Application of Risk Assessment in the Evaluation of Dredged Material

Tab O

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KEY WORDS: Tier IV, Bioaccumulation, Ecological Risk Assessment, Human Health Risk Assessment

Ecological Risk Assessment

What is Ecological Risk Assessment?

"The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors."

(USEPA 1992)

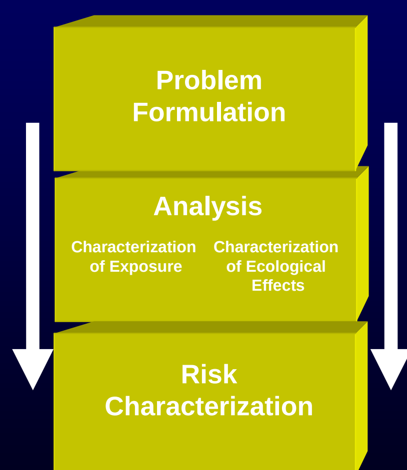
Existing Guidance

- 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, D.C. http://www.epa.gov/superfund/programs/risk/tooltrad.htm#gdec
- U. S. Environmental Protection Agency. (USEPA). (1997a). Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (interim final). Environmental Response Team, Edison, NJ. http://www.epa.gov/superfund/programs/risk/tooltrad.htm#gdec
- United States Environmental Protection Agency (USEPA). (1998). Guidelines for Ecological Risk Assessment. USEPA EPA/630/R095/002F 01 APRIL 1998. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, 175 pp. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12460
- U.S. Army Corps of Engineers. 1999. Risk Assessment Handbook Volume I: Human Health Evaluation. EM 200-1-4 http://www.usace.army.mil/inet/usace-docs/eng-manuals/em200-1-4/toc.htm
- U.S. Army Corps of Engineers. 1996. Risk Assessment Handbook Volume II: Environmental Evaluation. EM 200-1-4 http://www.usace.army.mil/inet/usace-docs/eng-manuals/em200-1-4vol2/
- Cura, J.J., Heiger-Bernays, W., Bridges, T.S., and D.W. Moore. (1999). Ecological and human health risk assessment guidance for aquatic environments. Technical Report DOER-4, US Army Corps of Engineers, Engineer Research and Development Center, Dredging Operations and Environmental Research Program, December. http://el.erdc.usace.army.mil/dots/doer/pdf/trdoer4.pdf

Ecological Risk Assessment

Components of ERA

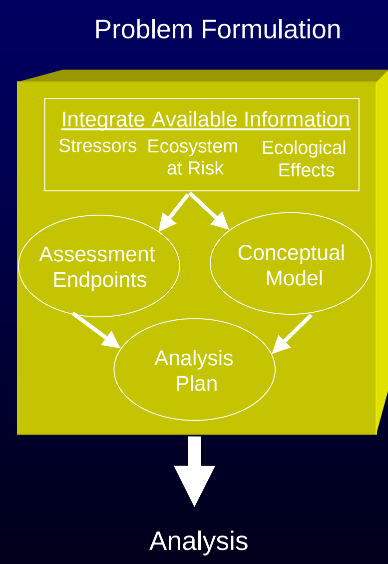
- Problem Formulation
- Analysis
  - Characterization of Exposure
  - Characterization of Ecological Effects
- Risk Characterization



Ecological Risk Assessment

Problem Formulation

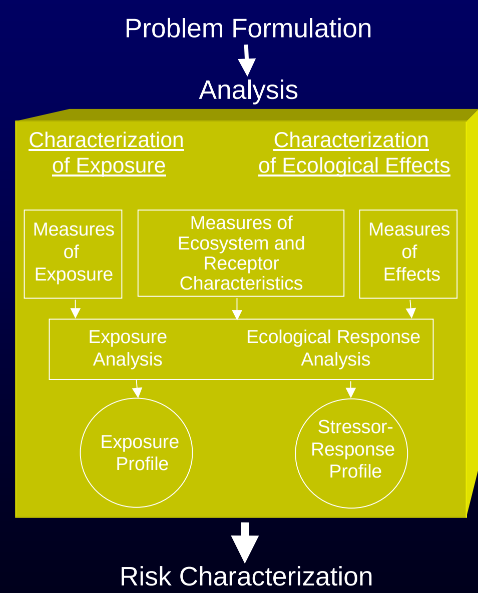
- Why is risk assessment being performed?
  - Screening-level activities
  - Identification of stressors, the ecosystem, and potential effects
- Assessment endpoints
- Development of conceptual model
  - Risk hypotheses
- Analysis plan
  - Study design, data needs
  - Selection of measures



Ecological Risk Assessment

Analysis

- Technical evaluation of data to reach conclusions about the relationship between stressors and ecological effects

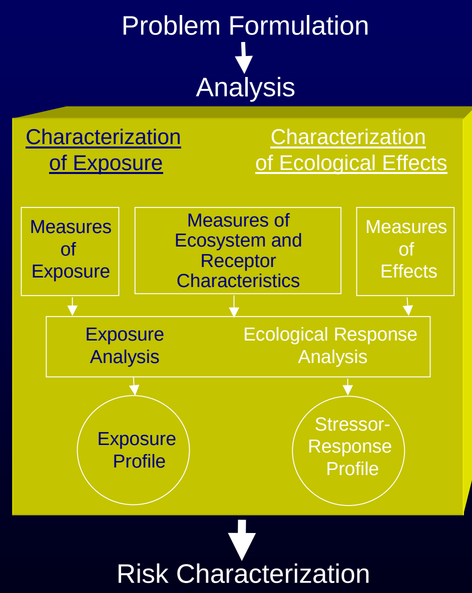


Ecological Risk Assessment

Analysis

Characterization of Exposure

- Describe contact between stressors and receptors
- Exposure analysis
  - Describe source, release, temporal and spatial distribution of stressor, and extent and pattern of contact with receptors
- Exposure profile
  - Narrative and numerical description

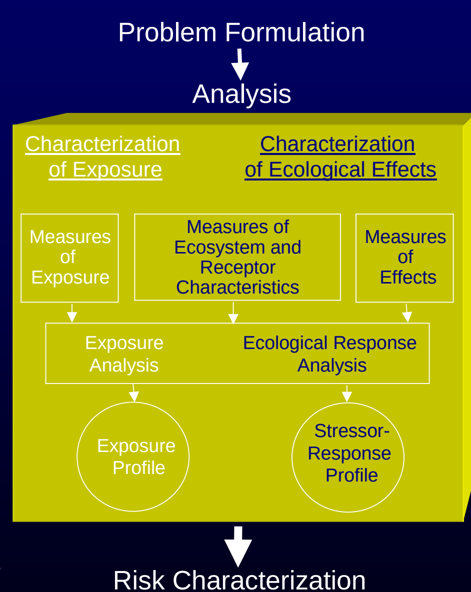


Ecological Risk Assessment

Analysis

Characterization of Ecological Effects

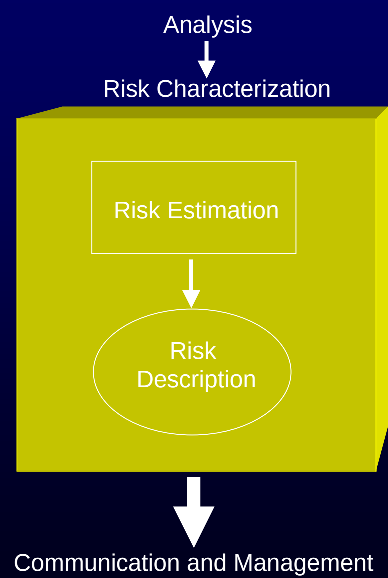
- Linking stressor with effect
- Ecological response analysis
  - Determine relationship between stressor levels and ecological effects
  - Evaluate likelihood that effects are or will occur
  - Link measures of effects with assessment endpoints



