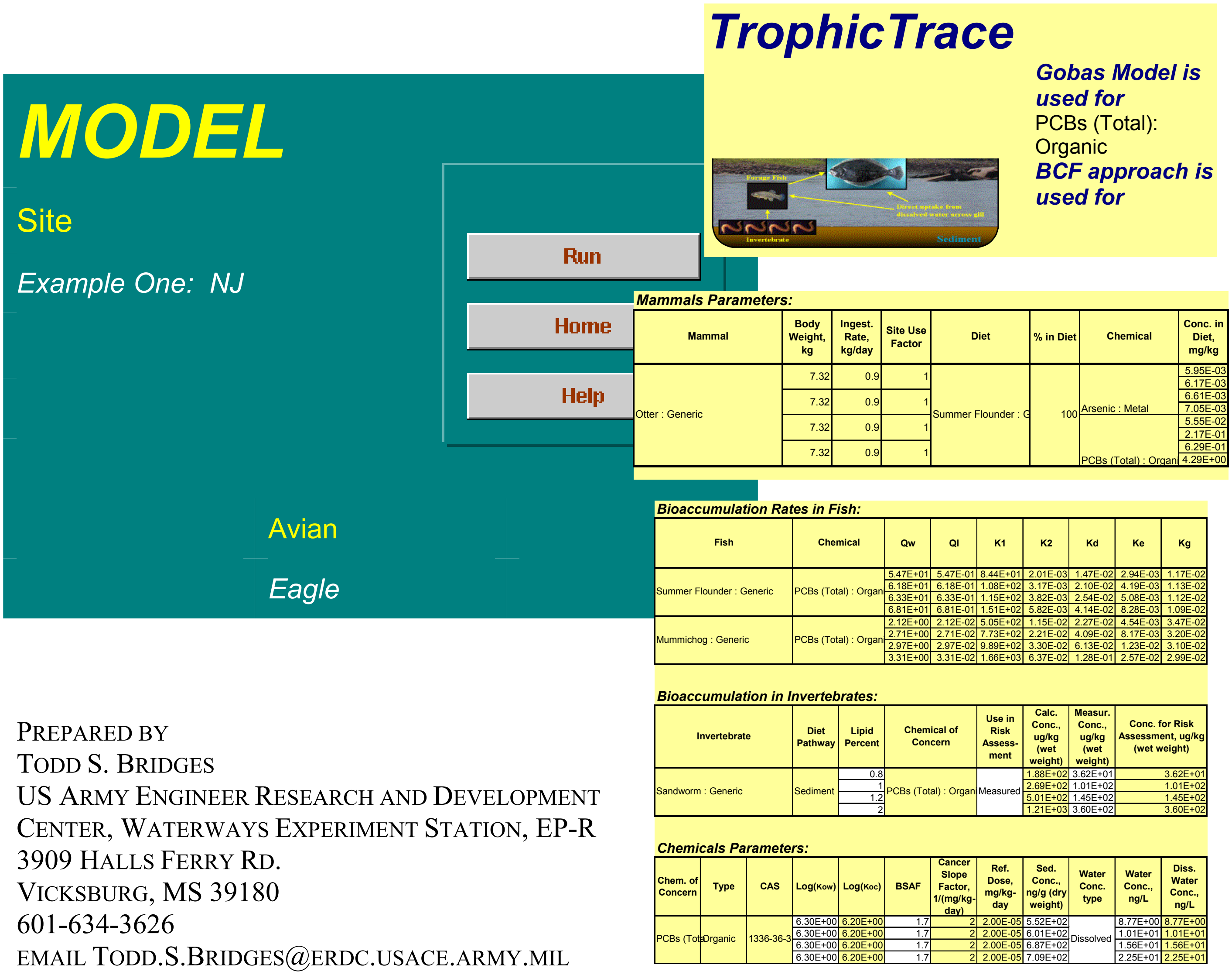
A MANAGEMENT GUIDE FOR A TIERED RISK ASSESSMENT PROCEDURE FOR EVALUATING BIOACCUMULATION DATA COLLECTED DURING REGULATORY EVALUATIONS OF DREDGED MATERIAL



Mammals Parameters:

Mammal	Body Weight, kg	Ingest. Rate, kg/day	Site Use Factor	Diet	% in Diet	Chemical	Conc. in Diet, mg/kg
Otter : Generic	7.32	0.9	1	Summer Flounder : G	100	Arsenic : Metal	5.95E-03
							6.17E-03
	7.32	0.9	1				6.61E-03
							7.05E-03
	7.32	0.9	1			PCBs (Total) : Organi	5.55E-02
							2.17E-01
	7.32	0.9	1				6.29E-01
							4.29E+00

Bioaccumulation Rates in Fish:

Fish	Chemical	Qw	Ql	K1	K2	Kd	Ke	Kg
Summer Flounder : Generic	PCBs (Total) : Organi	5.47E+01	5.47E-01	8.44E+01	2.01E-03	1.47E-02	2.94E-03	1.17E-02
		6.18E+01	6.18E-01	1.08E+02	3.17E-03	2.10E-02	4.19E-03	1.13E-02
		6.33E+01	6.33E-01	1.15E+02	3.82E-03	2.54E-02	5.08E-03	1.12E-02
		6.81E+01	6.81E-01	1.51E+02	5.82E-03	4.14E-02	8.28E-03	1.09E-02
Mummichog : Generic	PCBs (Total) : Organi	2.12E+00	2.12E-02	5.05E+02	1.15E-02	2.27E-02	4.54E-03	3.47E-02
		2.71E+00	2.71E-02	7.73E+02	2.21E-02	4.09E-02	8.17E-03	3.20E-02
		2.97E+00	2.97E-02	9.89E+02	3.30E-02	6.13E-02	1.23E-02	3.10E-02
		3.31E+00	3.31E-02	1.66E+03	6.37E-02	1.28E-01	2.57E-02	2.99E-02

Bioaccumulation in Invertebrates:

Invertebrate	Diet Pathway	Lipid Percent	Chemical of Concern	Use in Risk Assess-ment	Calc. Conc., ug/kg (wet weight)	Measur. Conc., ug/kg (wet weight)	Conc. for Risk Assessment, ug/kg (wet weight)
Sandworm : Generic	Sediment	0.8	PCBs (Total) : Organi	Measured	1.88E+02	3.62E+01	3.62E+01
		1			2.69E+02	1.01E+02	1.01E+02
		1.2			5.01E+02	1.45E+02	1.45E+02
		2			1.21E+03	3.60E+02	3.60E+02

Chemicals Parameters:

Chem. of Concern	Type	CAS	Log(Kow)	Log(Koc)	BSAF	Cancer Slope Factor, 1/(mg/kg-day)	Ref. Dose, mg/kg-day	Sed. Conc., ng/g (dry weight)	Water Conc. type	Water Conc., ng/L	Diss. Water Conc., ng/L
PCBs (Tota	Organic	1336-36-3	6.30E+00	6.20E+00	1.7	2	2.00E-05	5.52E+02	Dissolved	8.77E+00	8.77E+00
			6.30E+00	6.20E+00	1.7	2	2.00E-05	6.01E+02		1.01E+01	1.01E+01
			6.30E+00	6.20E+00	1.7	2	2.00E-05	6.87E+02		1.56E+01	1.56E+01
			6.30E+00	6.20E+00	1.7	2	2.00E-05	7.09E+02		2.25E+01	2.25E+01

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PREFACE

The purpose of this document is to convey general guidance to Corps personnel on the use of *TrophicTrace* to reach judgments on potential risks posed by contaminant bioaccumulation from dredged material. It is expected that, when appropriate and necessary, Corps project managers will, in conjunction with their local stakeholders and regulatory partners, use *TrophicTrace* with site and project-specific data to make informed management decisions when selecting appropriate management alternatives for dredged material.

INTRODUCTION

The current approach for evaluating dredged materials, as outlined in the Ocean and Inland Testing Manuals (USEPA/USACE 1991; 1998), involves comparing dredged material to Food and Drug Administration (FDA) action levels and reference sediments. If tissue concentrations in bioaccumulation test organisms exposed to dredged material are above FDA levels the material is judged to be unsuitable for unrestricted open water disposal. If tissue levels are below relevant action levels, then tissue concentrations of contaminants in organisms exposed to dredged material are compared to tissue concentrations in organisms exposed to a reference sediment. The reference comparison does provide a simple method for reaching the conclusion that material is suitable for open water disposal when no statistically significant bioaccumulation is observed in animals exposed to dredged materials. If statistically significant bioaccumulation is observed in organisms exposed to dredged material, the OTM and ITM provide qualitative guidance for evaluating the likelihood that the observed bioaccumulation would result in an unacceptable adverse effect to human or ecological receptors.

