Exposure Processes and Assessment

Dr. Paul R. Schroeder
Dr. Joe Z. Gailani

Paul.R.Schroeder@usace.army.mil
Joe.Z.Gailani@usace.army.mil
RISK FRAMEWORK

RISK ASSESSMENT PARADIGM

Exposure Assessment

Problem Formulation

Risk Characterization

Effects Assessment

Risk = (Exposure + Effect)

Risk Management

Economic Analysis, Socio-Political, Engineering Feasibility
Exposure

- Exposure is a quantification of the level and duration of a stressor affecting the receptor often expressed as a dose

\[ D = \sum_{i=1}^{n} C_i \Delta t \]
Topics

- Exposure Pathways and Drivers
- Sediment Characterization
- Resuspension Source Strength Predictions
- Dredging Residuals Generation and Transport
- Contaminant Release Predictions
- Screening Models
- Comprehensive Exposure Modeling
- Dose Modeling for Cumulative Exposure
- Example Case Study
Exposure Pathways

Release
Residual Consolidation, Porewater expulsion, Diffusion, Groundwater

Release
Dissolved Plume
$K_{ow}$ driven, kinetically limited

Solids Resuspension

partitioning
degradation

Flow

Residual Erosion (solids)

Clean Undisturbed Sediment

Residual (disturbed) Sediment
Other Sources

Dredged Material Assessment and Management Seminar
24-26 May 2011, Jacksonville, FL
Exposure Pathways and Risk Drivers

• Sediment Resuspension
  ➢ Turbidity
  ➢ Suspended solids
  ➢ Contribution to deposition and benthic impacts

• Transport of Dredged Material Residuals Out of Dredge Prism
  ➢ Burial
  ➢ Benthic toxicity
  ➢ Bioaccumulation

• Contaminant Release
  ➢ Water quality
  ➢ Water column toxicity
  ➢ Bioaccumulation
Sediment Resuspension

• Sediment resuspension will occur at dredging projects--the extent varies

• Often less than 1% of mass of fine-grained fraction of sediment dredged

• Factors:
  
  ➢ Sediment properties such as bulk density, particle size distribution, and mineralogy
  
  ➢ Site conditions: water depth, currents, and waves, presence of hardpan, bedrock, or loose cobbles or boulders
  
  ➢ Nature and extent of debris and obstructions
  
  ➢ Operations: production, thickness of dredge cuts, dredging equipment type, methods, operator skill
Sediment Characterization

- Sediment characteristics is the dominant driver for resuspension and residuals transport
- Sediment parameters for predicting sediment loss by resuspension and erosion (Source Strength) and transport:
  - Water content \( (w) \)
  - Atterberg limits -- \( LL, PL \) and \( PI = LL - PL \)
  - Liquidity index (LI) -- \( LI = (w - PL) / PI \)
  - Grain size distribution
  - Settling velocity
  - Erodibility coefficients

- Contaminant Release
  - Dredging Elutriate Test (DRET)
  - Partitioning and Mass Transfer Coefficients

Atterberg Limits

\( LL = \text{Liquid Limit} \)
\( PL = \text{Plastic Limit} \)
\( PI = \text{Plasticity Index} \)
Resuspension Source Predictions

• Hayes characteristic resuspension approach
  ➢ Process-based
  ➢ Sediment dependence correlated to liquidity index and grain size
  ➢ Equipment specific processes and characteristic losses
  ➢ Equipment factors: size and controls
  ➢ Site factors: debris, heterogeneity, water depth and current
  ➢ Operations: speed, cut, relative production rate
  ➢ Makes adjustments to characteristic loss rates by process based on empirical and theoretical evidence

• Empirical
  ➢ Equipment, Operations and Controls
  ➢ Sediment type
  ➢ Limited data sources and limited conditions for selection
Mechanical Dredge Operation