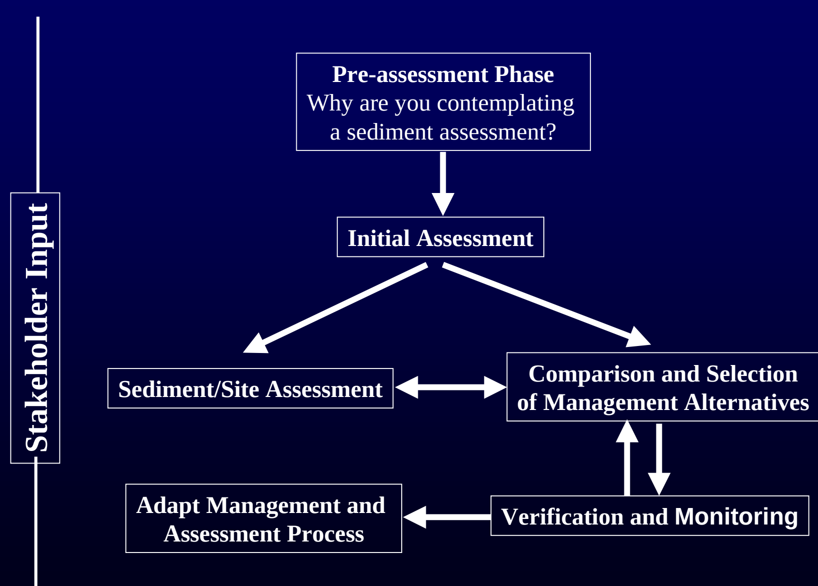
Ecological Risk Assessment

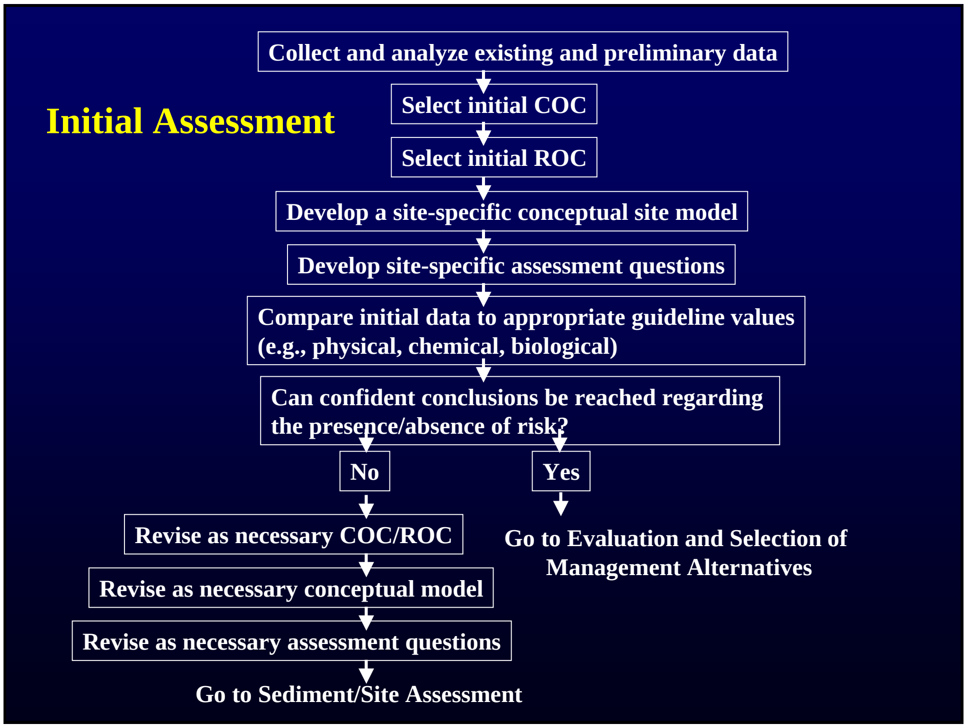
Risk Characterization

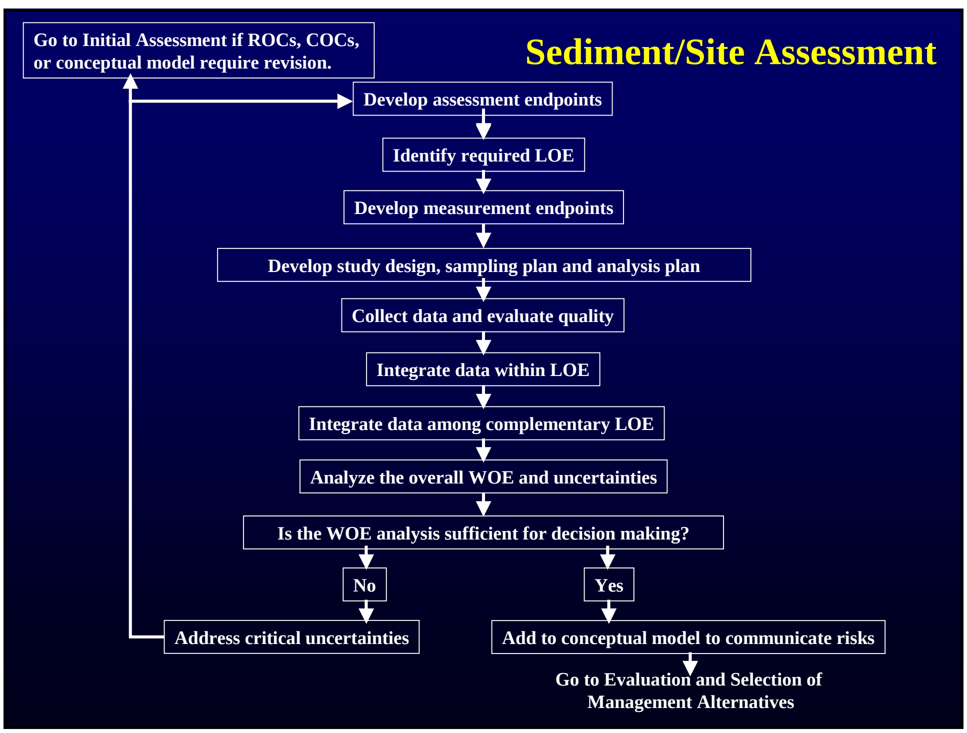
- Estimate risk to assessment endpoints using results from analysis
- Risk estimation
  - Estimate risk of adverse effects through integration of exposure and effects data
  - Evaluate uncertainties
- Risk description
  - Evaluate lines of evidence
  - Determine whether effects are adverse (interpretation)



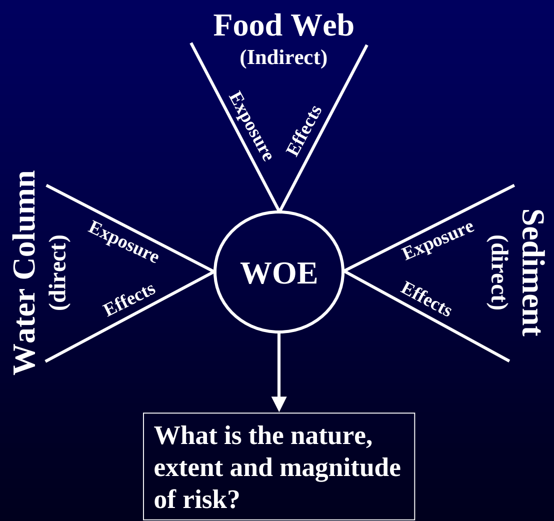
Generic, Risk-Based Sediment Assessment Framework
Bridges et al., 2005




Initial Assessment
Collect and analyze existing and preliminary data
Select initial COC
Select initial ROC
Develop a site-specific conceptual site model
Develop site-specific assessment questions
Compare initial data to appropriate guideline values (e.g., physical, chemical, biological)
Can confident conclusions be reached regarding the presence/absence of risk?
No
Yes
Revise as necessary COC/ROC
Revise as necessary conceptual model
Revise as necessary assessment questions
Go to Sediment/Site Assessment
Go to Evaluation and Selection of Management Alternatives


Sediment/Site Assessment
Go to Initial Assessment if ROCs, COCs, or conceptual model require revision.
Develop assessment endpoints
Identify required LOE
Develop measurement endpoints
Develop study design, sampling plan and analysis plan
Collect data and evaluate quality
Integrate data within LOE
Integrate data among complementary LOE
Analyze the overall WOE and uncertainties
Is the WOE analysis sufficient for decision making?
No
Yes
Address critical uncertainties
Add to conceptual model to communicate risks
Go to Evaluation and Selection of Management Alternatives

Lines and Weight of Evidence in Sediment Assessment



Evaluation and Selection of Management Alternatives

- Identify feasible/available management alternatives
- ↓ Evaluate and compare risks associated with the alternatives
- ↓ Evaluate and compare costs of the alternatives
- ↓ Develop management strategy
- ↓ Develop logic to apportion sediment among selected alternatives
- ↓ Develop monitoring plan
- ↓ Execute monitoring of management alternative performance
- ↓ Provide feedback for ensuring performance of management alternatives and the assessment/management process

