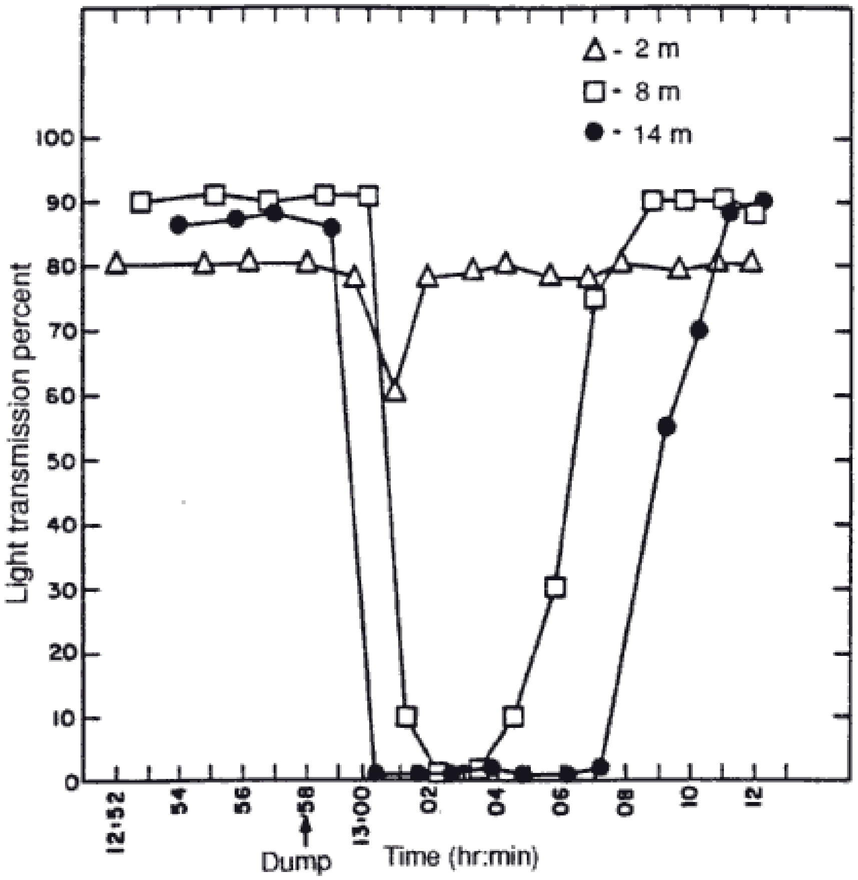
Hopper-Dredge Disposal. Figure 2 illustrates the watercolumn during disposal of dredged sediment from a hopper dredge. When the hopper-dredge is at the designated disposal location, the hopper doors are opened and the sediment is released. Most of sediment rapidly descends to the bottom as a fairly cohesive mass. As indicated in Figure 2, the descent of the dredged sediment from the hopper to the bottom of the watercolumn forms a turbid cloud in the waters of the region.

Figure 2. Illustration of Hopper Dredge Disposal of Dredged Sediment



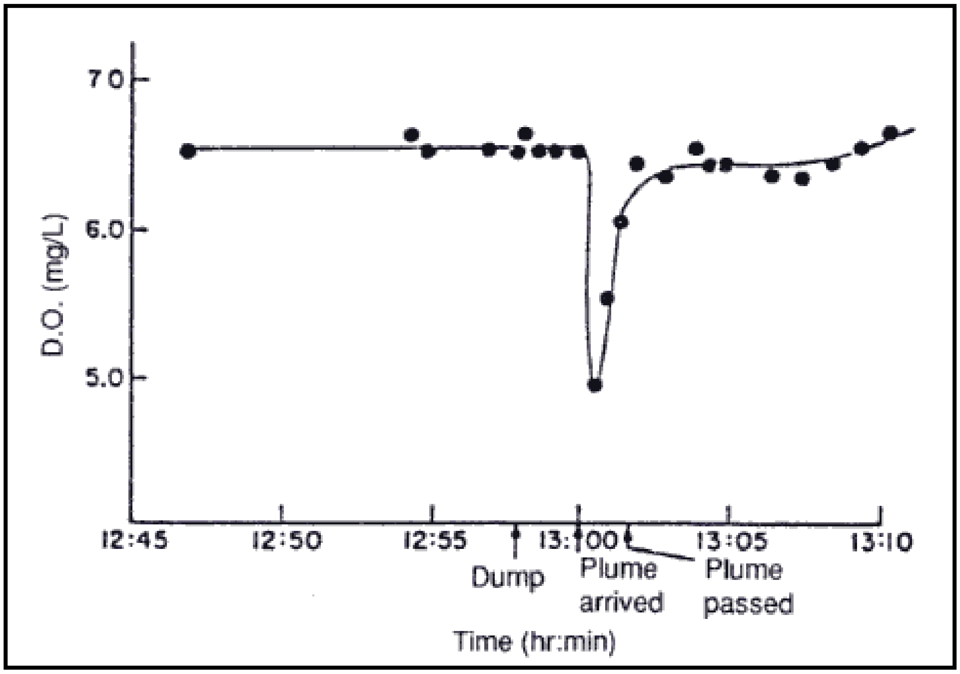
In their evaluation of the nature and water quality impacts of dredging and dredged sediment disposal, Lee et al. (1978) Jones and Lee (1978) monitored the watercolumn during more than 10 open-water disposal operations by measuring more than 30 physical and chemical parameters at various depths in the watercolumn before, during and after the passage of the turbid plume for each. Figure 3 shows the characteristic pattern of turbidity marking the passage of the turbid plume during open water disposal of dredged sediment. As indicated in this figure, near the surface (2-meter depth) the turbidity persisted at a location a few tens of meters down current from the dump for about 2 minutes. Near the bottom at 14 meters, the turbid plume turbidity persisted for about 7 minutes. The plume typically dispersed to indistinguishable from ambient turbidity of the disposal area in about one hour.