• **Release processes**
  - Bottom wake
  - Expulsion during closing
  - Stripping during raising
  - Draining during slewing
  - Washing during descent
  - Lost loads from debris

• **Operator controls**
  - Cycle time
  - Depth of cut
  - Debris removal

---

clamshel.avi
Example of Hayes Approach

- **Empty Bucket Descent**
  - \( r_1' = f_{aa} f_{dv} f_{dd} f_{sed} r_1 \)

- **Bucket Impact and Closure**
  - \( r_2' = f_{bv} f_{ec} f_{sed} r_2 \)

- **Full Bucket Ascent**
  - \( f_{ta} \leq 1 \quad r_3' = [(f_{la} w_{la} + f_{bw} w_{bw} + f_{ea} w_{eb}) f_{ta} + f_{sw} w_{sw}] f_{sed} r_3 \)
  - For \( f_{ta} > 1 \quad r_3' = [(f_{la} w_{la} + f_{ea} w_{eb}) f_{ta} + f_{bw} w_{bw} + f_{sw} w_{sw}] f_{sed} r_3 \)

- **Full Bucket Slewing**
  - \( r_4' = f_{so} f_{sed} r_4 \)

- **Where:** \( r_1 = 0.01 \quad r_2 = 0.09 \quad r_3 = 0.15 \quad r_4 = 0.25 \)

- **Sediment characteristics affect each process**

Other Contributors

• **Barge Overflow**

  For $V_{ds} \leq V_{hb}$

  $$R_{OF} = 0$$

  For $V_{ds} > V_{hb}$

  $$R_{OF} = 100 \left( \frac{\gamma_{OF}}{\gamma_{sed}} \right) \left[ \frac{(bV_{ds} - V_{hb})}{V_{ds}} \right]$$

• **Debris**

  $$R_{debris} = \frac{5 f_{sed} N_{debris}}{100}$$

• No predictive measures proposed for bottom sweeping, movement, anchoring, etc.
• **Factors affecting release rate:**
  - Pump rate
  - Cutterhead speed
  - Swing speed
  - Depth of cut
  - Direction of cut
  - Debris
  - Banks / slopes
Empirical Solids Releases

• Equipment
  ➢ Mechanical dredges
    ➢ Open or watertight ➤ 0.2 to 9%, typically 0.5 to 2%
    ➢ Environmental ➤ 0.1 to 5%, typically 0.3 to 1%
  ➢ Hydraulic dredges ➤ 0.01 to 4%, typically 0.2 to 0.8%

• Production versus turbidity control
  ➢ Operator feedback

• Erosion
  ➢ Weakening of sediment structure
  ➢ Entrainment of water in residuals
Residuals Source Predictions

- **Empirical**
  - Mass Available: 2 to 9% of sediment mass in last cut

- **Sediment Properties**
  - Erosion characteristics
  - Settling rates

- **Site Properties – bottom shear stress**

- **Dredging Work Plan**
  - Equipment
  - Operations
  - Sequence

- **Control Measures**
Near-Field Models

• Two primary purposes
  ➢ Evaluate source strength
  ➢ Evaluate acute impacts in vicinity of dredge-head during operations

• Spatial scale is restricted to ~10 m from dredge-head

• Examples of available models
  ➢ DREDGE (USACE)
  ➢ TASS (Wallingford)
Far-Field Models

• Primary purpose
  - Evaluate impacts during operational and post-dredge periods

• Spatial scale ranges from ~10 m to > 1,000 m from dredge-head

• Examples of available models
  - Plume models (screening)
    - DREDGE (USACE)
  - Particle tracking models
    - PTM (USACE)
  - Comprehensive models
    - Coupled hydrodynamic-sediment transport models
Dissolved Contaminant Releases

• Entrainment of porewater
  - 0.5 to 10% of porewater in dredged sediment lost to water column

• Dispersion of particulate and dissolution/partitioning of particulate-associated contaminants
  - Function of variable contaminant properties, availability and kinetics

