Development of a Contaminated Sediment Remediation Program[1]

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June 2005

The May 2005 issue of *World Dredging* contained an article, "Rhine Channel Sediment Remediation Feasibility Study (Newport Beach, California)," by S. Cappellino, R. Hiemstra and M. Danieli (Cappellino et al. 2005), which presents information on a Rhine Channel, Lower Newport Bay, California, sediment remediation feasibility study. According to the article, in June 2002 the US EPA (2002) Region 9 instituted TMDLs to control copper, lead, selenium, zinc, chromium, mercury, chlordane, dieldrin, DDT and PCBs in Rhine Channel and Lower Newport Bay. Cappellino et al. (2005) state that the purpose of the sediment remediation feasibility study is to *"restore beneficial uses to the Rhine Channel and Lower Newport Bay,"* including marine aquatic life habitat as well as other designated beneficial uses for these waterbodies. Cappellino et al. (2005) state,

> *"Because TMDLs do not exist for many chemicals of concern (COCs) at this site, additional cleanup values were needed. Effects range-low (ER-L) and effects range-medium (ER-M) values were added for all COCs where a TMDL was not available (Table 1)."*

Table 1 lists ER-L and ER-M values for nine heavy metals, and several other chemicals including DDT and PCBs. Table 1 also presents TMDL goals for the Rhine Channel contaminated sediments that were developed by US EPA Region 9 (US EPA 2002). For TMDLs for sediments the US EPA Region 9 used cooccurrence-based so-called sediment quality guidelines, such as Long and Morgan ER-L and ER-M values and MacDonald PEL/TEL values. A critical review of the technical basis for developing the ER-Ls, ER-Ms and MacDonald guideline values, as well as the TMDLs, shows that they are not based on a technically valid approach for defining the measured and unmeasured constituents in the Rhine Channel sediments that should be considered in developing an appropriate remediation plan for the Rhine Channel sediments.

Validity of ER-L and ER-M Values

The ER-L and ER-M values are derived from work originally conducted by Long and Morgan (1990), where a "cooccurrence" association was developed between total chemical constituent concentrations and some measured biological effect such as sediment toxicity to some form of aquatic life. No attempt was made to develop cause and effect between the total concentrations of a chemical(s) in a sediment sample and the biological effect that was used to establish the cooccurrence-based sediment quality guidelines. The Jones and Lee (1978) and Lee et al. (1978) data base for heavy metals, pesticides/PCBs, and nutrients, containing approximately 30,000 entries from about 100

[1] Submitted for publication in World Dredging, June (2005).

US waterway sediment sites, demonstrated that there is no relationship between the total concentration of a chemical or group of chemicals and sediment toxicity. A summary of the 1970s US Army Corps of Engineers (USACE) Dredged Material Research Program (DMRP) studies by the authors and their associates is available in Herbich's Handbook of Dredging Engineering (Lee and Jones-Lee 2000).

Long and Morgan used some of the data that the authors and his associates developed in the 1970s for the Corps of Engineers DMRP. Unfortunately some the key information in the Lee et al. (1978) DMRP studies was not used by Long and Morgan in developing their cooccurrence-based guidelines. From the information provided in the Cappellino et al. (2005) article, it appears that the elevated concentrations of several heavy metals compared to cooccurrence-based so-called sediment quality guidelines are being used to develop sediment cleanup goals for Rhine Channel sediments. There is a substantial literature that discusses the unreliability of using cooccurrence-based ER-L and ER-M values to define whether a sediment quality problem exists, as well as to define sediment cleanup objectives. Jones-Lee and Lee (2005) have recently published a comprehensive review of why cooccurrence-based sediment quality guidelines are unreliable for use for any purpose associated with sediment quality evaluation/remediation.

Reliability of US EPA Region 9 TMDL Sediment Cleanup Goals

During the mid to late 1990s the authors were involved in detailed studies of the Upper Newport Bay watershed and the Bay. This work was sponsored by the US EPA under 205(j) and 319(h) grants; by the California Regional Water Quality Control Board, Santa Ana Region; by the Orange County Public Facilities and Resources Department (stormwater runoff water quality management agency) and others. The total funding was on the order of a half-million dollars. The five-year program included review of the sediment quality data for Upper and Lower Newport Bay and the Rhine Channel. Lee and Taylor (1999) discussed some of the problems with the US EPA Region 9 approach for evaluation of sediment quality in Newport Bay, including the inappropriateness of using Long and Morgan ER-L and ER-M values to evaluate sediment quality. This approach can readily lead to incorrect assessment of sediment quality that leads to overregulation of regulated chemicals and underregulation of unregulated chemicals. The problems with the US EPA Region 9's using cooccurrence-based sediment quality guidelines for regulatory purposes have been discussed by Lee (2005).

