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Environmental Effects of Dredging Technical Notes

Proposed New Guidance for Interpreting the Consequences of Bioaccumulation from Dredged Material

Purpose

This note describes, for consideration, modifications to current guidance for evaluating and interpreting bioaccumulation data collected during regulatory evaluations of dredged material.

Background

Evaluating the environmental consequences of contaminant bioaccumulation resulting from dredged material disposal is a complex technical and regulatory problem. This problem is magnified by the high cost of bioaccumulation testing and the lack of explicit guidance on how bioaccumulation data should be interpreted and used within a regulatory program.

Bioaccumulation is a measurable phenomenon, rather than an effect. Consideration must be given to specific information about the likelihood of biological effects (for example, reduced survival, growth, and reproduction in animals; cancer risk in humans) that are associated with contaminant residue levels in order to make objective decisions, from a regulatory standpoint, about what level of bioaccumulation constitutes an "unacceptable adverse effect."

The existing guidance attempts to overcome this problem with two approaches, both of which use low trophic level aquatic organisms and a reference-based comparison. In the first approach, the level of bioaccumulation of a specific contaminant is compared with a numerical effect limit, such as a Food and Drug Administration action level or a fish advisory. If the level of the contaminant in the organism exceeds the numerical limit, there is the potential for the dredged material disposal to have an "unacceptable adverse effect." If it does not, or there is no numerical limit, a second approach is used which involves a comparison with data collected from

animals exposed to a reference sediment. If bioaccumulation in the animals exposed to the dredged material is statistically greater than that of animals exposed to the reference, a number of subjective factors are then evaluated to determine whether dredged material disposal will result in an "unacceptable adverse effect" (U.S. Environmental Protection Agency/U.S. Army Corps of Engineers (USEPA/USACE) 1991, 1994).

The first approach is straightforward in that it uses numerical evaluation factors. However, the utility of this approach is limited by the small number of published numerical limits compared with the large number of contaminants commonly present in freshwater and marine sediments. Because the evaluation factors in the second approach are subjective, they cannot be consistently applied in the decision-making process. This has created a major problem in the interpretation of bioaccumulation data.

In response to this problem, the Corps of Engineers and the Environmental Protection Agency held a joint bioaccumulation workshop in Denver, Colorado, on August 29-31, 1995. The purpose of the workshop was to determine if more effective regulatory guidance could be developed for interpreting the effects of bioaccumulation from data currently collected during evaluations of dredged material. Workshop participants were from the Corps of Engineers, EPA, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, Department of Defense, academia, and the private sector. The proceedings of this workshop are summarized in Bridges and others (1996).

Additional Information

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Discussion

Following the Denver workshop, the authors of this technical note were tasked by the Headquarters, U.S. Army Corps of Engineers, to suggest ways to improve current guidance regarding the use and interpretation of bioaccumulation data collected during evaluations of dredged material. Discussions and recommendations from the Denver workshop formed the basis for the group's subsequent considerations.

The suggested modifications, outlined below, are discussed within the four-tiered framework used in the guidance manuals for evaluation of dredged material (USEPA/USACE 1991, 1994) (Figure 1). These procedures are intended to increase the effectiveness of the regulatory process with regard to bioaccumulation. Comments regarding these suggestions should be directed to the authors.