• Advection and diffusion from residuals and face of dredge cut
ADDAMS Screening Models

• Mixing Models for Short-term, Near-/Mid-Field Water Quality and Toxicity Evaluations
  ➢ DREDGE - continuous resuspension
  ➢ CDFATE / CORMIX - continuous discharge/overflow
  ➢ STFATE - discrete discharges

• 1-D Models for Releases from Residuals and Sediment
  ➢ RECOVERY
  ➢ CAP
Prediction of Sediment Resuspension and Contaminant Release by Dredging
DREDGE INPUTS

[Image of software interface with options for selecting dredge type, estimating source strength, site characteristics, and far field model selection.]
CDFATE

Computation of Mixing Zone Size or Dilution for Continuous Discharges or Overflows
## CDFATE INPUTS

### Discharge Description
- Example - Hopper Dredge: Weir Overflow

### Discharge Case
- Hopper Dredge: Single Port Discharge
- Hopper Dredge: Weir Overflow
- Pipeline Slurry Discharge
- CDF Discharge From Side Stream Channel
- CDF Discharge From Partially Full Pipe
- CDF Dike Leakage

### Receiving Water Data
- Receiving Water Depth: 10.0 m
- Is the Receiving Stream Narrow? [No]
- Receiving Water Width: N/A
- Channel Type: Unbounded
- Bottom Roughness: 0.015
- Receiving Water Velocity: 0.50 m/s
- Wind Speed Conditions: Medium
- Receiving Water Density: 999.00 kg/m³

### Effluent Density and Modeling Parameters
- Effluent Density: 1100.00 kg/m³
- Plume Modeling Distance: 5000.0 m
- Number of Reporting Periods: 50

### Mixing Zone Data
- Pollutant: Lead
- Simulated Pollutant Concentration: 25.00
- Criterion Maximum Concentration: 5.00
- Criterion Continuous Concentration: 2.00
**MOTIVATION:**

- Dredged material mgmt and optimization requires long-term, far-field fate predictions for
  - Beneficial Use
  - Resource Management
  - Regulatory Compliance
- Field data collection not possible for these low concentration conditions
- Need to extrapolate sources to areas where no data exist
Estimating Exposure Using PTM

SOLUTION

- Lagrangian Particle Tracker for modeling transport only from specified sources
- Numerically efficient method for quantifying time-varying concentration, deposition, dose, and exposure
- Efficient modeling of multiple scenarios to quantify potential exposure pathways
Estimating Exposure Using PTM

- PTM is a Lagrangian model specifically designed to monitor dredge sources.
- Efficient simulation of multiple scenarios, sources and constituents
- User-defined or model generated source strengths for sediments and constituents
- Isolate and monitor fate of designated sources for exposure estimates
- Physical/chemical properties and processes incorporated into PTM
- Multiple classes of particles to represent different constituents
PTM Source Description

• User defines sources generated from:
  - Dredge source models
  - FATE models
  - Known release rates

• Sources from:
  - Dredging operations
  - Placement operations
  - ODMDS erosion
  - Overflow

• Source strengths vary temporally and spatially (incl. vertically)

• Each particle represents a defined mass of constituent and includes constituent behavior
PTM Hydro/Waves

- PTM hydro input directly from large-domain model
- Wave input (optional) from wave transformation model
- Hydro and wave forcings drive particles
- Hydro and wave models are mature, demonstrated
- Generally, field data insufficient to define hydro for complex domain
- Exposure is dependent on accurate predictions of wave and hydrodynamics
PTM Sediment Processes

- Particles include complex, physics-based description for first order processes influencing transport of the sediments they represent
  - Settling
  - Aggregation/flocculation
  - Resuspension
  - BBL Dynamics
- Processes are time-varying
- Accounts for particle interactions with native bed (mixing and burial)
- Native bed properties are spatially variable