The approach described in this paper for conducting a tiered risk assessment with bioaccumulation data builds upon the existing tiered structure within the Ocean and Inland Testing Manuals providing a modeling tool to evaluate the potential for contaminant bioaccumulation, trophic transfer, and risk. The evaluation is accomplished through the use of a flexible spreadsheet tool, *TrophicTrace*, that is designed to be adapted for regional use. The goal is to incorporate a risk-based evaluation into the decision-making process by providing a quantitative approach for evaluating the potential for adverse effects when bioaccumulation in organisms exposed to dredged material is higher than bioaccumulation observed in reference sediments. The tool incorporates an uncertainty analysis algorithm to provide perspective on the range of potential risks attributable to a test sediment. *TrophicTrace* is a tool that District personnel can use as an aid to reaching conclusions, based on the weight of evidence available, about the risks posed by bioaccumulation of contaminants. It is expected that District personnel will interact with local and regional stakeholders in developing data inputs for *TrophicTrace* and interpreting the data and results for making management decisions.

This guide provides an overview of a risk-based management approach and how the *TrophicTrace* tool can be used within a risk-based management context to evaluate dredged material disposal alternatives. The approach follows USACE risk assessment guidance for dredged material (Cura et al., 1999). A list of resources with hyperlinks to appropriate Web sites, when available, is provided in Appendix A, “Resources.”

BACKGROUND

The U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA) have established a tiered approach for assessing the potential for environmental impacts of open-water disposal of dredged materials. These approaches are outlined in two documents, *Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual (OTM)* (USEPA/USACE, 1991), and *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (ITM)* (USEPA/USACE, 1998). The approach for assessing the potential for environmental impacts of land disposal is outlined in the *Upland Testing Manual* (USACE, 2003).

Sediment-associated contaminants represent the primary source of environmental risks associated with the dredging and disposal of sediments due, in part, to the potential for bioaccumulation and biomagnification in aquatic food chains. Accumulation of these contaminants in fish tissue can lead to adverse effects in fish as well as to higher-level ecological and human receptors. The potential for direct toxicity is evaluated through Tier III bioassays. *TrophicTrace* is focused on the potential for effects from bioaccumulation. As such, it does not include other pathways such as direct ingestion, dermal exposure, and so on.

Using the approach described in USEPA/USACE (1991; 1998), a Tier I analysis examines whether potential environmental impact can be determined based on existing information. Tier II provides a rapid chemical screening for potential impacts. In Tier III, toxicity and bioaccumulation tests are performed on dredged material and reference sediment. When Tier III analysis results in a highly uncertain conclusion, Tier IV may include a risk assessment.

TrophicTrace can be used in Tiers I through III to provide information about potential risks associated with exposure to contaminants found in dredged materials. Rather than relying solely on comparisons to reference sediments, *TrophicTrace* allows the user to estimate potential risks attributable to contaminants in sediments. Users can develop site-specific and region-specific food webs, and populate the model with appropriate data libraries containing project- and site-specific information on species of concern, human population attributes, food web characteristics, and other relevant data. Fish concentrations are estimated via a food web model for lipophilic organic contaminants, and via either a trophic transfer factor approach or a bioconcentration factor approach for inorganic and hydrophilic organic contaminants. Water concentrations are estimated via a partitioning approach although users are strongly encouraged to input their own water concentrations. If tissue data are available, either for fish or for invertebrates (for example, from Tier III 28-day bioaccumulation test results), these can be used directly in the assessment.

Although the USACE risk assessment guidance (Cura et al., 1999) discusses several other exposure pathways in addition to those discussed above, the contribution of these other pathways to estimated risks is typically negligible for the types of contaminants and scenarios the Corps generally encounters in navigation dredging. Use of the model within a project should use site-specific information, including regional food webs, appropriate species, and exposure parameters for human and ecological receptors. It is expected that local and regional stakeholders will provide input on parameterizing *TrophicTrace* for site-specific and region-specific applications of the model.

WHAT DOES THE MODEL CALCULATE?

The model provides incremental lifetime cancer risks and hazard indices for noncarcinogenic human health effects via the fish ingestion pathway for several representative human populations. The tool also includes an ecological receptor module for fish, avian, and mammalian receptors. Potential ecological effects for avian and mammalian receptors are estimated by comparing average daily dose (mg/kg-day) to toxicity reference values (TRVs). Predicted fish body burdens are compared to critical body residues from the literature. In addition, fish and avian receptors can have TRVs in the form of egg concentrations, if these are available. Contaminant-specific bioaccumulation factors multiplied by the concentration of contaminants in the diet (mg/kg wet weight) are used to develop egg concentrations for avian receptors. For fish, a lipid-normalized predicted body burden is used. This tool can be used to provide estimates of human health risk using results from sediment chemistry tests or 28-day bioaccumulation tests together with health-protective assumptions. The more site-specific data available, the more refined the results become. The model contains several demonstration data libraries for two types of contaminants: metals (arsenic) and chlorinated organics (polychlorinated biphenyls or PCBs and DDD, DDE, and DDT). The model contains several example datasets for human and ecological exposure, which are presented and discussed in the companion Users Manual. The user can edit existing model parameters as well as create new models based on different fish species and/or human exposure parameters.

Both the food web model and the BCF approach require a freely dissolved water concentration as an input. *TrophicTrace* incorporates three approaches for estimating a freely dissolved water concentration: 1) a user-specified freely dissolved water concentration from site-specific data; 2) from a subroutine based on a user-specified whole water concentration (presented as Equation 5 in the Users Manual); or, 3) calculating a freely dissolved water concentration assuming equilibrium partitioning from a user-specified sediment concentration (presented as Equation 6 in the Users Manual). It is most preferable to have water concentrations input by the user within a site-specific context. These alternatives are provided for the benefit of the user only when no other information is available.

Estimates of fish burdens for inorganic and hydrophilic organic compounds rely on two different approaches, depending on data availability. The first approach uses a trophic transfer factor (TTF) to move contaminants between prey and predator, and the second is a bioconcentration factor (BCF) approach. In the BCF approach, water concentrations are multiplied by a bioconcentration factor to estimate fish body burdens. Water concentrations can either be provided by the user or estimated by the model assuming equilibrium partitioning from user-input sediment concentrations. For some chemicals, there are data available on bioaccumulation from invertebrates to fish (Dillon et al., 1995; USEPA, 2000). The current version of *TrophicTrace* contains TTF for copper, cadmium, lead, zinc, and arsenic.

Inorganic compounds, such as metals and hydrophilic organic contaminants, typically do not biomagnify in food webs (although there are exceptions, including mercury and selenium) and generally the approach for estimating fish body burdens involves applying a bioconcentration factor to a freely dissolved water concentration, or a trophic transfer factor to measured invertebrate concentrations. The inorganic calculations, however, do not account for speciation of metals, or allow for specification of factors that might influence biological bioavailability (*e.g.,* AVS/SEM, pH, presence of reducing bacteria, and so on). Thus, the estimates of predicted body burdens from inorganic contaminants in sediment can be highly uncertain.

The model incorporates interval analysis, or "fuzzy math," to characterize uncertainty. Instead of entering simple point estimates for parameters, users can enter a "possible" range (e.g., minimum and maximum or the broadest possible range of parameter values) as well as a "probable" range (e.g., an average, or an average and an upper-bound on the average such as a 95-percent upper confidence limit, i.e., the most likely range for the parameters of interest).

HOW THE MODEL FITS INTO THE TIERED APPROACH

TrophicTrace allows the user to make the best use of the data typically collected through the tiered approach. The key is developing food webs and pathways appropriate for the specific project and disposal sites of interest.

Tier I

Tier I establishes whether potential environmental impact can be determined on the basis of existing information. All previously collected chemical and biological monitoring and testing data are evaluated. This information can be used to make a preliminary determination concerning the need for additional dredged material testing, under a principle commonly known as "reason to believe." The reason to believe that contaminants are not present and no testing is required is based on the type of material to be dredged (*e.g*., sand, silt, etc.) and its potential to be contaminated (*e.g.,* due to proximity to sources of contamination). Contaminants of potential concern include those that might reasonably be expected to cause an unacceptable adverse impact if the dredged material is discharged.