Topic Areas

- Use of Sediment Quality Guidelines
- Conceptual model development
- Exposure Assessment
  - Bioaccumulation modeling
  - Spatial and temporal elements of exposure
- Uncertainty analysis
- Comparative assessment, a case study

Screening Sediments Using Sediment Quality Guidelines (SQG)

- SQG: Collective term for values used to differentiate sediment contaminant concentrations of little concern from those predicted to have adverse biological effects
  - Mechanistically derived
  - Empirically derived

SQG Derivation Methods

- Mechanistic Derivation Methods
  - Equilibrium Partitioning (EqP) - sediment:water partitioning of organics to predict concentrations above which effects are expected based on surface water quality criteria
  - Simultaneously Extracted Metals/Acid Volatile Sulfides (SEM/AVS) - sediment:water partitioning of metals (Cd, Cu, Hg, Ni, Pb, and Zn) to predict concentrations below which effects are not expected

SQG Derivation Methods

- Empirically Derived Methods
  - Apparent Effects Threshold (AET) - sediment contaminant concentration above which the biological response of concern was always observed in the data set from which the values were derived
  - Effects Range Low/Effects Range Median (ERL/ERM)- statistical analysis of sediment chemical concentrations with biological responses using only “effect” data
  - Threshold Effects Level/Probable Effects Level (TEL/PEL) - statistical analysis of sediment chemical concentrations with biological responses using “effect” and “no effect” data

SQG Uncertainties

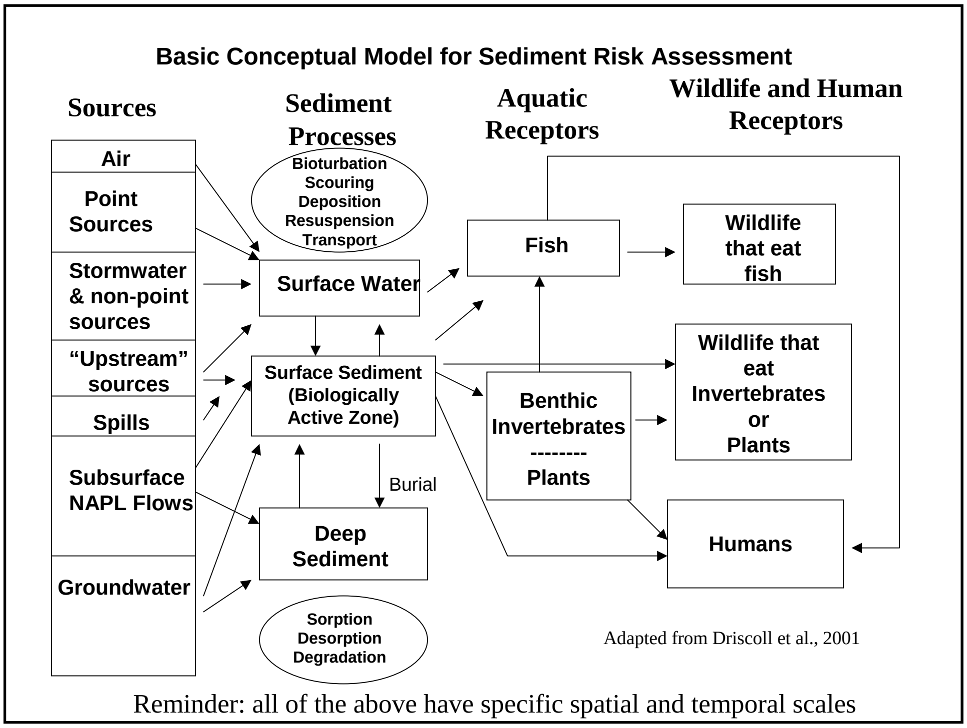
- Analysis limited to chemicals for which you have SQGs
- SQGs do not address interactions of chemicals
- SQGs do not address concerns due to bioaccumulation and trophic transfer
- SQGs developed for one environment have no relevance for other environments
- Reliability of EqP and SEM/AVS has not been quantified
- False negative and positive rates can be high
  - ~10% probability of toxicity when below all ERLs (Long et al. 1998)
  - Of 239 samples that exceeded at least one ERM, only 38% were toxic to amphipods (O’Connor et al. 1998)

SQG "Do's and Do not's"

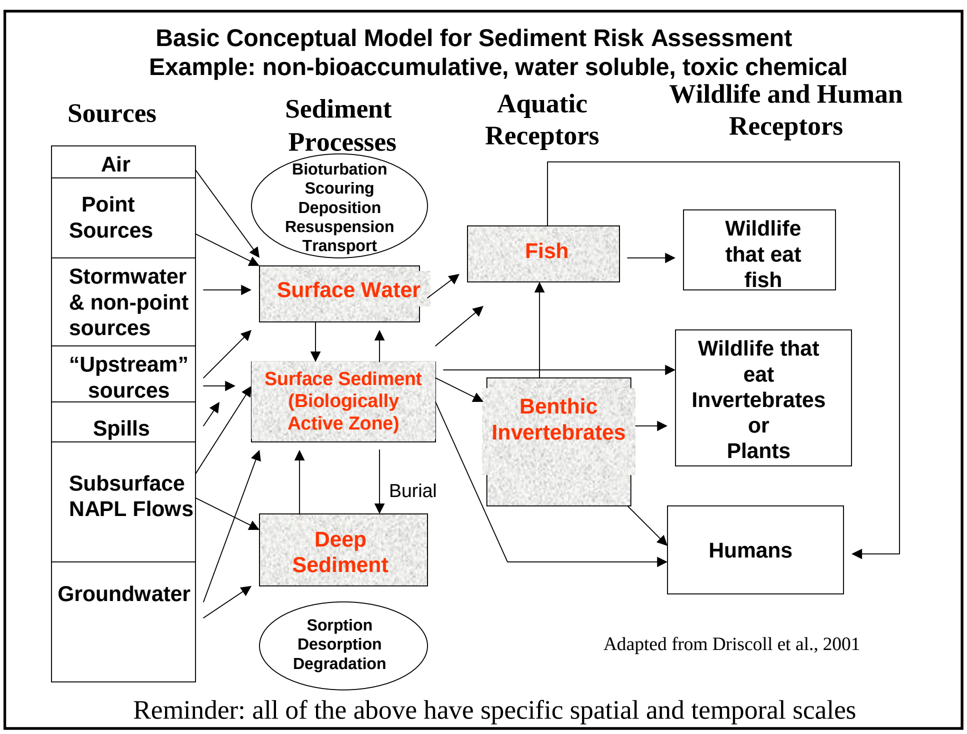
- SQGs do:
  - Help determine the need for additional evaluation of the likelihood for effects
  - Focus scope of additional study (e.g., reduce # of COC, ROC, or pathways to be considered in baseline assessment)
- SQGs do not provide quantitative estimates of risk
  - Error rates can be large
  - Some pathways not considered, e.g., bioaccumulation
- SQGs are not suitable for use as remedial targets or cleanup standards.

Conceptual Models

- Narrative and/or graphic descriptions of predicted relationships between ecological components and stressors in a system
  - Defines problem
  - Guides technical and managerial approach to the problem
  - Basis for developing risk hypotheses
- The completeness and accuracy of a risk assessment are dependent on the thoroughness of problem formulation and conceptual model development


Basic Conceptual Model for Sediment Risk Assessment
Sources
Sediment Processes
Aquatic Receptors
Wildlife and Human Receptors
Air
Point Sources
Stormwater & non-point sources
"Upstream" sources
Spills
Subsurface NAPL Flows
Groundwater
Bioturbation
Scouring
Deposition
Resuspension
Transport
Surface Water
Surface Sediment (Biologically Active Zone)
Burial
Deep Sediment
Sorption
Desorption
Degradation
Fish
Benthic Invertebrates

Plants
Wildlife that eat fish
Wildlife that eat Invertebrates or Plants
Humans
Adapted from Driscoll et al., 2001
Reminder: all of the above have specific spatial and temporal scales