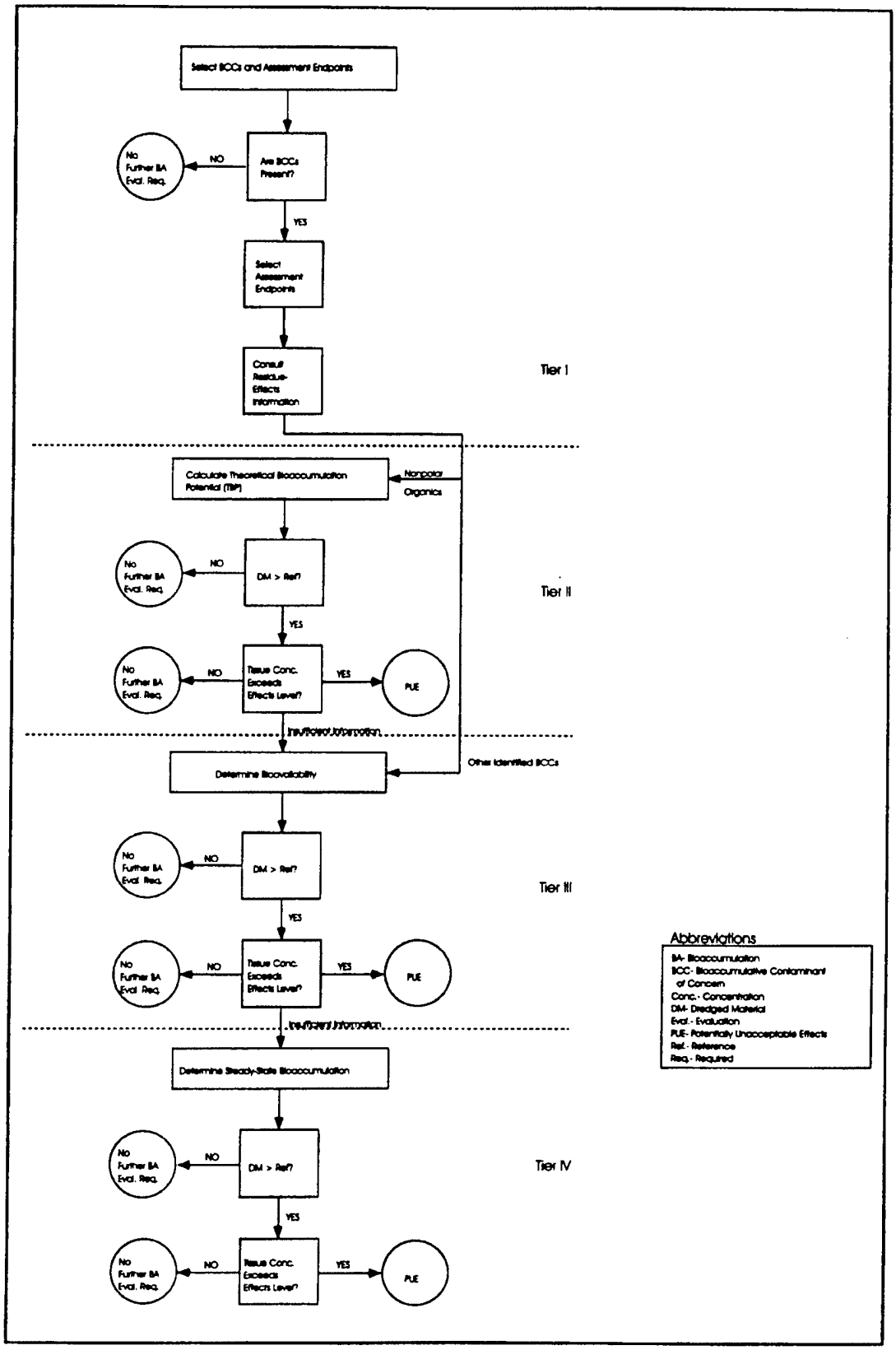

Figure 1. Flowchart describing proposed guidance for evaluating bioaccumulation data

Tier I

The purpose of Tier I, as described in existing guidance (USEPA/USACE 1991, 1994), is to determine whether a compliance decision can be reached regarding dredged material disposal on the basis of existing information, including all previously collected physical, chemical, and biological data. A primary task in Tier I is to identify the environmental contaminants of importance in the dredged material under consideration. Such an identification is necessary to select appropriate analyses in Tiers II, III, and IV.

Prepare List of Site-Specific Bioaccumulative Contaminants of Concern. As a result of discussions at the August 1995 workshop, it became clear that bioaccumulation data are most appropriately used to evaluate the potential for contaminant effects on higher trophic level organisms (for example, fish, wildlife, and humans). For such organisms, contaminant trophic transfer, that is, the movement of contaminants from lower to higher trophic levels through the ingestion of contaminated food, represents the major route of contaminant exposure. Direct contact or ingestion of sediments is a much less important route of exposure to vertebrates in most instances.

Trophic transfer, to the extent necessary to result in adverse effects, will occur only for a subset of the contaminants found in dredged material. This is largely the result of differences in chemistry among contaminants. Trophic transfer and bioaccumulation are most likely for those organic contaminants with a log K_{ow} > 4. Table 9-5 in the Ocean Testing Manual (USEPA/USACE 1991) and Table 9 in the Inland Testing Manual (USEPA/USACE 1994) should be consulted for a list of organic contaminants that meet this criterion.