Typically at least three to five sediment samples will be available for any given project. Since the *TrophicTrace* model allows the user to enter four values for any given parameter (e.g., minimum, likeliest range represented by two numbers, and a maximum), it is possible to evaluate the potential for risk incorporating all the limited data rather than just a point estimate. If the user feels the data do not support estimating a most probable range, a single average can be used for the two middle values. Thus, existing sediment chemistry can be used in *TrophicTrace* at Tier I to evaluate the potential for bioaccumulation within the user-specified regional food web.

The user must make decisions regarding the use of detection levels, particularly for organic contaminants that are known to bioaccumulate, such as PCBs. Ideally, risk-based detection levels will have been established with the laboratory doing the sediment analysis. However, even in this case judgments will need to be made by assessors and users. For example, if 18 PCB congeners were measured and only one or two were actually detected, project managers may determine that using half the detection limit for the remaining 16 is not appropriate.

Tier II

The purpose of Tier II is to provide a reliable, rapid assessment for potential impact and thereby eliminate the need for further testing. This tier uses a numerical mixing model to assess for compliance with State water quality standards (WQS) and a calculation of the theoretical bioaccumulation potential (TBP) to assess for potential impacts through bioaccumulation. TBP can be calculated only for nonpolar organics, such as PCBs. At equilibrium, a nonpolar organic chemical would be expected to associate with organic matter in sediment and with lipids in tissue. Therefore, the potential bioaccumulation of nonpolar organic chemicals from dredged material can be estimated from the organic carbon content of the material, the lipid content of the organism, and the relative affinities of the chemical for each of these phases. Biota-sediment accumulation factors (BSAFs) are ratios that describe the relationship between the concentration of a nonpolar organic chemical in the lipid phase in tissue of a sediment-dwelling organism to the concentration in the sediment organic carbon phase to which the organism is exposed.

McFarland (1994) calculated an average equilibrium BSAF of 1.7 for a suite of compounds, indicating a slight enrichment of chemical in the lipid phase. This value can be used in the TBP calculation to estimate the magnitude of bioaccumulation likely to be associated with nonpolar organic contaminants in the dredged material. As a follow-up to the TBP approach, sediment bioaccumulation tests are used in Tier III to measure actual accumulation of contaminants from samples of dredged material (USEPA/USACE 1991). USACE has developed a database of BSAFs and lipid values for aquatic organisms from bioaccumulation test data and other published sources that should be used as a resource to select the most appropriate BSAF and lipid input parameters for the TBP calculation when site-specific data for these values are not available. The BSAF and lipid database is available through the Dredging Operations Technical Support (DOTS) Web page of the USACE Waterways Experiment Station http://www.wes.army.mil/el/bsaf/bsaf.html.

The model incorporates a BSAF of 1.7 based on McFarland (1994) for the example organic contaminants contained in the data library. Consequently, by entering a range of sediment concentrations and using the BSAF of 1.7 (or other BSAF determined by the user), the user is able to run a TBP calculation simultaneously with a Tier I evaluation.

Tier III

Tier III testing assesses the impact of contaminants in the dredged material on appropriately sensitive organisms to determine whether there is potential for the dredged material to result in an unacceptable impact. Assessment methods used in Tier III are water-column and whole-sediment toxicity tests and bioaccumulation tests. The solid-phase tests are compared to the results for reference sediment, and if there is no significant difference, no further testing is required.

TrophicTrace allows the user to enter invertebrate concentrations directly from the results of the 28-day bioaccumulation tests. The model will automatically adjust the entered values for hydrophobic organic contaminants to steady-state concentrations by applying the K_{ow}-based Equation 4 from the Users Manual. This adjustment follows USACE guidance to account for the fact that steady state may not be achieved during a 28-day exposure. If the user does not wish to make this adjustment, be advised that the values entered for invertebrate concentrations will need to be revised downward to account for this automatic adjustment.

Tier IV

A Tier IV evaluation is performed when a decision regarding toxicity or bioaccumulation has not been reached in lower tier evaluations. Tier IV involves case-specific, state-of-the-art testing for toxicity and/or bioaccumulation. Toxicity identification evaluation procedures can also be used in this tier, especially with sediments for which ammonia or hydrogen sulfide could be responsible for toxicity. If these approaches do not provide adequate information to make a determination, a complete risk assessment can be performed. *TrophicTrace* allows the user to conduct a risk assessment for the fish ingestion pathway.

EXAMPLES OF SITE-SPECIFIC APPLICATION OF THE MODEL

Cura et al. (1999) provide guidance on conducting risk assessments for dredged materials. Users should consult that document for guidance on developing site-specific conceptual models, use of data in risk assessment, how to develop toxicity reference values, and other aspects of the risk assessment process. Several examples are provided here for demonstration purposes, but for detailed guidance on how to develop the information necessary to parameterize the model, users are urged to consult Cura et al. (1999). It cannot be emphasized enough that site-specific, regional information is necessary to run the model for a specific project. A list of resources for parameterizing the model and conducting risk assessments is provided in Appendix A. Hyperlinks to appropriate Web sites, if available, are also provided.

Following USEPA and USACE guidance (USEPA, 1989; 1997a; 1998; Cura et al., 1999), a risk assessment consists of the following steps:

- Problem Formulation/Hazard Identification
- Exposure Assessment
- Effects or Toxicity Assessment
- Risk Characterization
- Uncertainty Analysis

Problem Formulation/Hazard Identification

Any risk assessment, whether ecological or human health, requires a problem formulation step which includes the development of a conceptual model. Developing a conceptual model achieves two objectives for structuring the risk assessment; the conceptual model should:

- Characterize site conditions and provide a general description of the environmental setting.
- Define complete exposure pathways representing the links between sources of contamination and humans or organisms.

The site conceptual model establishes the framework for the assessment. Guidance on developing a conceptual model is provided in Cura et al. (1999) as well as USEPA guidance documents.

For purposes of demonstrating the use of *TrophicTrace* in dredged material evaluations we will assume a dredging project in the Northeast United States with three reaches or management units within an inland estuary. The sediments to be dredged are being evaluated for disposal at the same nearshore, open-water site. The three reaches are being evaluated independently for their suitability for open-water disposal. The material is judged to be suitable for open-water disposal with respect to potential for water column and benthic toxicity. However, the potential for adverse effects through bioaccumulation remains to be evaluated.

The conceptual model for this project is relatively simple based on discussions with stakeholders, including wildlife biologists familiar with the area, individuals from USEPA, USACE, National Oceanographic and Atmospheric Administration (NOAA), local academic researchers, and other interested parties. The decision was made to develop a primarily sediment-driven food web appropriate for the region. There is the possibility of developing a more complex food web later in the process, but for this initial assessment, it was agreed that a simple food web would suffice.

The representative invertebrate in the food web is the sandworm *Nereis verins*. The model assumes that sandworms are consumed by the mummichog (*Fundulus heteroclitus*), and that mummichog are consumed by summer flounder (*Paralichthys dentatus*). Discussions with wildlife biologists and stakeholders reveal that people are concerned about otter and eagles, which have been known to frequent the area. It is agreed that the assessment for humans will focus on recreational use of the disposal site. The recreational angler scenario assumes that there is a population of anglers who routinely return to a favorite fishing spot and this spot is assumed to be in the vicinity of the proposed disposal site.

Exposure Assessment

The exposure assessment quantifies the exposure characteristics of the human and ecological receptors. Again, Cura et al. (1999) and USEPA risk assessment guidance documents provide information on sources of exposure information. The USEPA Exposure Factors Handbook (http://cfpub.epa.gov/ncea/cfm/efprog.cfm) is the first choice of many analysts. In addition, there is often USEPA region-specific guidance available.

NOAA species profiles (http://www.nwrc.usgs.gov/publications/specintro.htm) provided the information on point estimates of lipid content and weight for the sandworm, mummichog, and summer flounder. Information for the higher order ecological receptors is obtained from the USEPA Wildlife Exposure Factors Handbook (http://cfpub.epa.gov/ncea/cfm/wefh.cfm?ActType=default). The USEPA Exposure Factors Handbook contains detailed information on many different fish ingestion studies from the literature. It is also helpful to consult with regional National Oceanographic and Atmospheric Administration (NOAA) offices, and the local Department of Health to determine whether there are any region-specific fish ingestion studies available. In this case, a local study was available from the New Jersey Department of Agriculture (NJDA, 1994) and those rates were used for this example.