Basic Conceptual Model for Sediment Risk Assessment
Example: non-bioaccumulative, water soluble, toxic chemical
Sources
Sediment Processes
Aquatic Receptors
Wildlife and Human Receptors
Air
Point Sources
Stormwater & non-point sources
"Upstream" sources
Spills
Subsurface NAPL Flows
Groundwater
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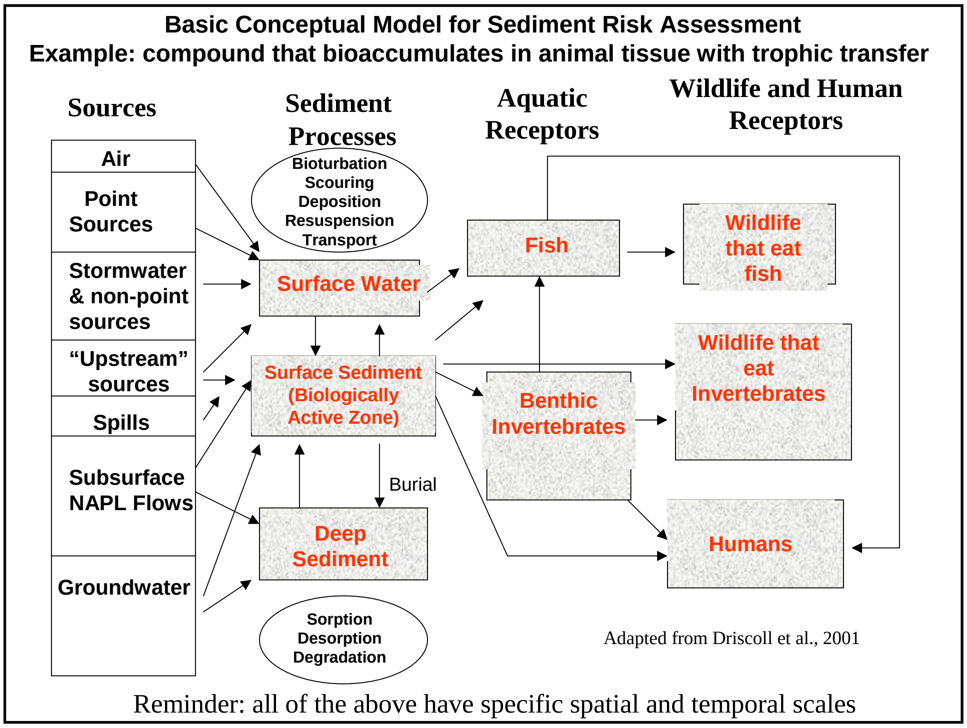
Basic Conceptual Model for Sediment Risk Assessment
Example: compound that bioaccumulates in animal tissue with trophic transfer
Sources
Sediment Processes
Aquatic Receptors
Wildlife and Human Receptors
Air
Point Sources
Stormwater & non-point sources
"Upstream" sources
Spills
Subsurface NAPL Flows
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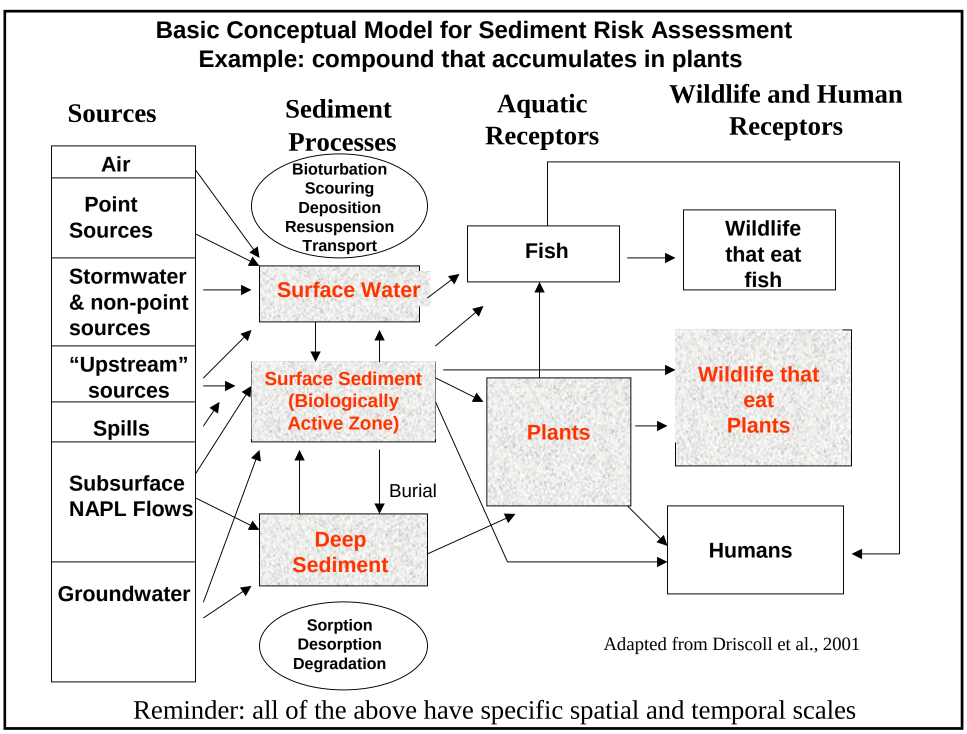
Basic Conceptual Model for Sediment Risk Assessment
Example: compound that accumulates in plants
Sources
Sediment Processes
Aquatic Receptors
Wildlife and Human Receptors
Air
Point Sources
Stormwater & non-point sources
"Upstream" sources
Spills
Subsurface NAPL Flows
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Plants
Wildlife that eat fish
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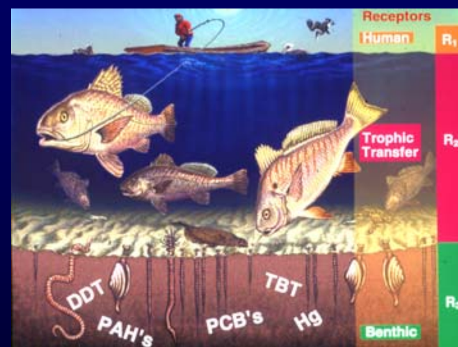
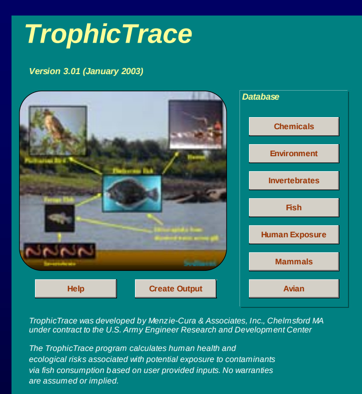
Assessing Exposure

- Direct exposure to sediment-dwelling organisms
- Direct exposure to organisms in the water column
- Indirect exposure through trophic transfer of contaminants
  - Human receptors
  - Ecological receptors

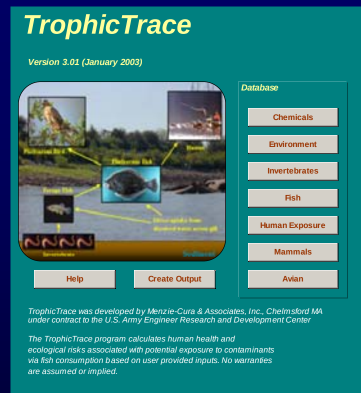


TrophicTrace

- Microsoft® Excel Add-In and stand alone v.
- Steady-state bioaccumulation model based on Gobas (1993 and 1995) for organics
- Uptake and trophic transfer of inorganics are modeled using empirical BCFs or Trophic Transfer Factors (TTF)
- Default sediment-driven food web can be edited



TrophicTrace

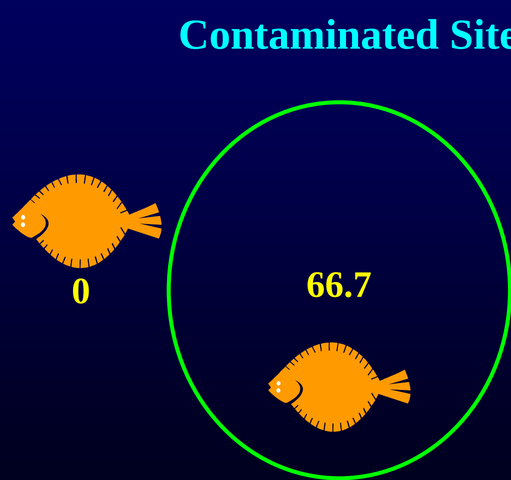


- **Calculates cancer risk and hazard indices for humans via fish ingestion**
- **Can calculate risks to ecological receptors, e.g., fish, osprey, bald eagle, mink, and otter**
- **Designed as flexible tool that can be customized for region/site-specific use**
- **http://el.erdc.usace.army.mil/trophictrace/index.html**