Metals and metalloids are much less likely to bioaccumulate and cause adverse effects at higher trophic levels, with a few notable exceptions (methyl mercury, lead, cadmium, organotins, arsenic, and selenium). During the selection of bioaccumulative contaminants of concern (BCCs) in Tier I, the evaluation should focus on the subset of organic and inorganic contaminants described above. If none of these contaminants is present, there may be no further need to evaluate the potential for bioaccumulation in subsequent tiers. If there is reason to believe that such contaminants are present in the dredged material, the evaluation should proceed to Tiers II and/or III (Figure 1).

Select Assessment Endpoints. After the contaminants of concern have been selected, consideration should be given to the nature of the assessment and measurement endpoints that will be used during subsequent evaluation. Corps districts, in consultation with EPA regions, should select the environmental components (receptors) that are to be protected from the effects of contaminant bioaccumulation from dredged material. Examples of such assessment endpoints include ensuring the protection of (1) human health, (2) a local population (for example, striped bass), or (3) a local endangered wildlife population (bald eagles, etc.).

After the assessment endpoints have been selected, consideration must be given to how bioaccumulation data are going to be used to ensure the protection of the assessment endpoints. How will the risks to a given receptor be measured? That is, what measurement endpoints will be considered? For example, risks can be quantified in terms of the number of excess cancers produced in humans or whether residue concentrations in exposed animals exceed levels that will produce adverse effects.

What data are collected and how those data are used in the decision-making process are determined by the nature of the assessment and measurement endpoints chosen. An effective evaluation is not possible before agreement is reached on the specific assessment and measurement endpoints to be considered.

Determine Availability of Relevant Effects Data. The environmental risk posed by a sediment-associated contaminant is a function of two factors: the likelihood that the receptors (organisms) to be protected will be exposed to the contaminant (that is, bioavailable forms of the contaminant can be transported into the tissues of the receptor) and the likelihood that the contaminant, once present within the receptor, will produce harmful effects.

The bioaccumulation tests described in the Ocean and Inland Testing Manuals are tools for measuring one aspect of contaminant exposure—bioavailability. To evaluate the risk that contaminant bioaccumulation will result in "unacceptable adverse effects," contaminant and receptor-specific residue-effects information for the contaminant of concern must be consulted. When evaluating risk to humans, and many other vertebrate species, residue information on relevant food/prey species must be used to estimate contaminant exposure before the likelihood of effects can be determined. Evaluating such information is essential to estimating the risk of adverse effects.

At this point in the bioaccumulation evaluation, three criteria should have been met. First, BCCs should have been identified and shown to be present in the dredged material. Second, one or more receptors for the contaminant should have been determined. That is, assessment and measurement endpoints have been selected. Third, residue-effects are consulted for the BCCs and receptors chosen.

With regard to the regulatory evaluation of dredged material, evaluating relevant residue-effects information for a specific BCC and receptor (considering the assessment endpoints chosen) is essential to making objective regulatory decisions concerning bioaccumulation. Evaluating such information is a necessary part of determining whether a given level of exposure will result in an adverse effect.

Some residue-effects data are available in the published literature. To ensure that future evaluations of bioaccumulation are effectively performed, the U.S. Army Engineer Waterways Experiment Station is currently developing a residue-effects database to be used by field personnel to interpret

bioaccumulation data. The database will be developed by reviewing and extracting relevant data from the published literature and will include residue-effects data for a broad range of organisms and contaminants.

Notices concerning availability of the residue-effects database will be posted on the Contaminants Bulletin Board System, which can be accessed via modem at (601) 634-4380. Technical assistance for the database will be available at (601) 634-2489.

Tier II

The tasks in Tier II are designed to provide a rapid screen for determining the potential for contaminant bioaccumulation from dredged material and for evaluating potential water column effects. Calculation of theoretical bioaccumulation potential provides an estimate of the potential for contaminants in dredged material to be bioaccumulated. Marine water quality criteria or state water quality standards are used in combination with a numerical mixing model to evaluate the potential for acute toxicity in the water column.