Toxicity Assessment

The toxicity assessment provides information on the potential toxicity of the contaminants. Potential human health effects are evaluated through Reference Doses (RfDs) for noncarcinogenic outcomes and Cancer Slope Factors (CSFs) for carcinogenic outcomes. Potential ecological effects are evaluated through toxicity reference values (TRVs). The Users Manual briefly describes these. Human health values are obtained from USEPA's Integrated Risk Information System (IRIS at www.epa.gov/iris) and TRVs are derived from studies published in the primary literature. TRV development requires significant professional judgment. The process is briefly described in the Users Manual and guidance is provided in Cura et al. (1999) as well as USEPA guidance documents.

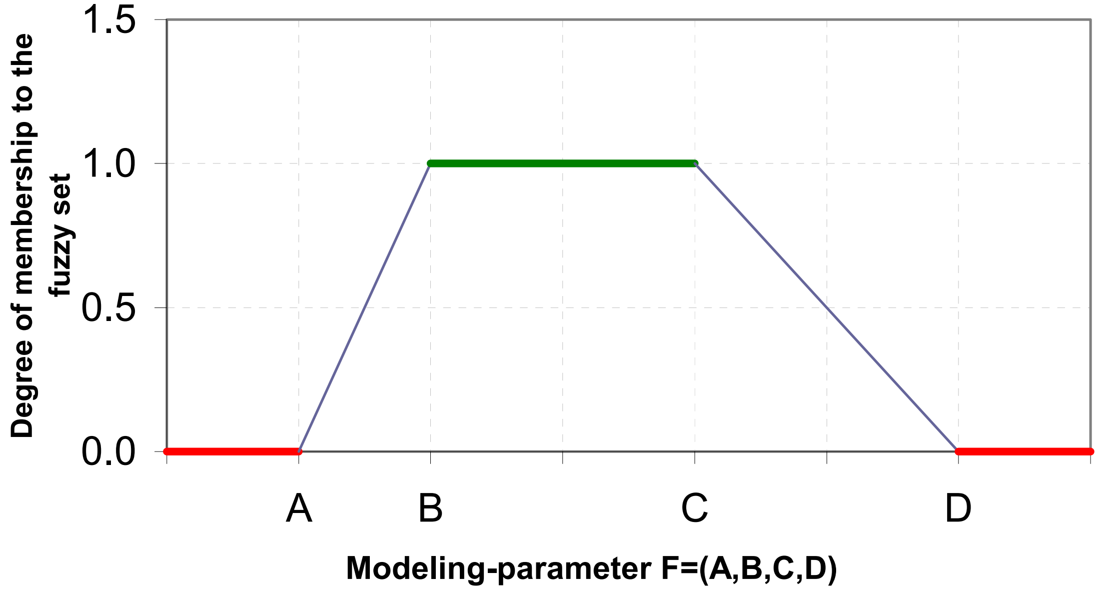
The TRVs provided in the model currently for PCBs, DDD/DDE/DDT, and arsenic were derived for actual projects by Menzie-Cura & Associates, Inc. staff toxicologists.

Risk Characterization

The risk characterization combines the information from all previous steps to characterize potential risks to human and ecological receptors. Average daily doses (mg/kg-day) for human and ecological receptors are compared to threshold effect levels (e.g., RfDs and TRVs), and also multiplied by CSFs to evaluate potential carcinogenic effects for humans. The USEPA has established an acceptable regulatory risk range of 10^{-4} to 10^{-6}, or a risk of one in ten thousand to one in a million. For noncarcinogenic effects in humans and ecological effects, exceedances of threshold levels (e.g., a hazard quotient or toxicity quotient exceeding one) are considered to pose potential health effects. However, the magnitude of the exceedance is not proportional (e.g., a toxicity quotient of ten is not ten times worse than one). *TrophicTrace* allows users to develop a range of values based on uncertain input parameters to provide perspective on the most probable risk range, given what is known about the site. The significance attached to being below or above acceptable risk ranges will depend on the extent to which conservative assumptions are used and the overall uncertainty associated with the risk estimates.

Ecological receptors are evaluated on both a lowest observed adverse effect level (LOAEL) and no observed adverse effect level (NOAEL) basis to provide better perspective on the potential for impacts. Exceedances of LOAELs are considered to present a greater potential for risk because the LOAEL is an observed effect level (from a laboratory or field study); thus, we know effects can occur at this concentration. NOAELs, on the other hand, are concentrations or doses at which effects have not been observed. However, the NOAEL depends on the dosing regime used in the experimental design. The true NOAEL could be higher and occurs somewhere between the NOAEL and the LOAEL. Thus, an exceedance of an NOAEL is not as indicative of the potential for risk. An exceedance of an NOAEL but not an LOAEL is equivocal with respect to risk, while exceedances of both NOAELs and LOAELs indicates the potential for risk.

Figure 1: Membership Function for Trapezoidal Fuzzy Number F=(A,B,C,D)



Uncertainty Analysis

The TrophicTrace model incorporates an uncertainty analysis algorithm in the form of interval analysis or "fuzzy math." This is a simple method for characterizing uncertainty and the theoretical basis is briefly described in the Users Manual. Parameters are described by "fuzzy numbers" – four numbers that represent the potential range (possible range) and the likeliest range (probable range) of values for a given parameter. The example will describe the use of fuzzy numbers in greater detail.

A fuzzy number is described graphically by a trapezoidal shape where the y-axis represents the "degree of membership" and the x-axis the values for the specific parameter. Note that the y-axis does not represent a probability or likelihood. The degree of membership in the fuzzy set is proportional, however, such that if the degree of membership = 1 (B to C, also called the likeliest or probable range), then the parameter value, given the inputs, will definitely be within that range. The parameter may take on values from the sides of the trapezoid (A to B and C to D, also called the full or possible range), but these values are only "possibilities" with the degree of possibility reflected by the degree of membership. For example, a value that has a degree of membership of 0.8 is much more possible than a value with a degree of membership that is only 0.1. Again, these are not probabilities.

In this hypothetical example, sediment chemistry from five samples is available for each of the reaches. This is enough information to estimate an average for the probable range (the same value is used for B and C), and to use the minimum and maximum (A and D, respectively) to evaluate the possible range for each of the reaches.

REACH NO. 1: EVIDENCE OF NO POTENTIAL RISK

Five sediment samples are available for the inland freshwater portion of the system. Based on past agricultural land use, sediments are known to contain measurable concentrations of DDD, DDE, and DDT. Thus, these contaminants are the primary focus of the assessment. The minimum, maximum, and average are entered into the "Environment" input screen of

TrophicTrace, along with information on TOC and water temperature. TOC is available from the sediment chemistry results, and the water temperature was taken from data from the proposed disposal site (it is the water temperature at the disposal site rather than currently in the estuary that is of interest). Chemical-specific parameters were taken from Lyman et al. (1990), Mackay et al. (1992), and the Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profile for DDT compounds (ATSDR, 2000). A BSAF of 1.7 is used based on the USACE BSAF Database (http://www.wes.army.mil/el/bsaf/bsaf.html) to evaluate TBP. These inputs are shown in Figure 2.

Figure 3 presents the predicted incremental lifetime cancer risks and hazard indices for the adult and children recreational anglers. These results show that predicted incremental lifetime cancer risks are within the USEPA regulatory risk range, and that predicted hazard indices are below USEPA regulatory thresholds of concern. The results for the ecological receptors, although not presented, are also below regulatory thresholds of concern. These results were obtained using "conservative," health protective assumptions (e.g., site use factor for fish = 1, percent of fish from the site = 1, high fish ingestion rates, etc.). Consequently, since predicted risks, hazard indices, and toxicity quotients were within acceptable risk ranges or below threshold values, no further study or analyses to refine the estimates were considered warranted in this case. The management decision reached from this analysis is that the material from Reach No. 1 is suitable for open-water disposal.