Spatial/Temporal Scales of Predicting Far-field Impacts

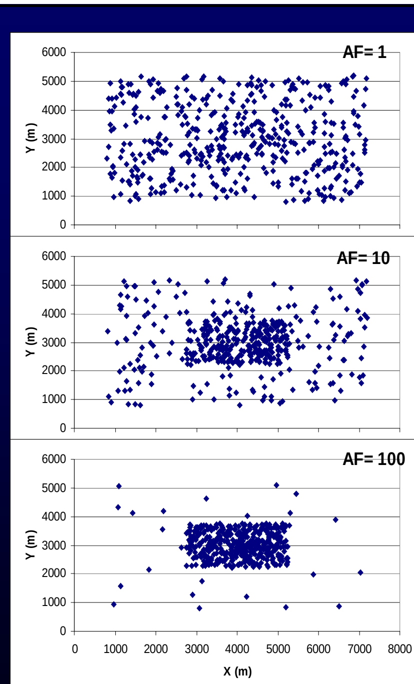
- **Contaminant concentration varies over space/time at sites**
- **Animals spend variable amounts of time in or around sites**
- **Exposure estimates must include spatial/temporal variables**

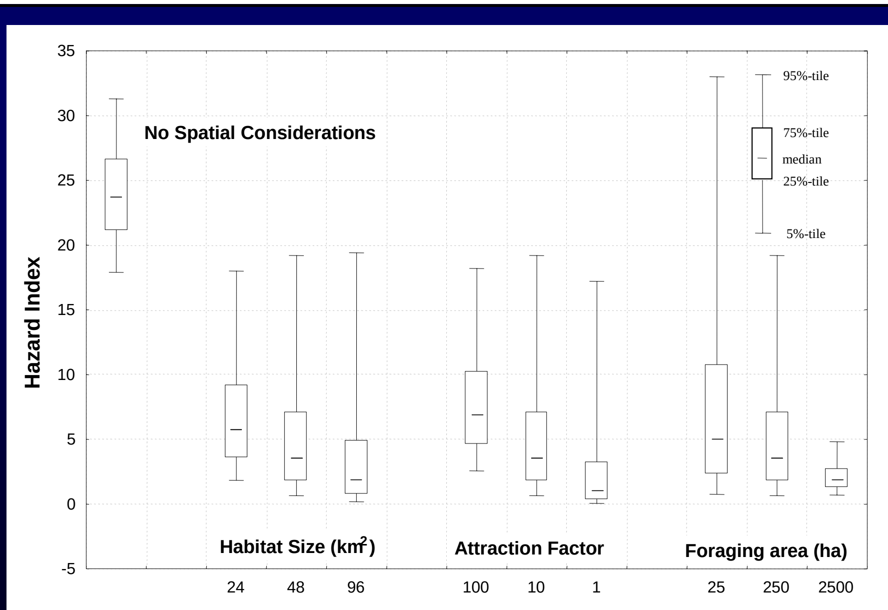
Modeling Exposure in Spatially Heterogeneous Environments



Spatial Issues in Exposure Assessment

- Disposal sites are relatively small (3.75 km^2)
- Fish mobility varies among species
  - Many recreational and commercial species range over large areas
- Do disposal sites attract fish?
  - How will this affect exposure?

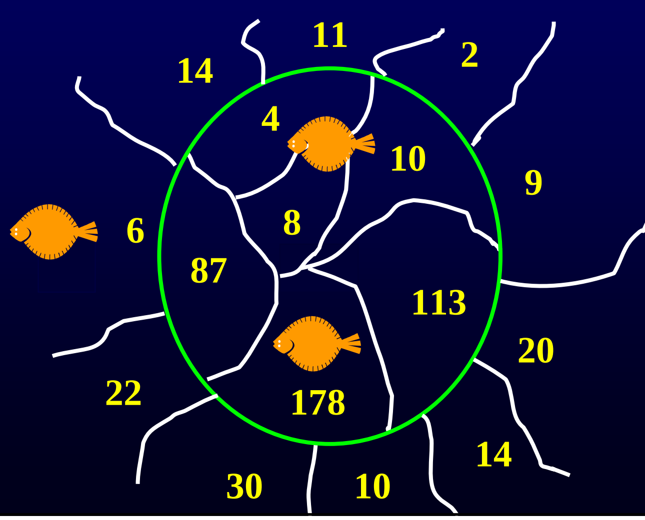




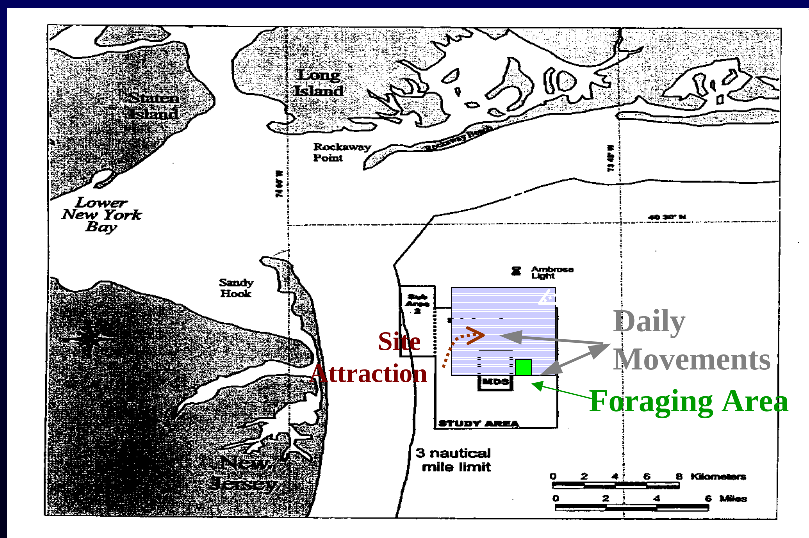
Linkov, I., D. Burmistrov, J. Cura, T.S. Bridges. 2002. Risk-Based Management of Contaminated Sediments: Consideration of Spatial and Temporal Patterns in Exposure Modeling. *Environmental Science and Technology* 36:238-246.

Modeling Exposure in Spatially Heterogeneous Environments

Contaminated Site



Spatial Submodel: Approach



Model Structure

Spatial Submodel
- Habitat size
- Fish abundance
- Foraging area
- Size of the site
- Sediment concentrations
- Water concentrations

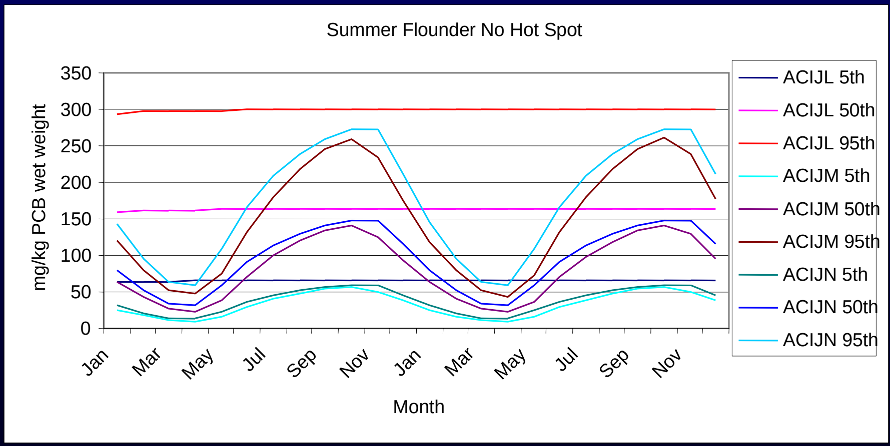
Output: Time-varying (monthly) sediment and water concentrations to which fish are exposed

Bioaccumulation Submodel
- Lipid content
- Body weight
- Food web characteristics
- Physical-chemical properties of contaminant

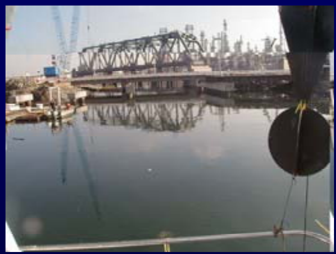
Output: Time-varying (monthly) predicted fish tissue concentrations

Risk Submodel
- Human exposure parameters
- Body weight
- Fish ingestion rate
- exposure duration
- toxicity estimates