Figure 3. Passage of Turbid Plume during Open Water Disposal of Hopper-Dredged Sediment



Lee et al. (1978) found that there was, in some instances, some increase in concentration of some chemical constituents in this turbid cloud as well as some decrease in the dissolved oxygen (DO) concentration as is shown in Figure 4.

Figure 4. Dissolved Oxygen Concentration in Near-Surface Waters during Passage of Turbid Plume from Hopper-Dredge Disposal of Dredged Sediment

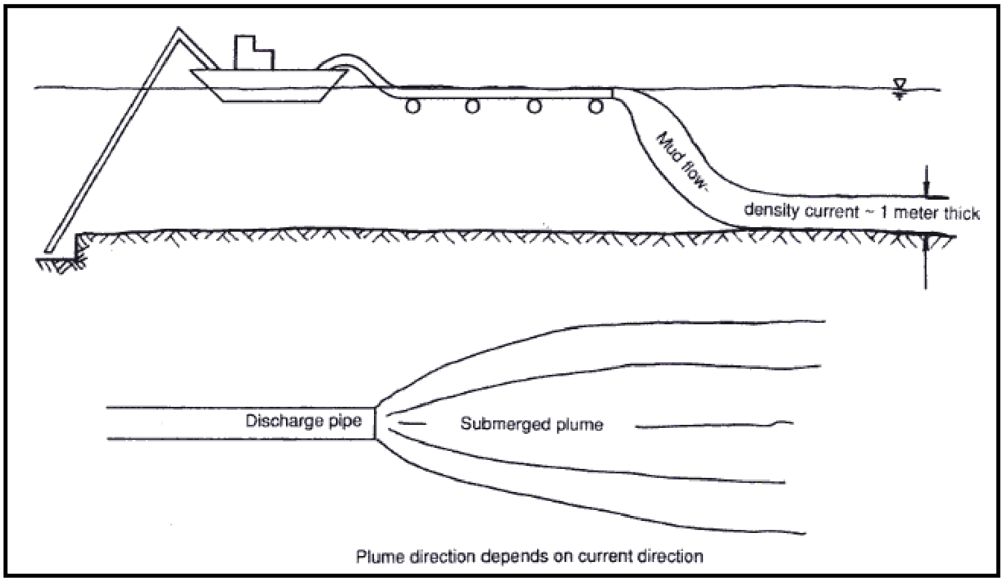


In the studies conducted by Lee et al. (1978), the only constituent of potential concern that was released was ammonia. The potential impact of ammonia on aquatic organisms at an open-water disposal site would have to be reviewed on a site-by-site basis since it would be controlled largely by the sensitivity of the organisms there and the rate of dilution.

The turbid plume associated with open water dumping of mechanically dredged sediment is even less pronounced than with hopper-dredge disposal because the mechanically dredged sediment is a more cohesive mass. It was concluded by Lee et al. (1978) that open-water disposal of even contaminated sediments would not be expected to cause water quality problems in the disposal site watercolumn because of the limited releases and the short exposures that aquatic organisms could experience from such releases.