Figure 2: Input Screen for Reach No. 1

Example Site 2

Choose One:

- Add New
- Edit
- Delete
- Home
- Detail

Water Temperature (C)	Reference
12	*Assumed: site-specific*
13	
15	
18	

Total Organic Carbon in Sediment (%)	Reference
2.2	*Site-specific (from data)*
3.8	
4	
4.2	

Chemical	Type of Water Concentration	Water (ng/L)	Sediment (ng/g) Bulk Dry Weight
DDD : Organic	*Dissolved*	0.20	8.5
		0.4	16
		0.42	16
		1.90	42
DDE : Organic	*Dissolved*	0.12	24
		0.38	68
		0.40	68
		1.23	121
DDT : Organic	*Dissolved*	0.02	3
		0.13	14
		0.14	14
		0.39	23

Figure 3: Output from Reach No. 1 Example: No Significant Risk

Human Health Risk

Risk Summary:

Population	Site	Chemical	Incremental LCR	Hazard Index
Recreational Adult Angler	NJ	DDD : Organic	8.8E-07	7.30E-03
			2.0E-06	1.67E-02
			2.6E-06	2.14E-02
			1.5E-05	1.27E-01
		DDE : Organic	2.6E-06	1.51E-02
			9.2E-06	5.41E-02
			1.3E-05	7.37E-02
			5.4E-05	3.19E-01
		DDT : Organic	2.1E-07	1.22E-03
			1.2E-06	6.96E-03
			1.6E-06	9.17E-03
			6.0E-06	3.55E-02
Recreational Child Angler	NJ	DDD : Organic	2.3E-07	2.26E-02
			5.3E-07	5.15E-02
			6.8E-07	6.60E-02
			4.0E-06	3.91E-01
		DDE : Organic	6.8E-07	4.66E-02
			2.4E-06	1.67E-01
			3.3E-06	2.28E-01
			1.4E-05	9.87E-01
		DDT : Organic	5.5E-08	3.77E-03
			3.1E-07	2.15E-02
			4.1E-07	2.83E-02
			1.6E-06	1.10E-01

REACH NO. 2: EVIDENCE OF POTENTIAL RISK

In the lower end of the estuary closest to the harbor, there is known PCB contamination and five sediment samples are available for this contaminant. The minimum, maximum, and average are entered into the "Environment" input screen, along with information on TOC and water temperature, as shown in Figure 4.

Figure 4: Input Screen for Reach No. 2

Example Site 2

Temperature (C)	Reference
12	*Assumed: site-specific*
13	
15	
18	

Total Organic Carbon in Sediment (%)	Reference
2.2	*Site-specific (from data)*
3.8	
4	
4.2	

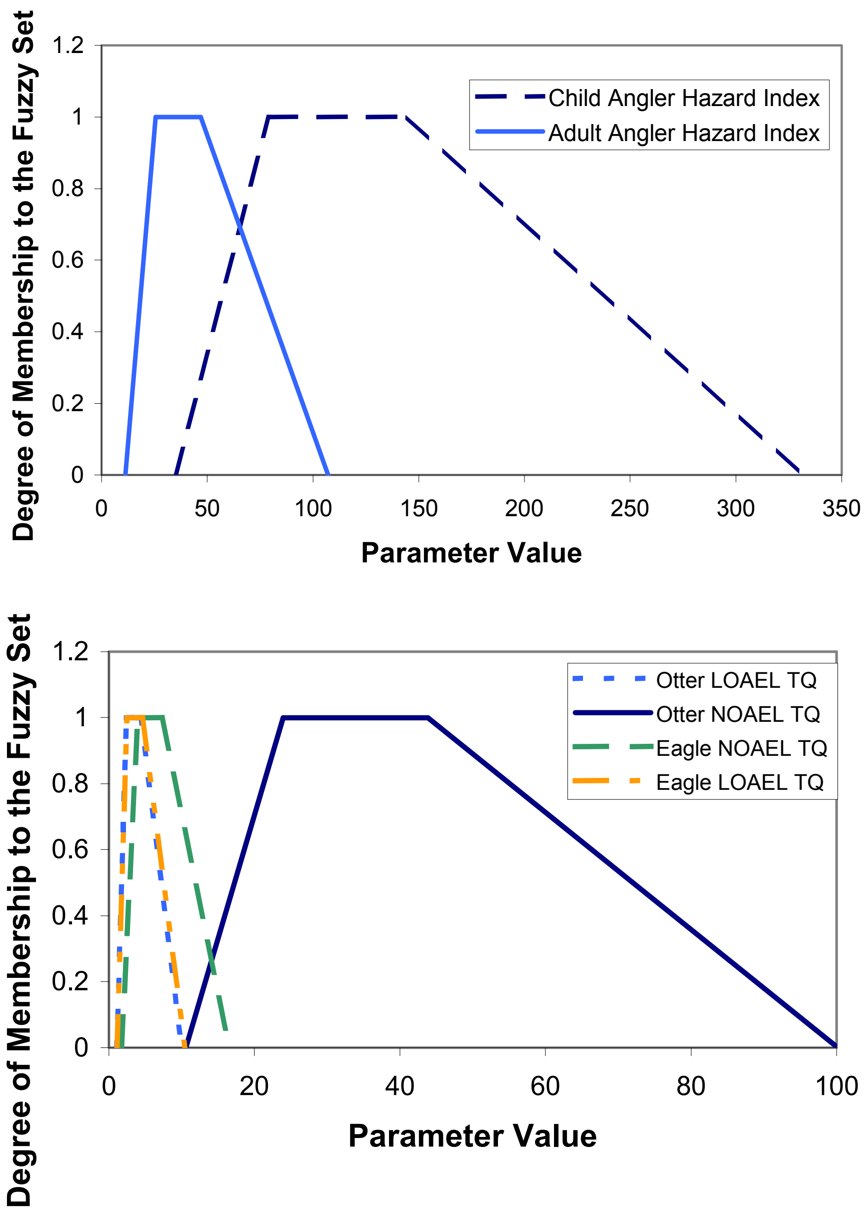
Choose One:

- Add New
- Edit
- Delete
- Home
- Detail

Chemical	Type of Water Concentration	Water (ng/L)	Sediment (ng/g) Bulk Dry Weight
PCBs: Organic	*Dissolved*	0.20	8.5
		0.4	16
		0.42	16
		1.90	42

In this case, predicted incremental lifetime cancer risks exceed USEPA regulatory risk ranges, and hazard indices greatly exceed USEPA regulatory thresholds of concern, as shown in the following figures. Even the lowest portion of the hazard index range is above one, and the likeliest range greatly exceeds one, suggesting that these sediments pose potential human health effects.

Figure 5: Output from Reach No. 2



Ecological risks also show exceedances of USEPA regulatory thresholds. Both LOAEL- and NOAEL-based comparisons exceed one, which is a greater indication of potential risk than if only the NOAEL had been exceeded but not the LOAEL.In the case of Reach No. 2, predicted risks, hazard indices, and toxicity quotients clearly show the potential for adverse effects. Consequently, risks are considered unacceptable and no further analysis is warranted to conclude that the material is unsuitable for open-water disposal at the subject site.

REACH NO. 3: EVIDENCE OF EQUIVOCAL RISK

The test sediment for this reach was obtained from the main portion of the estuary. PCBs are a known contaminant in this area, and there is evidence of arsenic contamination as well. Several sediment sample results are available but no bioaccumulation testing has been conducted. The available data from five sediment samples are entered into the environment screen as shown in Table 1:

Table 1: Input Data for the *Environment* Screen for Reach No. 3

Fuzzy Number	TOC (%)	Arsenic Sediment Concentration (ng/g dry weight)	PCB Sediment Concentration (ng/g dry weight)	Surface Water Temperature (deg Celsius)
Minimum	1.8	14,450	180	12
Average	2.4	16,560	374	13
95% UCL	3.2	16,560	374	15
Maximum	4	18,680	601	18

The program estimates dissolved water concentrations using Equation 5. Therefore, POC and DOC are not required. All other parameters are left as point estimates based on the data provided in the Appendices to the Users Manual. Since a BSAF of 1.7 based on McFarland (1994) for hydrophobic organic contaminants is used in the model, this run simultaneously evaluates theoretical bioaccumulation potential (TBP). Figure 6 presents the output from the model for this run:

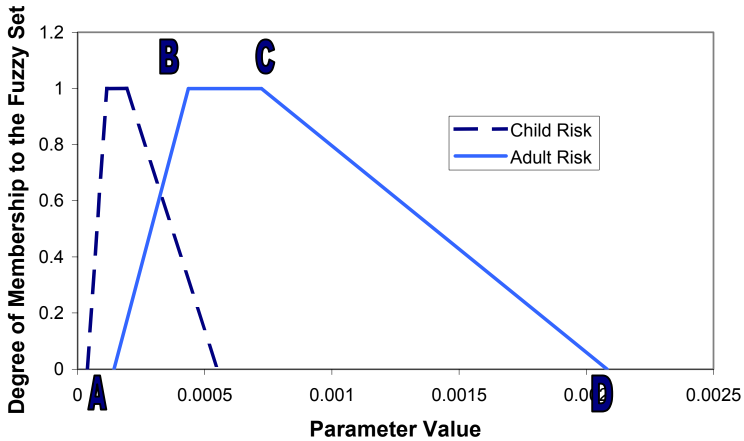
Figure 6: Output for Tiers I and II for Reach No. 3