Example of FISHRAND-migration Output



Sources of Uncertainty in Aquatic Systems



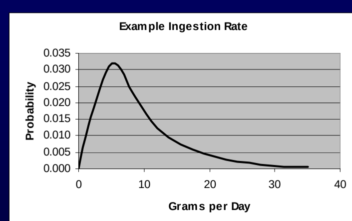
- **Sediments are part of a complex, dynamic system**
  - **Water and sediment move**
  - **Gradients are steep**
  - **Species are highly mobile**
  - **Food webs can be complex**

Uncertainty: “The state of being in doubt”

- **Uncertainty due to incertitude or ignorance**
  - **Can collect more data/information**
- **Uncertainty due to variability**
  - **Known population heterogeneity**
  - **Cannot be reduced only better understood**
- **Both important – consider separately when possible**

> **“Teach yourself to work in uncertainty”**
> **Bernard Malamud**

Sources of Uncertainty in RA



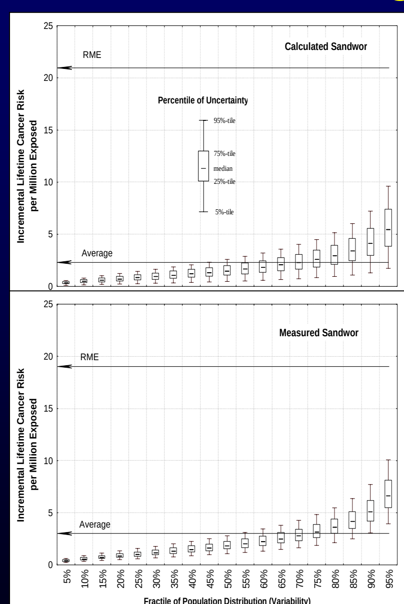
- **Scenario**
  - **Missing elements**
  - **Often qualitative**
- **Model**
  - **“All models are wrong, but some are useful”**
- **Parameter**
  - **Specification of model parameters**

Uncertainty in Sediment Assessments

- Vorhees, D.J., K. von Stackelberg, S.K. Driscoll and T.S. Bridges. 2002. Evaluation of sources of uncertainty to improve dredged material evaluations for open water disposal, *Human and Ecological Risk Assessment* 8(2):369-389
- von Stackelberg, K., D. Burmistrov, D. Vorhees, T.S. Bridges, I. Linkov. 2002. Importance of uncertainty and variability to predicted risks from trophic transfer of PCBs in dredged sediments. *Risk Analysis* 22: 499-512.
- Linkov, I, K. von Stackelberg, D. Burmistrov, T.S. Bridges. 2001. Ecological risk assessment: uncertainty and variability from trophic transfer in management of contaminated dredged sediments. *The Science of the Total Environment* 274: 255-269.

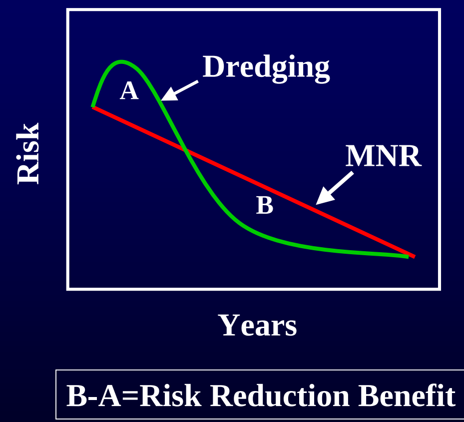
Application of Probabilistic Modeling to Sediment

- Human health effects evaluated by using mean, RME and probabilistic input parameters
  - RME always over-estimated risk
- Defaulting to conservative point estimates will create programmatic “burdens”

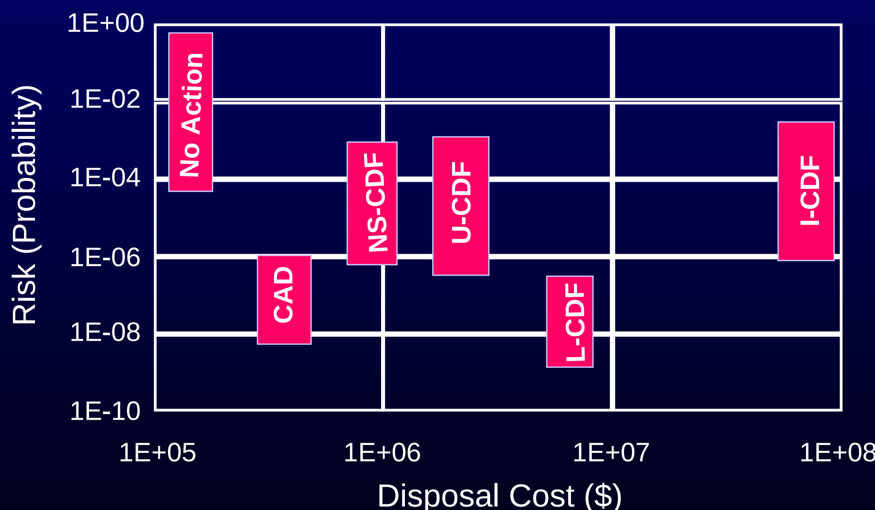


Risk Characterization and Management

- **Value of comparative approaches**
  - **NAS report**
- **Risks and uncertainties exist for each management alternative**
  - **There is no zero-risk option**



Risk Assessment



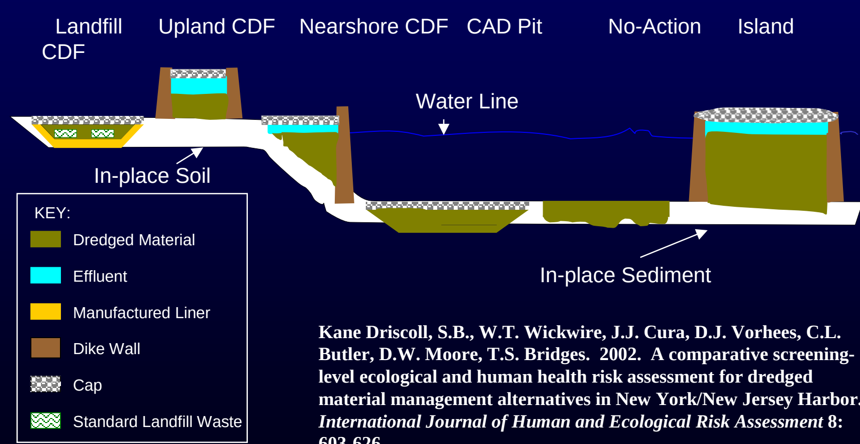
Case Study: NY/NJ Harbor

Case Study: NY/NJ Harbor

Issues

- Harbor among most polluted in U.S.
- $>10^6$ yd^3 fail regional criteria for ocean disposal
- Existing disposal site closed 1 Sep. 97
- Proposed deepening

Conceptual Illustration of Disposal Alternatives



Kane Driscoll, S.B., W.T. Wickwire, J.J. Cura, D.J. Vorhees, C.L. Butler, D.W. Moore, T.S. Bridges. 2002. A comparative screening-level ecological and human health risk assessment for dredged material management alternatives in New York/New Jersey Harbor. *International Journal of Human and Ecological Risk Assessment* 8: 603-626.