In October 2002 the Aquatic Ecosystem Health and Management Society (AEHMS, 2002) held an international conference ("Aquatic Ecosystems and Public Health: Linking Chemical, Nutrient, Habitat and Pathogen Issues"), where a number of keynote speakers discussed the unreliability of cooccurrence-based sediment quality guidelines. Jones-Lee and Lee (2005) have summarized several of these presentations. The presentations from this conference have been published in the journal *Aquatic Ecosystem Health & Management*, Volume 7, Number 3, and Volume 8, Number 1. At this conference Lee and Jones-Lee (2004a) presented a review, "Appropriate Incorporation of Chemical Information in a Best Professional Judgment 'Triad' Weight of Evidence Evaluation of Sediment Quality." The best professional judgment triad weight of evidence approach is recognized as the approach that should be used to evaluate sediment quality. It incorporates chemical effect information (such as aquatic life toxicity) with aquatic organism assemblage information, to characterize the impacts of chemicals on aquatic ecosystems. Chemical information is used in this approach through toxicity investigation evaluations (TIEs) to determine the cause of aquatic life toxicity. It should not be used to establish critical concentrations of chemicals in sediments based on cooccurrence guidelines.

How Should the Water Quality Impacts of Contaminated Sediments be Evaluated?
The key to developing a technically valid, cost-effective sediment quality evaluation, as impacted by chemicals present in the sediments on the beneficial uses of the waterbody in which the sediments are located, is the development of a clear definition of the objectives of the evaluation. The focus of the evaluation should initially be on defining the water quality impairments that are related to the presence of chemicals in the sediments. Typically, the water quality field focuses on chemical concentrations rather than chemical effects on water quality beneficial uses of the waterbody. As part of the work in the Upper Newport Bay watershed studies, Jones-Lee and Lee (1998) developed the Evaluation Monitoring approach which changes the focus of water quality evaluations to evaluating water quality impacts rather than chemical concentrations. As they discuss, there is often a poor correlation between the total chemical concentration in the water column and/or aquatic sediments, and the impacts of chemicals on aquatic life and other beneficial uses of waterbodies.

There are two areas of primary concern with respect to potential impacts of chemicals on water quality: toxicity to aquatic life, and serving as a source of chemicals that bioaccumulate in higher trophic level organisms such as fish that are a threat to the health of those who use the organisms as a source of food. Also of concern are the potential impacts to wildlife such as birds and terrestrial mammals that use fish as a source of food. The organochlorine "legacy" pesticides such as DDT, dieldrin, chlordane and toxaphene as well PCBs and dioxins are common constituents that accumulate and persist in aquatic sediments and bioaccumulate in fish and, therefore, are a threat to cause cancer in those who use the fish as food. There is also concern about the bioaccumulation of mercury (methyl mercury) that occurs in fish that is a threat to human health (fetuses and pregnant women) and fish-eating birds. Methyl mercury is formed in aquatic sediments as a result of biochemical reactions between inorganic mercury and organic matter.

Evaluating Sediment Toxicity. It is relatively easy to determine whether a sediment is toxic to aquatic life. There are well-established standardized sediment toxicity tests that can be used to determine whether a chemical(s) in sediments causes toxicity to the standard test organism (see US EPA 2000). Toxicity test results can be used to identify **potential** water quality problems that are caused by chemicals in sediments. Finding sediment toxicity does not necessarily mean that the beneficial uses of a waterbody are being significantly impaired. The finding of sediment toxicity should be followed up by an assessment of whether the numbers and types of benthic/epibenthic aquatic organisms are significantly different from that expected based on the benthic organism habitat characteristics. Typically this evaluation will require that gradient analyses be conducted to determine if there is a relationship between the presence/magnitude of toxicity in the sediments and the numbers and types of organisms present in the sediments. Also there will likely be need to establish one or more reference sites that are apparently unimpacted by the chemicals of potential concern as well as other known chemicals that could be impacting the organism assemblages in the sediments of concern.