Collect Sediment Chemistry Data for Evaluation of Theoretical Bioaccumulation Potential (TBP). Following preparation of the site-specific list of BCCs, sediment chemistry data should be collected for these contaminants. One of the significant problems identified during the workshop regarding the statistical treatment of dredged material was the fact that adequate consideration was not being given to natural variation in contaminant concentrations; this is particularly true when laboratory tests are performed on composited samples. Considerable latitude is granted in current guidance regarding the intensity of sampling at a particular dredging project. However, current guidance does state that when important environmental contaminants are present, more intensive sampling is desirable (USEPA/USACE 1991).

When bioaccumulation is expected to be an important exposure pathway for contaminants in the material to be dredged from a particular project or project segment, care should be taken to ensure that an adequate number of replicate samples (five, for example) are collected from each of the operational units where bioaccumulation is a concern.

Evaluate TBP. TBPs should be calculated for nonpolar organic BCCs using the chemistry data described above and the most appropriate and available Biota-Sediment Accumulation Factors (BSAFs). Current predictive methods are valid only for nonpolar organics. If the dredged material contains BCCs other than nonpolar organics (log K_{ow} > 4), the potential for bioaccumulation can be evaluated only through Tier III and/or Tier IV testing.

Selection of a BSAF can be approached in several ways, depending on circumstances. The Inland Testing Manual contains an up-to-date discussion describing the selection of BSAFs. The Ocean Manual is outdated in that it

recommends using a default BSAF = 4 in all TBP calculations. That factor (4) is at the 94th percentile of all BSAFs contained in the Contaminants Bulletin Board System (BBS) Database, (601) 634-4380, and is about 12-fold greater than the median BSAF (0.520) for all listings in the database, making it unreasonably conservative for predictive purposes (McFarland and Ferguson 1994, McFarland 1995). The following recommendations are given regarding the calculation of TBP:

- TBP should be calculated for a specific BCC and receptor of concern, using locally generated data if at all possible. If a Corps district has a history of conducting 28-day bioaccumulation tests using specific organisms (for example, *Nereis virens* or *Macoma nasuta*) and has data from past tests, it may be possible to generate local BSAFs. Such BSAFs can be calculated if the four components of a BSAF calculation were measured and retained:
  - Concentration of the BCCs in sediment used in the bioaccumulation test.
  - Total organic carbon (TOC) of that sediment.
  - Concentration of the BCCs in the exposed organism at the end of the test.
  - Lipid content of the organism.

  If a local database from previous testing contains such data, it should be possible to generate organism/BCC-specific mean BSAFs complete with measures of variance. It is reasonable to expect that BSAFs generated in this way will provide the most accurate predictions of theoretical bioaccumulation potential in future evaluations. It is recommended that Corps districts begin to acquire these types of data as part of their dredged material evaluations, if they are not already doing so. Corps districts with the necessary data to generate local BSAFs can contact the authors of this technical note for further guidance as necessary.
- If local BSAFs are not available, the Contaminants BBS can be queried to find BSAFs that were generated in field or laboratory studies for specific organisms, chemicals, and levels of TOC in sediments. A practical approach in using the BBS to select BSAFs for a specific sediment would be as follows:
  - Begin with the concentration of a specific BCC and the TOC content of the reference sediment and the dredged material.
  - Go to the BBS and search for cases in which BSAFs are reported for the same BCC in sediments with similar TOC content.
  - Choose the reported BSAF for the organism for which TBP is to be calculated (or the organism most closely related).
- Alternatively, use the median BSAFs reported in McFarland and Ferguson (1994). Table 1 in that paper presents a statistical analysis of all the BSAF data in the Contaminants BBS Database as of November 1994. Median BSAFs (and 25th and 75th percentiles) are reported for nine categories in which the BSAF data are broken out in various ways (PCBs, PAHs, dioxins/furans, etc.).
- Separate TBP values should be calculated for each nonpolar organic BCC identified at the end of Tier I. A separate TBP value should be calculated for each chemistry value. Assuming a sample number equal to 5, this would

result in five estimates of TBP for each BCC in the dredged material and reference sediment.

A statistical analysis should then be performed to compare the dredged material and reference sediment TBP values. If the TBP value for a BCC in the dredged material is not statistically greater than the reference TBP value, no further evaluation of bioaccumulation should be necessary for that BCC. If some BCC TBP values are statistically greater than the reference TBP value, a consideration of effects should follow, as described below. In those cases when contaminant tissue concentrations are less than the detection limit of the analytical method employed, the statistical methods outlined in Clarke (1995) and Clarke and Brandon (in preparation) should be used.