Risk Summary:

Population	Site	Averaging Time, years	Chemical	Incremental LCR	Hazard Index
Recreational Adult Angler	NJ	70	Arsenic : Metal	6.2E-06	1.39E-02
				7.2E-06	1.59E-02
				7.2E-06	1.59E-02
				8.1E-06	1.79E-02
			PCBs (Total) : Organic	1.4E-04	3.58E+00
				4.4E-04	1.09E+01
				7.2E-04	1.81E+01
				2.1E-03	5.20E+01
Recreational Child Angler	NJ	70	Arsenic : Metal	1.7E-06	4.28E-02
				1.9E-06	4.91E-02
				1.9E-06	4.91E-02
				2.1E-06	5.54E-02
			PCBs (Total) : Organic	3.8E-05	1.11E+01
				1.2E-04	3.37E+01
				1.9E-04	5.59E+01
				5.5E-04	1.61E+02

The results show that there is there is the potential for bioaccumulation based on the available data and a BSAF of 1.7. Predicted hazard quotients and incremental lifetime cancer risks generally exceed USEPA regulatory ranges or thresholds. Figure 7 presents the incremental lifetime cancer risks for adults and children predicted by the model as graphical output. The likeliest or probable range (the top of the trapezoid) is relatively narrow, while the possible range (the full width of the trapezoid) is quite large. The values between B and C represent the likeliest or probable range. Given the assumptions, risks will certainly fall between B and C, but could be as low as between A and B, or as high as between C and D. Thus, predicted risks could be as low as A or as high as D, but as the lines approach zero, the possibility decreases accordingly. Note that the degree of membership in the fuzzy set is not to be interpreted as a probability. The width of B and C, or the likeliest range, depends on the likeliest values specified by the user. These could be averages and 95-percent upper confidence limits, or some other statistical measure of uncertainty around a mean or median value.

Figure 7: Incremental Lifetime Cancer Risk for Tiers I and II, Reach No. 3



Thus, predicted risks could be as low as A or as high as D, but as the lines approach zero, the possibility decreases accordingly. Note that the degree of membership in the fuzzy set is not to be interpreted as a probability.

The width of B and C, or the likeliest range, depends on the likeliest values specified by the user. These could be averages and 95-percent upper confidence limits, or some other statistical measure of uncertainty around a mean or median value.

Results for the ecological receptors show that all predicted toxicity quotients for summer flounder are below one; thus, there is no expected risk to this receptor. These results are presented in Figure 8:

Figure 8: Results for Fish for Tiers I and II, Reach No. 3

Summary for Fish:

Fish	Chemical of Concern	NOAEL TQ	LOAEL TQ	NOAEL HQ for Eggs	LOAEL HQ for Eggs
Summer Flounder	Arsenic : Metal	1.35E-02	1.35E-03		
		1.54E-02	1.54E-03		
		1.54E-02	1.54E-03		
		1.74E-02	1.74E-03		
	PCBs (Total) : Organic	5.73E-02	1.17E-02		
		1.74E-01	3.56E-02		
		2.89E-01	5.91E-02		
		8.33E-01	1.70E-01		

Predicted toxicity quotients for avian and mammalian receptors, however, do exceed one for several comparisons, suggesting the potential for adverse effects.

Figure 9: Results for Avian and Mammalian Receptors for Tiers I and II, Reach No. 3

Ecological Risk

Summary for Mammals:

Mammal	Chemical of Concern	NOAEL TQ	LOAEL TQ
Otter	Arsenic : Metal	7.07E-04	
		8.11E-04	
		8.11E-04	
		9.14E-04	
	PCBs (Total) : Organic	3.35E+00	3.35E-01
		1.02E+01	1.02E+00
		1.69E+01	1.69E+00
		4.87E+01	4.87E+00

Summary for Avian:

Bird	Chemical of Concern	NOAEL TQ	LOAEL TQ	NOAEL TQ for Eggs	LOAEL TQ for Eggs
Eagle	Arsenic : Metal	1.57E-04	6.28E-05		
		1.80E-04	7.20E-05		
		1.80E-04	7.20E-05		
		2.03E-04	8.12E-05		
	PCBs (Total) : Organic	7.71E-03	1.95E-03	5.54E-01	3.50E-01
		2.35E-02	5.95E-03	1.69E+00	1.07E+00
		3.89E-02	9.87E-03	2.80E+00	1.77E+00
		1.12E-01	2.84E-02	8.06E+00	5.09E+00

This example demonstrates that the tool can be used in Tiers 1 and 2 using all the available information to characterize uncertainty attributable to sediment concentrations and TOC. Instead of relying on a single point estimate, *TrophicTrace* incorporates all the data (however limited). The potential for bioaccumulation is assessed using a BSAF of 1.7; thus, the analysis simultaneously evaluates TBP in one run. Results suggest the potential for risk, and the decision is made to conduct bioaccumulation tests and to use the measured invertebrate concentrations in the model. Again, invertebrate concentrations entered in *TrophicTrace* undergo an automatic adjustment based on K_{ow} and Equation 4 of the Users Manual following USACE guidance (USEPA/USACE 1998). If users do not wish to make this adjustment, then the entered values need to be decreased accordingly. This adjustment applies only to organic contaminants and is only relevant for contaminants with K_{ow} values greater than 5.

If users do not enter a freely dissolved water concentration, then the model will estimate water concentrations from the sediment concentrations. Water concentrations are required for the Gobas Model (fish respiration, direct gill uptake and loss), but often bioaccumulative substances are found only at low concentrations if at all in the water column. It may be appropriate in some circumstances to enter the detection level, or half the detection level, for the dissolved water concentration.

Based on the results of the previous analysis, bioaccumulation testing is conducted on the test sediment. The bioaccumulation test results are entered as shown in Table 2:

Table 2: Input Data for Tier III Reach No. 3

Fuzzy Number	Arsenic Concentration (ug/kg wet weight)	PCB Concentration (ug/kg wet weight)
Minimum	2.9	18.9
Average	3.5	33.5
95% UCL	3.5	33.5
Maximum	4.2	48.9

The program now uses TTF for arsenic, and uses the measured PCB concentration in sandworms in the Gobas Model in place of the calculated value. The sandworm concentrations for PCBs are adjusted by a K_{ow}-dependent relationship to account for the fact that the 28-day test results may not have achieved steady-state (Equation 5 in the Users Manual). Entered values should be adjusted accordingly if steady-state results are available. Arsenic concentrations are not adjusted. The Gobas model does not use the entered sediment concentration for PCBs, but it does require a dissolved water concentration. For this run, mixing zone calculations showed that dissolved water concentrations were less than 2 ng/L. This value was entered for all four fuzzy numbers. In addition, further information from a local wildlife biologist and NOAA species profiles (see the Users Manual for detailed references) is entered into the program as shown in Table 3:

Table 3: Input Data for Fish in Tier III for Reach No. 3

Fuzzy Number	% Lipid Sandworm	% Lipid Mummichog	Weight Mummichog (g)	% Lipid Summer Flounder	Weight Summer Flounder (g)
Minimum	0.8	1.3	2	1.3	450
Average	1.0	1.5	3	1.5	552
95% UCL	1.2	1.75	3.5	1.7	574
Maximum	2.0	2.2	4.2	2.1	648

A recent tagging study conducted in the area for the fish species in the model reveals that the site use factor of one, used in the previous analysis, is closer to 0.6 for summer flounder and 0.8 for mummichog. Although the analyst could have entered the minimum and maximum values, the choice was made to use the average value for all four fuzzy numbers as there is low confidence in the minimum and maximum.