If toxicity is found in the sediments and it appears to be significantly adversely impacting the aquatic organism assemblages, then it will be important that an effort be made to determine the cause of the toxicity. This evaluation will require the use of a toxicity identification evaluation (TIE) to relate the magnitude of toxicity to the concentration of a chemical(s) or some form of the chemical in the sediments. It is important to not try to use Long and Morgan or MacDonald cooccurrence-based so-called sediment quality guidelines (such as ER-L, ER-M and PEL/TEL values) to determine the cause of toxicity. As discussed by Jones-Lee and Lee (2005), these values are not reliable to discern the cause of toxicity in a sediment.

It is important to understand that the cause of toxicity in a sediment can be due to unregulated chemicals. For example it is now being found (Weston et al. 2004 and Weston 2005) that some aquatic sediments in California are toxic to aquatic life due to pyrethroid-based pesticides used in agriculture and urban areas. Pyrethroid-based pesticides, as well as most other currently used pesticides, are essentially unregulated with respect to water quality impacts. The sediments in the Rhine Channel could be dredged to remove the heavy metals and PCBs, yet still be toxic due to pyrethroid or other pesticides that are introduced into the sediments from areas where they are being used for urban and agricultural purposes. Lee and Jones-Lee (2003) have discussed the potential problems of evaluating the cause and sources of contaminants that accumulate in the sediments near boat works, marinas and harbors, such as in the Rhine Channel. Urban and agricultural stormwater runoff can be an important source of regulated and unregulated sediment-associated chemicals that can accumulate in sediments in these areas, and can affect the beneficial uses of waterbodies in which the sediments are located.

Evaluating Excessive Bioaccumualtion. To determine if the sediments of an area are a source of chemicals that are bioaccumulating to excessive levels in edible fish, the initial phase of the evaluation should be on determining whether the edible fish in an area of concern have excessive tissue concentrations compared to US EPA and California Office of Environmental Health Hazard Assessment (OEHHA) human health guidelines. If excessive concentrations of a chemical are found in edible fish tissue, then samples of sediments should be taken to determine if the sediments have concentrations of available forms of the chemical that could be bioaccumulated through the food web to excessive edible tissue concentrations in fish. Lee and Jones-Lee (2002) have provided a detailed discussion of approaches that can be used to evaluate whether aquatic sediments are a potentially significant source of bioaccumulatable chemicals that are causing higher trophic level organisms to be a threat to human health when used as food.

If after appropriate study it is found that the sediments of an area are a source of chemicals that are bioaccumulating to excessive concentrations in edible fish tissue, an evaluation should be conducted to determine if sediment remediation can be effectively implemented, either by removal from the waterbody or, if possible, capping of the sediments to remove them from contact with organisms that can transfer the sediment-associated chemicals to the food web. Luthy et al. (1997) and Luthy (2003), in his presentation at the USACE/USEPA/SMWG (2003) Workshop on Environmental Stability of Chemicals in Sediments, has discussed the potential for using activated carbon to immobilize some organic pollutants (such as chlorinated hydrocarbon pesticides, PAHs and PCBs) in sediments and thereby reduce the bioaccumulation of the chemical through the food web.

If it is found that real significant water quality problems are occurring in the waterbody that are impairing the beneficial uses of the waterbody, which are caused by sediment-associated chemicals, and it is decided that sediment removal is appropriate, then an approach for management of the dredged sediments that properly considers the near-term and long-term potential impacts of the various management approaches should be developed.

Alternatives for Dredged Sediment Management

One of the "Alternatives" for contaminated dredged sediment management listed by Cappellino et al. (2005) is *"mechanical dredging with disposal at upland landfill."* Cappellino et al. (2005) have listed *"Upland Disposal" "Technical Effectiveness" "Long Term"* as *"Good."* However, this assessment does not properly evaluate the long-term effectiveness of upland disposal in today's modern US EPA Subtitle D landfills. The issue of disposal of contaminated dredged sediments in a municipal solid waste (MSW) landfill is an area of discussion by many of those concerned about the total environmental impact of waste management. It is often assumed that disposal of contaminated dredged sediments in a minimum design US EPA Subtitle D single composite lined MSW landfill is environmentally safe. However, as discussed by Lee and Jones-Lee (2005a) ("Flawed Technology"), minimum design Subtitle D MSW landfills with a single composite liner at best only postpone when groundwater pollution will occur by landfill leachate; this type of landfill containment system based on thin plastic sheeting and compacted clay liners will not prevent it, and the groundwater monitoring systems allowed by regulatory agencies at Subtitle D landfills will not necessarily detect it before widespread groundwater pollution has occurred. Lee and Jones-Lee (2004b) have reviewed many of the problems associated with current practices of managing contaminated sediments and soils in today's landfills.