Compare TBP Values with Effects Data. The likelihood for adverse effects should be evaluated for those BCCs predicted to exceed reference tissue levels. The potential for an adverse environmental effect due to bioaccumulation will be determined by evaluating information concerning the relationship between contaminant tissue concentration and relevant effects in the receptor(s) of concern (identified in Tier I). Consideration must be given to the relevance of the collected data and what extrapolation is necessary in making an effects determination (for example, worm tissue contaminant concentrations alone are insufficient to determine if a population of bald eagles will be jeopardized by disposal of dredged material). Bald eagles are more likely to be exposed to contaminants via the ingestion of tissues of higher trophic level organisms (fish and other vertebrates) rather than worms.

The residue-effects database should be consulted to reach a determination as to the potential for adverse effects. In those cases where BSAF-predicted tissue concentrations are close to or above relevant effects concentrations, or excessive uncertainty exists regarding the predicted tissue concentration, the evaluation should proceed to Tier III (Figure 1).

Tier III

Tier III testing is designed to evaluate the toxicity and bioavailability of contaminants in dredged material. Short-term toxicity tests are performed using sensitive organisms to evaluate the potential for contaminants in dredged material to produce significant lethality. Longer term bioaccumulation tests are performed to evaluate the bioavailability of contaminants in dredged material.

Perform Bioaccumulation Tests. When the information that has been accumulated in preceding tiers is insufficient to make a decision regarding bioaccumulation, bioaccumulation testing (as outlined in the Ocean and Inland Testing Manuals) may be necessary. Such testing is necessary when predictive techniques for estimating tissue concentrations are not appropriate or when the uncertainty associated with predictive techniques is excessive.

Uncertainty associated with the predicted tissue concentration is particularly important when the predicted tissue concentration is close to the level at

which effects would be expected. Bioaccumulation testing should be performed on an adequate number of replicates from a given project or project segment to ensure a satisfactory description of the mean and associated variance. Statistical comparisons should be made using the same guidance proposed in Tier II. If the concentrations of BCCs in tissue are not significantly greater than the reference concentration, no further evaluation of bioaccumulation should be necessary. If some BCC concentrations are significantly greater in animals exposed to the dredged material than for animals exposed to the reference sediment, the likelihood of effects must be evaluated (Figure 1).

Compare Tissue Concentrations with Effects Data. As discussed in Tier I, consideration of residue-effects data is essential to making objective decisions regarding dredged material disposal and management. The procedures followed here should be the same as those followed in Tier II.

Tier IV

When insufficient information has been acquired during previous tiers to allow a decision regarding dredged material disposal, Tier IV evaluations may be used. Tier IV evaluations consist of case-specific tests for evaluating the potential for significant toxicity or bioaccumulation resulting from long-term exposures to dredged material.

Perform Steady-State Bioaccumulation Test. When the information that has been accumulated in preceding tiers is insufficient for making a decision regarding bioaccumulation, steady-state bioaccumulation testing, or an evaluation of steady-state concentrations (as outlined in the Ocean and Inland Testing Manuals), may be necessary. Testing should be performed on an adequate number of replicates from the material to be dredged and the reference site. Statistical comparisons should be made using the same guidance proposed in Tiers II and III. If the concentrations of BCCs in tissues of animals exposed to the dredged material are not significantly greater than those in tissues of animals exposed to the reference sediment, no further evaluation of bioaccumulation should be necessary. If some BCC tissue concentrations are greater for animals exposed to dredged material than to the reference sediment, the likelihood of effects must be evaluated.

Compare Tissue Concentrations with Effects Data. Consideration must be given to whether or not the contaminant concentrations measured are likely to produce adverse effects. Such an evaluation will be accomplished by consulting relevant residue-effects information.

Summary

The evaluation process outlined above will provide for a more effective regulatory evaluation of the potential for "unacceptable adverse effects" due to contaminant bioaccumulation from dredged material.

This guidance is different from existing guidance in two important respects: (1) developing site-specific lists for the BCCs, assessment endpoints, and measurement endpoints will ensure that site-specific questions are well thought out and explicitly defined and (2) comparing tissue contaminant concentrations with relevant residue-effects data emphasizes the need to evaluate *effects* data in order to determine the potential for "unacceptable adverse *effects*."

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