Pipeline Disposal. The open-water pipeline disposal of hydraulically dredged sediments, illustrated in Figure 5, presents a situation significantly different from that of dumping of mechanically or hopper-dredged sediments in open waters. In this process, the dredged sediment slurry is transported via pipeline to the discharge location where it is discharged. The slurry sinks to the bottom and moves downcurrent as an approximately one-meter-thick density current along the bottom. This density current has been found to persist for thousands of meters from the point of discharge during disposal operations. Because this dredged sediment density current is typically characterized by low DO and/or the release of constituents such as ammonia, its presence at a location for extended periods of time (many hours to a day or so) could represent a significant adverse impact on aquatic organisms residing on the bottom in the path of the current. Ordinarily, however, such density currents do not persist in one location for extended periods because of the intermittent nature of pipeline disposal operations owing to frequent mechanical adjustments and the movement of the dredge. Further, the point of discharge is frequently moved because of the accumulations of sediments near the point of discharge.

Figure 5. Hydraulic Dredging with Open-Water Pipeline Disposal



Upland-"Confined" Disposal of Dredged Sediments. It has been commonly assumed that “confined” disposal of dredged sediment on land or behind a dike to form an island in water is less environmentally damaging than open-water disposal. This assumption misjudges the adverse impacts of open-water disposal and misjudges the water quality protection afforded by “confined” disposal. It is now more widely recognized that upland disposal of contaminated dredged sediments has a greater potential for causing adverse environmental impact than open-water disposal of dredged sediments.

As generally practiced, "confined" disposal does not truly confine deposited sediment or eliminate adverse impact. Rather, it provides a settling area where the larger, denser particles settle and the supernatant water and fine materials from the hydraulic dredging overflow the confinement and enter the nearshore areas of the nearby watercourse. Ironically, it is this overflow water that would represent a threat to water quality. It is the fine materials that do not readily settle in the disposal area that contain chemicals that could become available to adversely affect water quality. The area where the confined disposal overflow occurs, i.e., nearshore, is generally the most ecologically sensitive area of the waterbody. Thus, rather than being more protective of ecological/water quality, "confined" disposal operations pose a potentially greater risk than open-water disposal.

There are also potential adverse impacts associated with the materials that remain in the confined area. Studies conducted at the COE Waterways Experiment Station (Palermo, 1986) have shown that when the sediments in a confined disposal area dry, they tend to release constituents such as heavy metals. This appears to be related to the oxidation of the amorphous sulfides present in the sediments which keep the heavy metals in particulate form while the sediment is wet, and the development of acidic conditions. It may also be related to the aging of the ferric hydroxide precipitate (hydrous oxides). While freshly precipitated ferric hydroxide has a substantial holding power for constituents, aged precipitates, especially those that dry out, lose some of this holding power. It is therefore not surprising to find that dredged sediments that dry in a confined disposal area release appreciable heavy metals when the area is subjected to precipitation or receives additional dredged sediment. The contaminants released then drain from the confinement area to the nearby nearshore waters. There is also the potential for chemicals released from the confined dredged sediments to pollute area groundwater. It is important therefore that those who advocate upland disposal of contaminated dredged sediments conduct a proper, critical review and evaluation of the potential adverse impacts of the constituents associated with the sediments which leave the confined disposal area during overflow during dredging operations or via drainage or seepage from the disposal site.

Contaminant Release from Redeposited Sediment. In addition to there being concern about the potential watercolumn impacts of contaminants in dredged sediment, there is need to evaluate the potential for chemicals in the redeposited dredged material to be released to the watercolumn at the disposal site at sufficient rate to be adverse to water quality. In order to assess whether measured or unmeasured chemicals could have an adverse impact on watercolumn organisms or organisms that might colonize the redeposited dredged sediments shortly after deposition, Lee et al. (1978) developed a dredged sediment elutriate screening toxicity test. The dredged sediment toxicity screening test involves introduction of standard test organisms into the settled elutriate from a standard oxic elutriate test procedure (oxic mixing of one volume sediment with 4 volumes water and oxic settling). Grass shrimp (*P. pugio*) were used for marine conditions and daphnids were used for freshwater. Lee et al. (1978) Jones and Lee (1978) found that sediments collected near urban and industrial areas, showed toxicity to aquatic life under the conditions of the laboratory test. Typically, in tests in which toxicity was found, from 10 to 50% of the test organisms were killed in the 96-hour test period. Toxicity was substantially less than may have been expected based on the elevated concentrations of the myriad measured and unknown contaminants in the sediments. Thus, while many of the sediments tested had high concentrations of heavy metals and chlorinated hydrocarbons of various types, those constituents were present in the sediments largely in unavailable, non-toxic forms. In the case of contaminated New York Harbor sediments, Jones and Lee (1988) and Jones-Lee and Lee (1993) found that the toxicity found in the toxicity testing was due to ammonia. Other investigators are also finding that ammonia is one of the principal causes of sediment toxicity to aquatic life. In general, however, it has been found that disposal sites are of sufficiently high energy and the rates of release of pollutants sufficiently slow that water quality problems in the watercolumn do not occur from redeposited sediments.