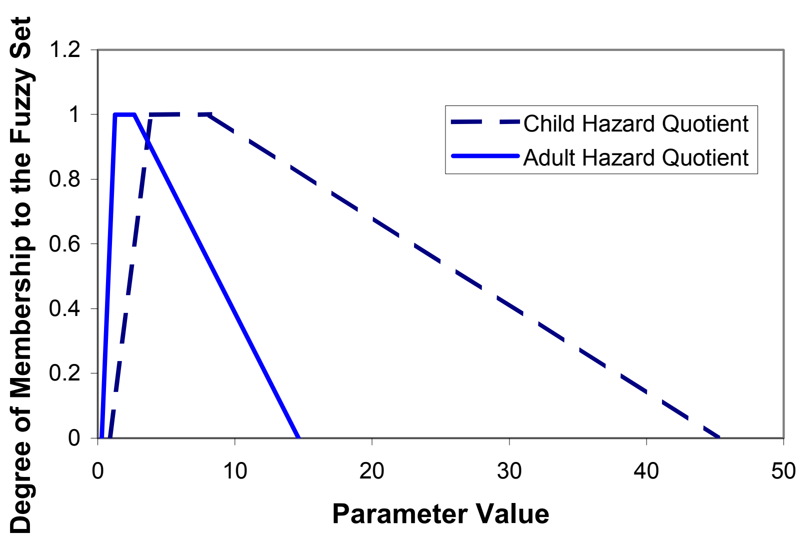
The model shows the following results for human health as shown in Figures 10 and 11:

Figure 10: Human Health Output for Tier III for Reach No. 3

Risk Summary:

Population	Site	Averaging Time, years	Chemical	Incremental LCR	Hazard Index
Recreational Adult Angler	NJ	70	Arsenic : Metal	4.3E-07	9.53E-04
				5.2E-07	1.15E-03
				5.2E-07	1.15E-03
				6.2E-07	1.38E-03
			PCBs (Total) : Organic	1.1E-05	2.84E-01
				5.0E-05	1.26E+00
				1.1E-04	2.64E+00
				5.9E-04	1.46E+01
Recreational Child Angler	NJ	70	Arsenic : Metal	1.1E-07	2.95E-03
				1.4E-07	3.56E-03
				1.4E-07	3.56E-03
				1.6E-07	4.27E-03
			PCBs (Total) : Organic	3.0E-06	8.77E-01
				1.3E-05	3.89E+00
				2.8E-05	8.17E+00
				1.6E-04	4.52E+01

Figure 11: Graphical Output for Human Health in Tier III for Reach No. 3



The likeliest range for risk for PCBs for the adult angler is almost within the regulatory risk range, and is within the regulatory risk range for the recreational child angler. The hazard quotients for PCBs are just above one, but below ten for both the child and the adult angler. The widest range for both the child and the adult falls below one at the low end and exceeds ten at the high end.

The results for fish, as before, show no exceedances of regulatory thresholds.

Figure 12: Output for Fish from Tier III for Reach No. 3

Summary for Fish:

Fish	Chemical of Concern	NOAEL TQ	LOAEL TQ	NOAEL HQ for Eggs	LOAEL HQ for Eggs
Summer Flounder	Arsenic : Metal	9.26E-04	9.26E-05		
		1.12E-03	1.12E-04		
		1.12E-03	1.12E-04		
		1.34E-03	1.34E-04		
	PCBs (Total) : Organic	4.55E-03	9.29E-04		
		2.02E-02	4.12E-03		
		4.23E-02	8.65E-03		
		2.34E-01	4.79E-02		

Predicted toxicity quotients for mammals for PCBs just barely exceed one on an NOAEL basis, but the likeliest range does not exceed one on an LOAEL basis. The interpretation is equivocal with respect to risk – predicted daily doses do not exceed known effect levels but do exceed threshold levels based on no effects as shown in Figure 13:

Figure 13: Output for Mammals from Tier III for Reach No. 3

Ecological Risk

Summary for Mammals:

Mammal	Chemical of Concern	NOAEL TQ	LOAEL TQ
Otter	Arsenic : Metal	4.46E-05	
		5.38E-05	
		5.38E-05	
		6.45E-05	
	PCBs (Total) : Organic	2.65E-01	2.65E-02
		1.18E+00	1.18E-01
		2.47E+00	2.47E-01
		1.37E+01	1.37E+00

Predicted toxicity quotients for avian receptors do not exceed one based on the probable range, although there is the possibility that they could when considering the overall range.

Figure 14: Output for Avian Receptors in Tier III for Reach No. 3

Ecological Risk

Summary for Avian:

Bird	Chemical of Concern	NOAEL TQ	LOAEL TQ	NOAEL TQ for Eggs	LOAEL TQ for Eggs
Eagle	Arsenic : Metal	1.08E-05	4.32E-06		
		1.30E-05	5.21E-06		
		1.30E-05	5.21E-06		
		1.56E-05	6.25E-06		
	PCBs (Total) : Organic	6.12E-04	1.55E-04	4.40E-02	2.78E-02
		2.72E-03	6.88E-04	1.95E-01	1.23E-01
		5.69E-03	1.44E-03	4.09E-01	2.59E-01
		3.15E-02	7.99E-03	2.27E+00	1.43E+00

The results of this analysis are equivocal with respect to risk, suggesting that further analysis may be necessary to make a decision regarding the potential for adverse effects. This would likely involve a Tier IV evaluation and obtaining additional data to characterize potential exposures more fully. Exposure parameters for all the receptors could be evaluated in greater detail and specified as fuzzy numbers (currently all of the exposure parameters use only point estimates). Human population fish ingestion rates, which are based on a single study (NJDA, 1994), could be evaluated further and the percent of fish caught from the site, currently set at 100 percent, might be revised if the data warrant. Additional sediment and/or tissue samples could be obtained to provide greater confidence and a potentially narrower most probable sediment and/or tissue concentration range. The simplistic aquatic food web portion of the model (sandworm → mummichog → summer flounder) could be expanded. In addition, all the species in the aquatic food web have a site use factor of one. Based on the species biology, availability of prey, size of the disposal site, and other issues, a lower site use factor may be warranted (see von Stackelberg et al., 2002). Finally, none of the chemical-specific parameters that influence uptake have been specified as fuzzy. For example, Log K_{ow}, which is an important term in both uptake and depuration of contaminants, is specified as a single number.

The decision to proceed with further analysis would be based in part on the amount of sediment to be dredged in Reach No. 3, the availability of alternative management options (e.g., capping, upland placement), and the costs and risks associated with those options.

CONCLUSIONS

This document provides guidance to Corps personnel on the use of *TrophicTrace* to reach judgments on potential risks posed by contaminant bioaccumulation from dredged material. The examples explored in the text of this paper are intended to illustrate the utility of using a quantitative tool like *TrophicTrace* to reach conclusions about potential risks posed by contaminated sediment and to make informed decisions about managing those risks in cases where simple comparisons to FDA action levels and reference sediment do not provide sufficient information upon which to base management decisions. The principal challenge confronting users of a tool like *TrophicTrace* is populating its algorithms with timely, relevant, and appropriate data. An effort has been made within the body of this document to reference relevant sources of data and supporting guidance that users will need to conduct evaluations using *TrophicTrace*. Appendix A provides additional references and hyperlinks, where available, to Web-based sources of information for parameterizing *TrophicTrace*. Users of TrophicTrace are strongly encouraged to develop approaches for applying this tool in consultation with their regional regulatory partners and stakeholders.

Point of Contact:

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APPENDIX A: RESOURCES

Army Corps/USEPA Guidance

USEPA/USACE. United States Environmental Protection Agency and United States Army Corps of Engineers. (1991). "Evaluation of dredged material proposed for ocean disposal: testing manual." EPA-503/8-91/001. http://www.wes.army.mil/el/dots/guidance.html

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Risk Assessment Guidance

U.S. Environmental Protection Agency (USEPA). (1989). "Risk Assessment Guidance for Superfund, Volume 1 – Human Health Evaluation Manual, Part A, Interim Final." EPA/540/1-89/0002. Publication 9285.7-01A. Office of Emergency and Remedial Response, Washington, DC.