McAnally (1999)
PTM Constituent Processes

- Particles can simulate ammonia, DO, contaminant, or other non-conservative substance
- Process descriptions include
  - Non-equilibrium partitioning
  - Volatilization
  - Chemical Reactions
  - Settling/Buoyancy
- Address contaminant, WQ, and species issues associated with dredging
- Modular code permits modification for inclusion of additional processes
PTM Concentration Predictions

- Time Series at point
- Average over user-specified domain (point or area)
- Snapshot over entire domain
- Analysis for user-specified combination of constituents
- Vertically varying concentration analysis
- Extract data for further analysis
- Generally used in exposure analysis and resource protection
PTM Concentration Predictions
PTM Deposition/Sedimentation

- Temporally varying fate (deposition) of dredged material is critical to many exposure estimates.
- Deposition and re-entrainment are highly dependent on native bed dynamics.
- PTM does not account for transport of native sediments.
- PTM deposits particles and includes interactions with native bed active layer:
  - Probability of Deposition
  - Mixing
  - Burial
  - Re-entrainment
Estimating Exposure

- Effects of sediment or constituent on organisms is both concentration and time dependent.
- Exposure estimates, coupled with effects are used directly in Risk Characterization.

\[ D = \int_{t}^{t+\Delta t} C \, dt \]
Estimating Exposure in PTM

• **Virtual Gages**
  - point
  - volume

• **Present (fixed space)**
  - drifting with flow
    - passive larvae
  - moving with behaviors
    - fish
    - motile larvae

• **Future (moving)**
Hypothetical Example: Exposure

- Ebb Shoal Environment
- Three resources of concern for exposure
  - Coral Reef
  - Fish
  - SAV
- 3-Day Hopper Dredging (overflow and no-overflow)
- 6-Day PTM Simulation to allow for post-dredging transport and deposition
- Assess exposure due to deposition, suspended solids
- Compare various scenarios (dredging rate, method, etc)
Hypothetical Example: Exposure

Understanding time-varying concentration and wave conditions over complex regions requires validated wave and hydrodynamic models.
Hypothetical Example: Exposure

PTM 6-day simulation with overflow indicates most sediment remains in channel with some north of channel. Very little near coral reef.
Hypothetical Example: TSS Exposure

- Concentration is highly variable both spatially and temporally
- Significant TSS difference between overflow and no overflow cases
- PTM maintains all data for each particle: mass, location, properties
- These are translated to concentration of each sediment type and each constituent
- Assess exposure due to suspended solids
- Convert TSS to NTU to assess light attenuation
Time Series of Concentration → Dose

\[ D = \int C \, dt \]

2.2 kg*hr/m³
Cross-Section of Inlet TSS

Depth (m)

Cross-section Distance (m)

Concentration

0.00315
0.0028
0.00245
0.0021
0.00175
0.0014
0.00105
0.0007
0.00035
0.0
Case Study: Bed Exposure

- Most deposition in channel or in harbor
- In-Harbor deposition will not impact juvenile Salmonid, where exposure pathway is the water column
- Some deposition occurs in SAV habitat
- Combine deposition data with effects data to determine risk
- No pathway to coral reef
- SAV exposure may be season-dependent
Time Series of Deposition

Deposition (mm)

Time (days)

31-May 2-Jun 4-Jun 6-Jun 8-Jun 10-Jun 12-Jun 14-Jun 16-Jun
Time Series of Light Attenuation

% Reduction in Surface Irradiance

2-Jun 4-Jun 6-Jun 8-Jun 10-Jun 12-Jun 14-Jun 16-Jun
Summary

• No Pathway for exposure to coral reef
• Suspended Solids move into the Juvenile Salmon migration pathway but covers only a portion of the channel cross-section
• Deposition and light attenuation occur over southern half of the SAV
• Dredge-induced turbidity moves out of the region after approximately two weeks
• Concentration and deposition patterns are dynamic