At a recent contaminated sediment management workshop organized by the Corps of Engineers, US EPA Superfund, and the Sediment Management Work Group (USACE/USEPA/SMWG 2004), the topic of the appropriateness of disposal of contaminated dredged sediments in MSW landfills was discussed. As a followup to this discussion, Lee and Jones-Lee (2005b) ("Disposal of Contaminated Dredged Sediments in MSW Landfills: Need to Consider the True Cost") have reviewed the potential public health, groundwater resource and environmental problems associated with disposal of contaminated dredged sediments in today's minimum design US EPA Subtitle D MSW landfills. As they discuss, while the contaminated dredged sediments are not considered to be “hazardous wastes” in accord with the US EPA TCLP waste classification approach, the constituents in contaminated dredged sediments can be a threat to public health, groundwater resources and the environment when present in landfill leachate. It is well understood (see Lee and Jones-Lee 2005a) that a single composite liner allowed in Subtitle D MSW landfills will not be effective in preventing MSW leachate from polluting groundwater for as long as the wastes in a MSW “dry tomb” landfill will be a threat to generate leachate. Further, the groundwater monitoring systems allowed by regulatory agencies is normally highly unreliable for detecting landfill leachate-polluted groundwater in accordance with regulatory requirements when it first reaches the point of compliance for groundwater monitoring. As discussed by Lee and Jones-Lee (2005a), disposal of contaminated dredged sediments in a minimum design landfill allowed under US EPA Subtitle D is a flawed technology that postpones when groundwater pollution occurs and could lead to a Superfund-like groundwater cleanup. Lee and Jones-Lee (2005b) have provided guidance on issues that need to be considered in upland disposal areas and landfills that do not lead to long-term liability of the agency/entity that disposes of contaminated sediments.

An important issue in developing a remediation program for contaminated sediments is an evaluation of whether current sources of regulated as well as unregulated contaminants are being contributed to the sediments proposed for remediation that would negate improving the beneficial uses of the waterbody associated with spending funds for sediment remediation. An example of this type of situation is the US Fish and Wildlife Service proposed remediation of Grand Calumet River (northern Indiana) sediments by dredging in order to remove the elevated concentrations of chemicals present in the sediments and the toxicity associated with the sediments. Lee (2004) has reviewed the US Fish and Wildlife Service report which serves as the basis for the recommendation that the Grand Calumet River sediments be dredged as part of a sediment remediation program.

The US Fish and Wildlife Service based their assessment on the use of MacDonald cooccurrence-based sediment quality guidelines. As Lee discussed, theses guidelines are not technically valid for determining whether a chemical or group of chemicals present in sediments is a cause of aquatic life toxicity or otherwise impairing the beneficial uses of a waterbody. Since the Grand Calumet River still receives combined sewer overflows and urban stormwater runoff from Hammond, Indiana, and other communities, it is quite likely that spending many millions of dollars dredging the Grand Calumet River sediments to remove elevated concentrations of potential pollutants and aquatic life toxicity would have little or no impact on the beneficial uses of the Grand Calumet River, since current sources of regulated as well as unregulated chemicals are being added to the River that are accumulating in the sediments that could cause aquatic life toxicity.

It is essential that any credible, cost-effective sediment remediation program include a detailed understanding of the current sources of constituents that could accumulate in the sediments and thereby affect sediment quality/beneficial uses after remediation of the sediments has been accomplished. Where this type of situation occurs, the sediment remediation program must include source control of the constituents that could lead to continued water quality problems with sediment-associated contaminants.

Conclusion

Overall, at this time the water quality problems caused by the elevated chemicals in the Rhine Channel sediments have not been adequately defined. The Cappellino et al. (2005) article's focus on chemical concentrations in sediments rather than on the impact of the chemicals on water quality/beneficial uses could lead to spending large amounts of funds remediating the Rhine Channel sediments and failing to improve the aquatic life related beneficial uses of the waters associated with this channel, due to failing to properly characterize the water quality impacts of the sediment-associated chemicals. Before proceeding with formulating the remediation plan for the Rhine Channel sediments, it will be essential that an adequate evaluation be made of the water quality impacts of the regulated and unregulated chemicals that are present in Rhine Channel sediments, their current sources and the potential long-term impacts of the approaches for the management of the contaminated sediments. While this discussion has focused on the Lower Newport Bay Rhine Channel contaminated sediment situation, it has broader applicability to developing technically valid, cost-effective approaches for managing contaminated sediments.

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