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These documents and several other human health and ecological risk assessment guidance documents from USEPA can be found at: http://www.epa.gov/superfund/programs/risk/tooltrad.htm#gdec

The USEPA National Center for Environmental Assessment contains several risk assessment guidance documents at: http://cfpub1.epa.gov/ncea/cfm/nceahome.cfm

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Risk assessment guidance prepared by the Environmental Sciences Division and Life Sciences Division of Oak Ridge National Laboratory for the U.S. Department of Energy. can be found at: http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html

Ecological Exposure Factors

U.S. Environmental Protection Agency (USEPA). (1993). "Wildlife Exposure Factors Handbook." Office of Research and Development, Washington, DC. EPA/600/R-93/187a. December, 1993. http://cfpub.epa.gov/ncea/cfm/wefh.cfm?ActType=default

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates

This series describes the life histories and environmental requirements of coastal aquatic organisms along the coasts of the United States; the organisms are principally fish (of sport, commercial, or ecological importance). The profiles were designed to provide coastal managers, engineers, and biologists with a brief, comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Individual profiles have sections on taxonomy, life history, ecological role, and environmental requirements. http://www.nwrc.usgs.gov/publications/specintro.htm

U.S. Environmental Protection Agency (USEPA). (1999). "Data Collection for the Hazardous Waste Identification Rule, Section 12: Ecological Exposure Factors [s0042.pdf]." Prepared by the Center for Environmental Analysis for the Office of Solid Waste. October. http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/risk.htm

The California Wildlife Exposure Factor and Toxicity Database (Cal/Ecotox) is a compilation of exposure factors (i.e., ecological and physiological data) and toxicity data for a number of California mammals, birds, amphibians, and reptiles. The database has been created by the Office of Environmental Health Hazard Assessment, in collaboration with the University of California at Davis, to provide an information resource for risk assessors conducting ecological risk assessments in California. (http://www.oehha.org/cal_ecotox/) Cal/Ecotox is searchable by species or chemical. In addition, complete species reports are available for downloading.

Human Exposure Factors

U.S. Environmental Protection Agency (USEPA). (1997b). "Exposure Factors Handbook, Volume I: General Factors. Office of Research and Development." Washington DC: Government Printing Office. EPA/600/P-95/002Fa. http://cfpub.epa.gov/ncea/cfm/efprog.cfm

U.S. Environmental Protection Agency (USEPA). (1997c). "Exposure Factors Handbook, Volume II: Food Ingestion Factors. Office of Research and Development." Washington DC: Government Printing Office. EPA/600/P-95/002Fb. http://cfpub.epa.gov/ncea/cfm/efprog.cfm

Human Toxicity

U.S. Environmental Protection Agency (USEPA). (1999). "Integrated Risk Information System Database (IRIS)." http://www.epa.gov/iris.

HazDat, the Agency for Toxic Substances and Disease Registry's Hazardous Substance Release/Health Effects Database, is the scientific and administrative database developed to provide access to information on the release of hazardous substances from Superfund sites or from emergency events and on the effects of hazardous substances on the health of human populations. http://www.atsdr.cdc.gov/hazdat.html

National Library of Medicine's TOXNET, a cluster of databases on toxicology, hazardous chemicals, and related areas: http://toxnet.nlm.nih.gov/

Agency for Toxic Substances and Disease Registry has developed Toxicological Profiles for over a hundred chemicals at: http://www.atsdr.cdc.gov/toxpro2.html

Ecological Toxicity

See the USEPA ecological risk assessment guidance documents for guidance on developing Toxicity Reference Values (TRVs). Some "screening-level" TRVs can be found in the documents below. http://www.esd.ornl.gov/programs/ecorisk/reports.html

AQUATIC BIOTA:

Suter, G. W. II, and Tsao, C. L. (1996). "Toxicological Benchmarks for Screening of Potential Contaminants of Concern for Effects on Aquatic Biota on Oak Ridge Reservation: 1996 Revision." Oak Ridge National Laboratory, Oak Ridge, TN. 104pp, ES/ER/TM-96/R2 (PDF file, tm96r2.pdf; WP file, tm96r2.wpd; self-extracting WP file of Appendix A, 96r2appa.exe).

Environmental Management and Enrichment Facilities. (1998). "Radiological Benchmarks for Screening Contaminants of Potential Concern for Effects on Aquatic Biota at Oak Ridge National Laboratory, Oak Ridge, Tennessee." Bechtel Jacobs Company LLC, Oak Ridge, TN. BJC/OR-80 (PDF file, bjcor80.pdf; WP file, bjcor89.wpd.

WILDLIFE:

Sample, B.E., D.M. Opresko, and G.W Suter II. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. Oak Ridge National Laboratory, Oak Ridge, TN. 227 pp, ES/ER/TM-86/R3 (PDF file, tm86r3.pdf; self-extracting WP file, tm86r3.exe).

U.S. Army Corps of Engineers/U.S. Environmental Protection Agency Environmental Residue-Effects Database (ERED) is a compilation of data, taken from the literature, where biological effects (e.g., reduced survival, growth, etc.) and tissue contaminant concentrations were simultaneously measured in the same organism. Currently, the database is limited to those instances where biological effects observed in an organism are linked to a specific contaminant within its tissues. http://www.wes.army.mil/el/ered/index.html

U.S. Environmental Protection Agency (USEPA). (1999). "Data Collection for the Hazardous Waste Identification Rule, Section 14: Ecological Bench marks [s0044.pdf]." Prepared by the Center for Environmental Analysis for the Office of Solid Waste. October. http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/risk.htm

The ECOTOX (ECOTOXicology) database provides single chemical toxicity information for aquatic and terrestrial life: http://www.epa.gov/ecotox/

The California Wildlife Exposure Factor and Toxicity Database (Cal/Ecotox) is a compilation of exposure factors (i.e., ecological and physiological data) and toxicity data for a number of California mammals, birds, amphibians and reptiles. The database has been created by the Office of Environmental Health Hazard Assessment, in collaboration with the University of California at Davis, to provide an information resource for risk assessors conducting ecological risk assessments in California. http://www.oehha.org/cal_ecotox/ Cal/Ecotox is searchable by species or chemical. In addition, complete species reports are available for downloading.

Biota-Sediment Accumulation Factors

Bechtel Jacobs Company LLC. 1998. Biota Sediment Accumulation Factors for Invertebrates: Review and Recommendations for the Oak Ridge Reservation. Bechtel Jacobs Company LLC, Oak Ridge, TN. BJC/OR-112 [PDF file, bjcor-112a1.pdf (400K)]. http://www.esd.ornl.gov/programs/ecorisk/guidance.html

USACE BSAF and lipid database: http://www.wes.army.mil/el/bsaf/bsaf.html

U.S. Environmental Protection Agency (USEPA). (1999). Data Collection for the Hazardous Waste Identification Rule, Section 11: Aquatic Food Web Data [s0041.pdf] Prepared by the Center for Environmental Analysis for the Office of Solid Waste. October. http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/risk.htm

Trophic Transfer Factors (Invertebrate to Prey)

Dillon, T.M., Suedel, B.C., Peddicord, R.K., Clifford, P.A., and Boraczek, J.A. (1995). "Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems." *Environmental Effects of Dredging Technical Notes*, EEDP-01-33, U.S. Army Corps of Engineers, January. http://www.wes.army.mil/el/e2d2/index.html

U.S. Environmental Protection Agency, Region 2 (USEPA). (2000). "Proposed changes to the bioaccumulation testing evaluation framework and response to scientific peer reviewers comments on the existing framework for determining the suitability of dredged material to be placed at the Historic Area Remediation Site (HARS); Appendix E: Potential for Trophic Transfer of Metals in Benthic Invertebrate Prey to Finfish." USEPA, Region 2, October. http://www.epa.gov/region02/water/dredge/testing.htm

Chemical-Specific Parameters

U.S. Environmental Protection Agency (USEPA). (1999). "Partition Coefficients for Metals in Surface Water, Soil, and Waste [s0524.pdf]." Prepared by HydroGeoLogic, Inc., and Allison Geoscience Consultants, Inc. for the Office of Solid Waste. June. http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/risk.htm

Lyman, W.J., Reehl, W.F. and Rosenblatt, D.H. (1990). *Handbook of Chemical Property Estimation Methods, Environmental Behavior of Organic Compounds.* American Chemical Society, Washington, DC.

Mackay, D., Shiu, W.Y. and Ma, K.C. (1992). Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals; Volume 1-Monoaromatic Hydrocarbons, Chlorobenzenes, and PCBs. Lewis Publishers, Boca Raton, FL. http://www.uswaternews.com/books/bksbycategory/4iEnvCheGeneral/pc0849321921.html

National Library of Medicine's TOXNET, a cluster of databases on toxicology, hazardous chemicals, and related areas: http://toxnet.nlm.nih.gov/

HazDat, the Agency for Toxic Substances and Disease Registry's Hazardous Substance Release/Health Effects Database, is the scientific and administrative database developed to provide access to information on the release of hazardous substances from Superfund sites or from emergency events and on the effects of hazardous substances on the health of human populations. http://www.atsdr.cdc.gov/hazdat.html

Agency for Toxic Substances and Disease Registry's Toxicological Profiles, http://www.atsdr.cdc.gov/toxpro2.html, contain summaries and references of physical-chemical data for individual chemicals.