Case Study: NY/NJ Harbor

Design and Operation Features:

	Duration (yr)	Capacity (10^6 cu yd)	Size (acres)
CAD	5	25	300
Island	20	100	1200
Near-shore	3	6	120
Upland	3	6	120
Landfill	3	6	120

Case Study: NY/NJ Harbor

Assessment Endpoints

- Reproducing populations of benthic invertebrates, fish, and birds

Ecological Receptors of Concern

- Benthic invertebrates - Polychaete worm (*Nereis virens) &* Clam (*Macoma nasuta*)
- Forage Fish - Sand lance *(Ammodytes americanus)*
- Piscivorous Fish - Black sea bass *(Centropristis striata)*
- Foraging Birds - Spotted sandpiper *(Actitus macularia)*
- Piscivorous Bird - Osprey *(Pandion haliaetus)*

Case Study: NY/NJ Harbor

Human Receptors of Concern

- Fishermen
- On-site worker
- Handler and transporter of dredged material

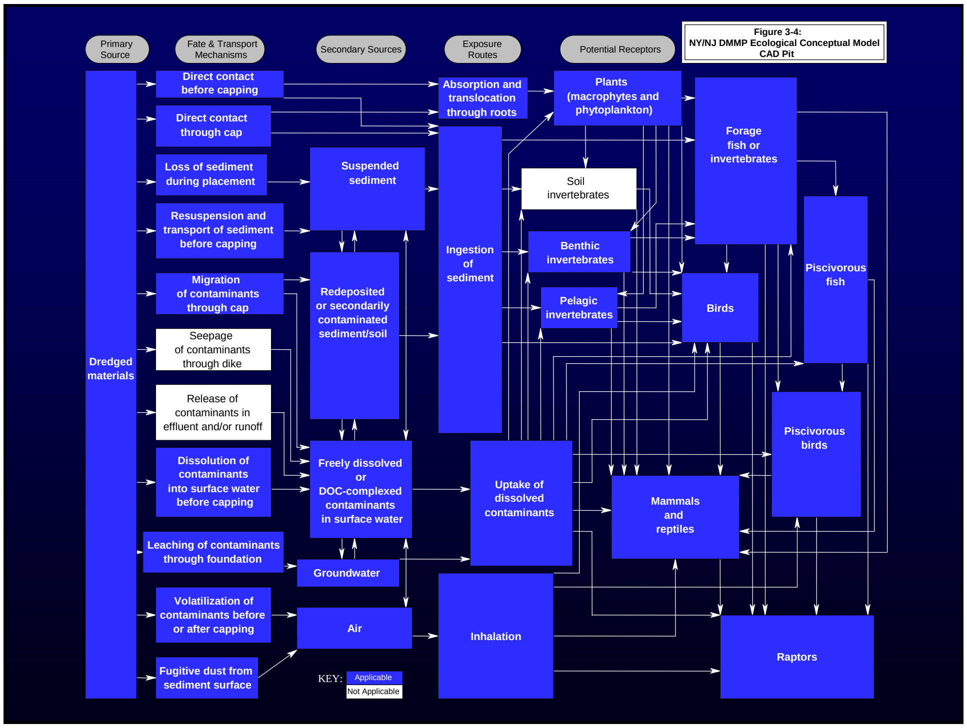
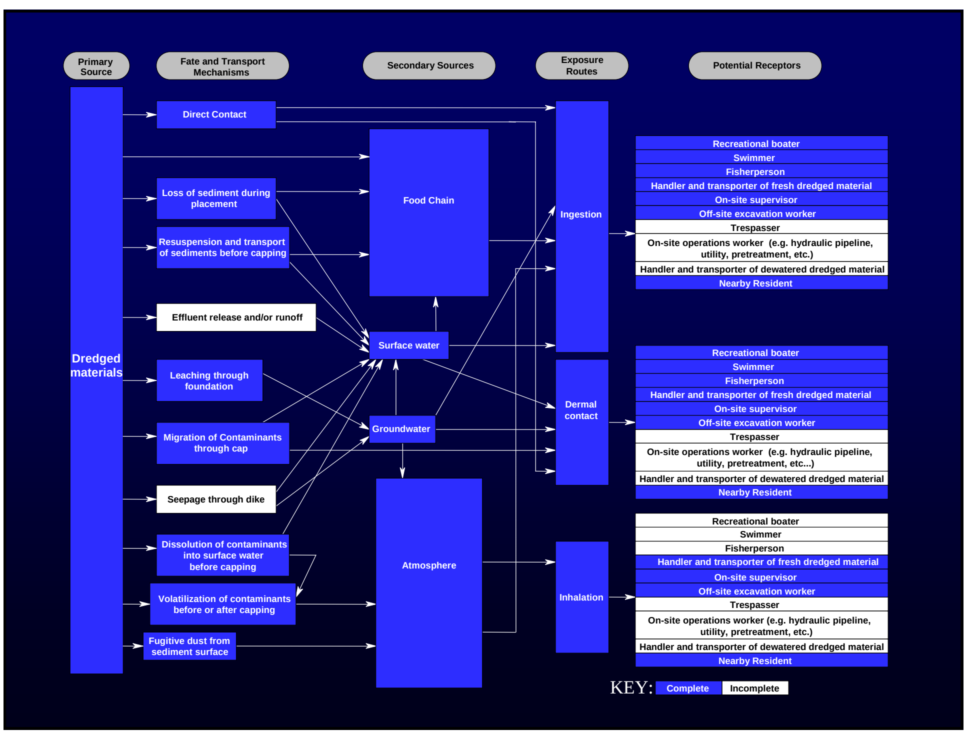
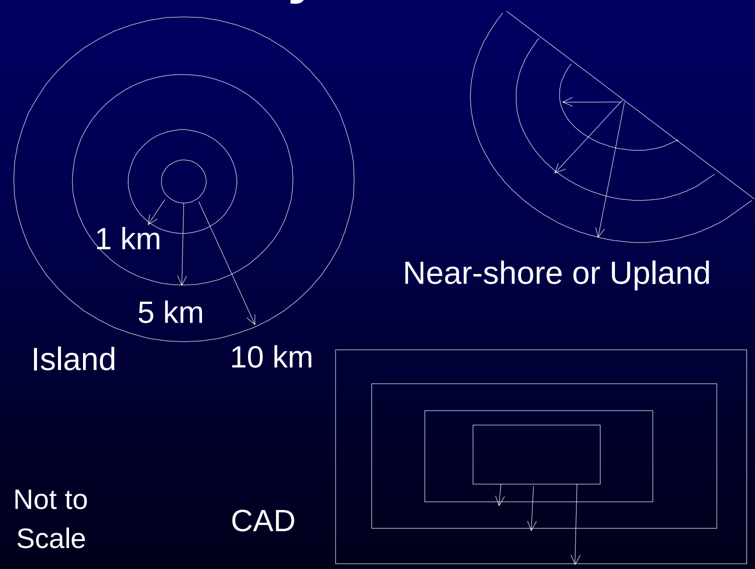


Figure 3-4:
NY/NJ DMMP Ecological Conceptual Model
CAD Pit
Primary Source
Fate & Transport Mechanisms
Secondary Sources
Exposure Routes
Potential Receptors
Dredged materials
Direct contact before capping
Direct contact through cap
Loss of sediment during placement
Resuspension and transport of sediment before capping
Migration of contaminants through cap
Seepage of contaminants through dike
Release of contaminants in effluent and/or runoff
Dissolution of contaminants into surface water before capping
Leaching of contaminants through foundation
Volatilization of contaminants before or after capping
Fugitive dust from sediment surface
Suspended sediment
Redeposited or secondarily contaminated sediment/soil
Freely dissolved or DOC-complexed contaminants in surface water
Groundwater
Air
Absorption and translocation through roots
Ingestion of sediment
Uptake of dissolved contaminants
Inhalation
Plants (macrophytes and phytoplankton)
Soil invertebrates
Benthic invertebrates
Pelagic invertebrates
Forage fish or invertebrates
Birds
Piscivorous fish
Piscivorous birds
Mammals and reptiles
Raptors
KEY:
Applicable
Not Applicable



Primary Source
Fate and Transport Mechanisms
Secondary Sources
Exposure Routes
Potential Receptors
Dredged materials
Direct Contact
Loss of sediment during placement
Resuspension and transport of sediments before capping
Effluent release and/or runoff
Leaching through foundation
Migration of Contaminants through cap
Seepage through dike
Dissolution of contaminants into surface water before capping
Volatilization of contaminants before or after capping
Fugitive dust from sediment surface
Food Chain
Surface water
Groundwater
Atmosphere
Ingestion
Dermal contact
Inhalation
Recreational boater
Swimmer
Fisherperson
Handler and transporter of fresh dredged material
On-site supervisor
Off-site excavation worker
Trespasser
On-site operations worker (e.g. hydraulic pipeline, utility, pretreatment, etc.)
Handler and transporter of dewatered dredged material
Nearby Resident
Recreational boater
Swimmer
Fisherperson
Handler and transporter of fresh dredged material
On-site supervisor
Off-site excavation worker
Trespasser
On-site operations worker (e.g. hydraulic pipeline, utility, pretreatment, etc...)
Handler and transporter of dewatered dredged material
Nearby Resident
Recreational boater
Swimmer
Fisherperson
Handler and transporter of fresh dredged material
On-site supervisor
Off-site excavation worker
Trespasser
On-site operations worker (e.g. hydraulic pipeline, utility, pretreatment, etc.)
Handler and transporter of dewatered dredged material
Nearby Resident
KEY:
Complete
Incomplete

Case Study: NY/NJ Harbor



Case Study: NY/NJ Harbor

Characterization of Exposure

- Use 28-d bioaccumulation data for polychaete worm, *N. virens*
- Estimate steady-state tissue concentration for *N. virens*
- For bioaccumulative organics, model trophic transfer to fish (Gobas Model)
- Use food chain multiplier (30) to estimate tissue residue in eggs of fish-eating birds

Case Study: NY/NJ Harbor

Characterization of Exposure (Cont.)