However, the bioaccumulation or buildup of chemical contaminants in higher trophic-level aquatic organisms that recolonize the disposal site is of concern. There are a few constituents, including methylmercury, PCBs, and PAHs, that have the potential for trophic magnification in aquatic environments. The bioaccumulation of constituents within organisms occurs from both direct uptake of constituents from the water and the consumption of particles that have constituents associated with them as well as the consumption of other organisms. The bioaccumulation and subsequent impact of chemical contaminants cannot be predicted based on their concentration in the sediment. Evaluation of this potential impact needs to be made on a site-specific basis using organism bioaccumulation tests of the type described by the US EPA and COE (1991; 1998).

Regulating Dredged Sediment Disposal

In the 1972 amendments to the Federal Water Pollution Control Act (PL 92-500), Congress specified in Section 404 that the disposal of dredged sediments in US waters may take place, provided that there is an avoidance of "unacceptable effects." It further stated that the disposal of dredged sediments should not result in violation of applicable water quality standards after consideration of dispersion and dilution, toxic effluent standards, or marine sanctuary requirements, and should not jeopardize the existence of endangered species. In order to implement these regulations, the US EPA and Corps of Engineers developed two dredged sediment testing manuals, *Evaluation of Dredged Material Proposed for Ocean Disposal - Ocean Testing Manual* (US EPA and COE, 1991), and *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Inland Testing Manual* (US EPA and COE, 1998). The Ocean Testing Manual was developed to implement Section 103 of Public Law 92-532 (the Marine Protection, Research, and Sanctuaries Act of 1972). These manuals prescribe testing procedures to assess biological effects such as toxicity and bioaccumulation of hazardous chemicals from dredged sediments.

The reliable evaluation of the potential adverse effects that may occur from dredging and dredged sediment disposal in a particular manner requires effort and understanding of the biological, chemical and physical processes involved. It has been long-recognized that potential adverse impacts cannot be determined based on the bulk chemical composition of the sediment; this understanding had, in fact, led to the DMRP studies of the 1970s. However, in an attempt to simplify the process and make determinations more administratively expedient, the US EPA and other regulatory agencies have again attempted to regulate dredged sediment disposal based on chemical concentration-based “sediment quality criteria.” One such approach that has been advanced is based on the “co-occurrence” in a sediment of a total concentration of a chemical and a biological response not even necessarily caused by the chemical of concern. Lee and Jones-Lee (2004a) reported on their reviews of co-occurrence-based so-called sediment quality guidelines and discussed why they are technically invalid and cannot provide a reliable evaluation for any purpose. Lee and Jones-Lee (2004b) recommended that a “best professional judgment” triad, weight-of-evidence approach be used to evaluate the water quality significance of chemicals in aquatic sediments. This approach is based on the integrated use of aquatic toxicity, bioaccumulation, organism assemblage information, and physical and chemical information focused on identifying the cause of aquatic life toxicity. Additional information on the water quality impacts of chemicals in sediments is available from Lee and Jones-Lee (1993; 1996), DOER (2002), and in the US Army Corps of Engineers bulletin, “Dredging Research,” available on request from www.wes.army.mil/el/dots/drieb.html.

Dredging for Sediment Cleanup

In addition to dredging for maintaining navigation depth of waterways, dredging is being undertaken to remove (remediate) contaminant-laden sediments from Superfund and other sites. Evison of the US EPA Office of Emergency and Remedial Response summarized the magnitude of the problem of contaminated sediments at Superfund sites in a presentation entitled, “Contaminated Sediment at Superfund Sites: What We Know So Far” at a US EPA and US Army Corps of Engineers national workshop (Evison, 2003). At the same workshop, Ellis, Sediments Team Leader with the US EPA Office of Emergency and Remedial Response, presented a discussion entitled, “Superfund Cleanup Issues at Contaminated Sediment Sites.” The dredging of contaminated “Superfund” sediments and their disposal requires attention to the same water quality/environmental quality, and contaminant availability, transport, and impact issues that are faced in dredging of contaminated sediment for channel depth maintenance.

An example of the use of dredging for sediment remediation is the current cleanup of PCB-contaminated sediments in the Hudson River in New York state. The Hudson River sediments from Hudson Falls to New York City (a distance of 200 miles) were contaminated by PCBs discharged for decades in wastewaters by General Electric Company. US EPA (2004a) provides information on the past and proposed dredging of the PCB-contaminated sediments in that area. Another example Superfund dredging is the dredging of PCB-contaminated sediments from the Wisconsin Fox River, WI (US EPA, 2004b). There, an issue of considerable concern is the appropriateness of placing PCB-contaminated sediments in municipal landfills.

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