- Gobas Aquatic Food Chain Model (1993):
  - Uses mass transfer coefficients (i.e. gill uptake rate constant) to describe uptake of chemical from water and food, elimination by excretion, and dilution by growth
  - Predicts steady-state concentrations of nonmetabolized hydrophobic organic chemicals (not used for PAHs or metals) in forage and piscivorous fish

Case Study: NY/NJ Harbor

Characterization of Exposure (Cont.)

- Exposure to higher trophic level organisms estimated as:
  - Daily dietary dose to birds (mg chemical/kg BW*day)
  - Tissue concentration in fish and osprey egg (mg chemical/kg BW)

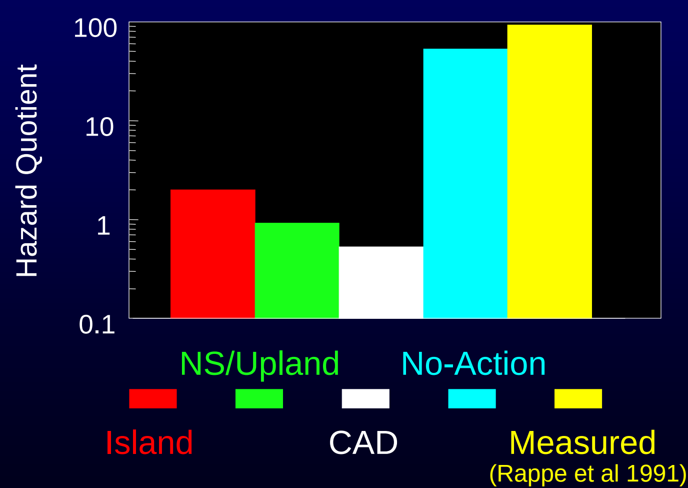
Case Study: NY/NJ Harbor

Characterization of Effects

- Toxicity to benthic invertebrates (Sum PAH, Narcosis)
- Higher trophic levels (fish, birds)
  - Dioxin toxic equivalents (TEQs)
  - Tissue-based values from literature & databases (ERED)

Case Study: NY/NJ Harbor

Hazard Quotients for 2,3,7,8-TCDD in Fish



Case Study: NY/NJ Harbor

Human Health Exposure Assessment

- Identify exposed populations
- Delineate complete exposure pathways
- Determine fate and transport mechanisms
- Estimate exposure point concentrations
- Calculate contaminant intake for receptors in complete exposure pathways

Case Study: NY/NJ Harbor

Human Health Toxicity Assessment

- Toxicity factors:
  - Non-cancer threshold (RfD or Reference Dose)
  - Cancer probability (CSF or Cancer Slope Factor)
  - Absorption factors
  - Special cases: TEFs (PAHS, Dioxins, Furans), Lead and Arsenic
  - Data Sources: IRIS, HEAST, Literature

Case Study: NY/NJ Harbor

Human Health Risk Characterization

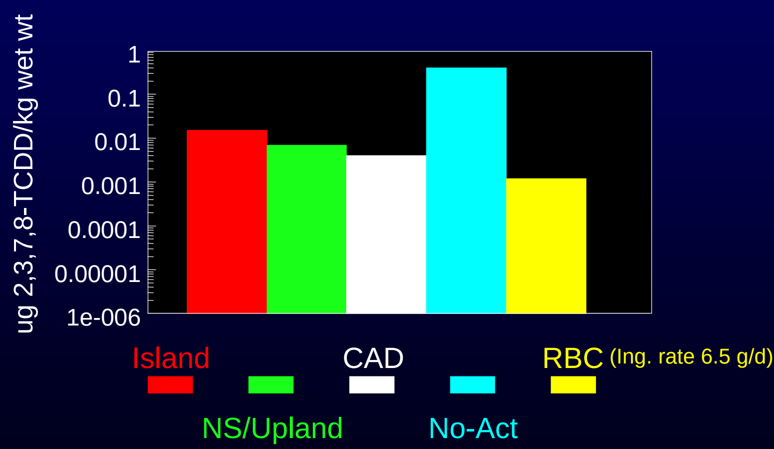
- Integration of exposure assessment and toxicity assessment into a quantitative estimate of risk
- Non-cancer hazard quotient
- Cancer risk
- Risk-based concentrations

Case Study: NY/NJ Harbor

Receptor	Non-Cancer Hazard Index	Cancer Risk
Barge Operator	7×10^{-1}	4×10^{-5}
Site Worker – CDF	3×10^{-1}	1×10^{-5}
Site Worker - Landfill	4×10^{-1}	3×10^{-4}

Case Study: NY/NJ Harbor

Est. Fish Tissue Conc. vs. HH Risk-Based Fish Conc. (RBC)

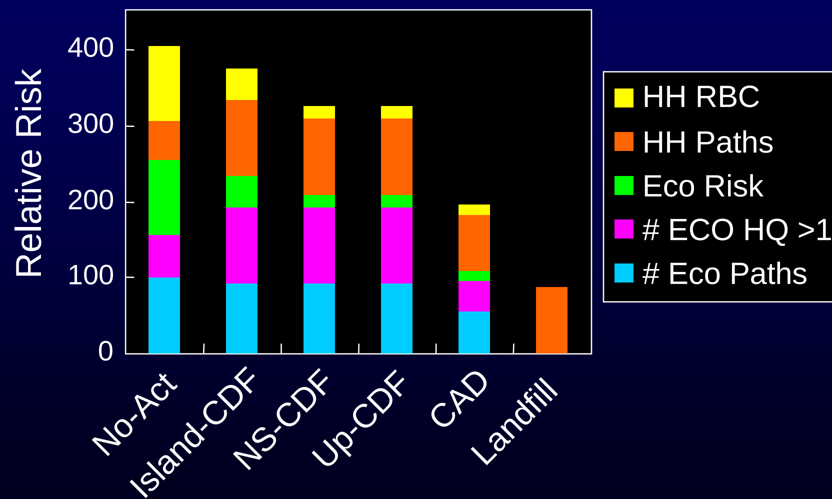


Case Study: NY/NJ Harbor

Comparative Risk Evaluation Criteria

- Ratio of Area/ Capacity (acres/ 10^6 cu yd)
- Ratio of Duration/ Capacity (years/ 10^6 cu yd)
- Number of Complete Ecological Exposure Pathways
- Number of Ecological Hazard Quotients > 1
- Magnitude of Ecological Hazard Quotients
- Number of Complete HH Exposure Pathways
- Ratio of Conc. of COCs in Fish/Risk-based Conc.

Comparative Risk Evaluation



Case Study: NY/NJ Harbor

Uncertainties of Screening Level Approach

- Conservative bias in screening level approach
  - Examines most contaminated sediments
  - Steady-state exposure model may overestimate exposure
  - Assessment estimates risk to individual ecological receptors, not populations
- Design features (i.e. size and capacity) and site selection not finalized
- Performance of alternative as designed

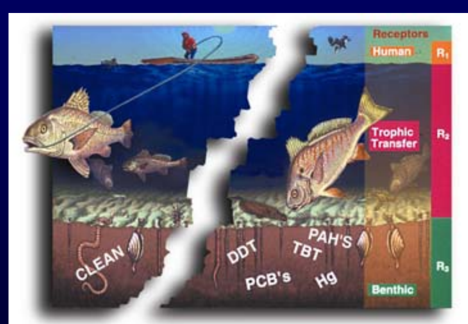
Case Study: NY/NJ Harbor

Conclusions

- Relative risk to ecological receptors and fishermen:
  – No-Action > Island > NS/Upland CDF > CAD > Landfill
- Design and operation features of each alternative must be incorporated into site-specific conceptual models and exposure scenarios
- Comparative risk assessments should consider both magnitude of risk and spatial scale over which risk occurs

Conclusions

- **Comparative assessment will increase the quality of decisions**
- **Sediment risk assessments must be supported by a thorough uncertainty analysis**



- **Effective regulatory implementation of risk-based approaches will require a degree of routinization**