Exposure Processes and Assessment

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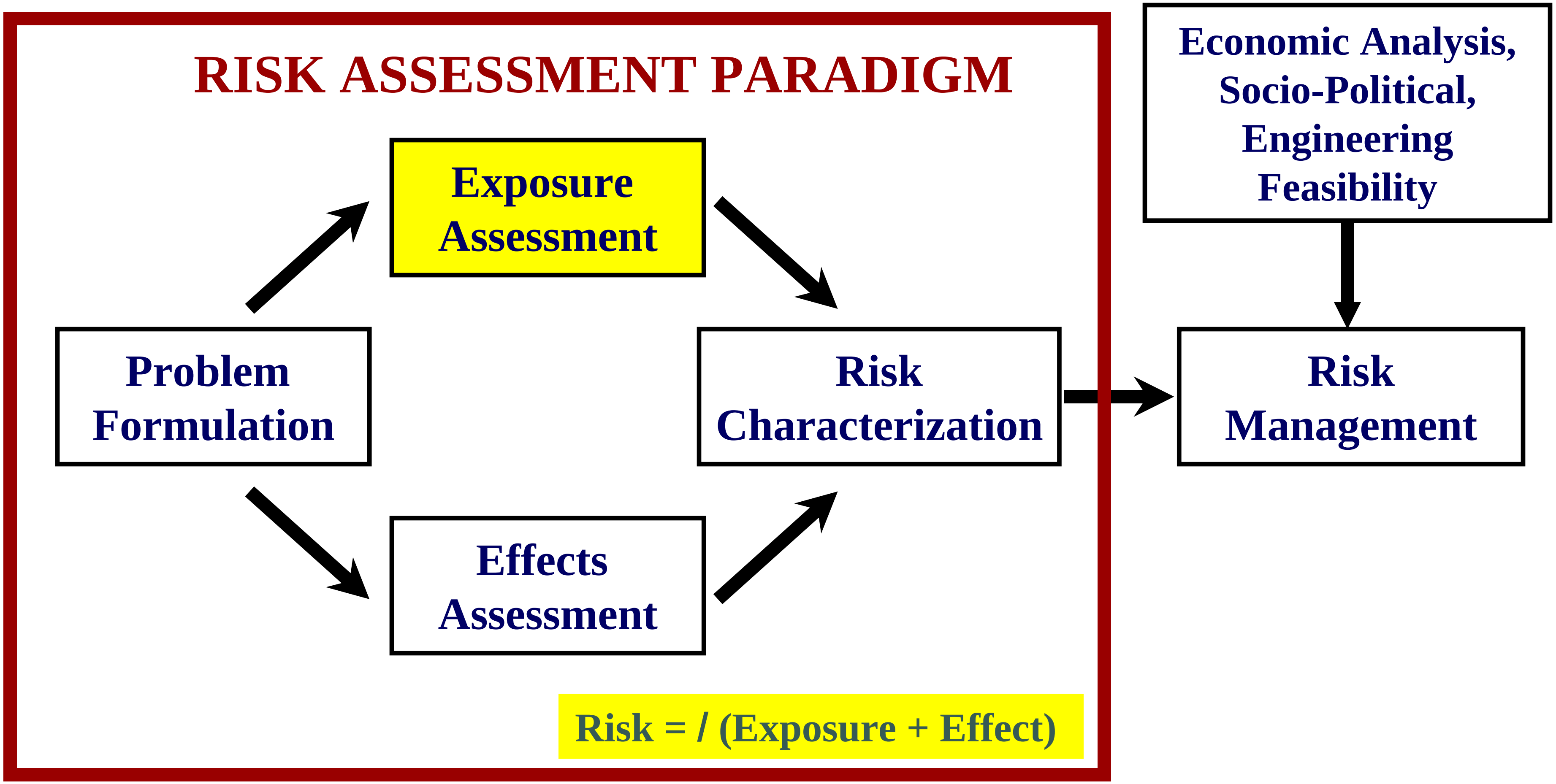
Engineer Research and Development Center

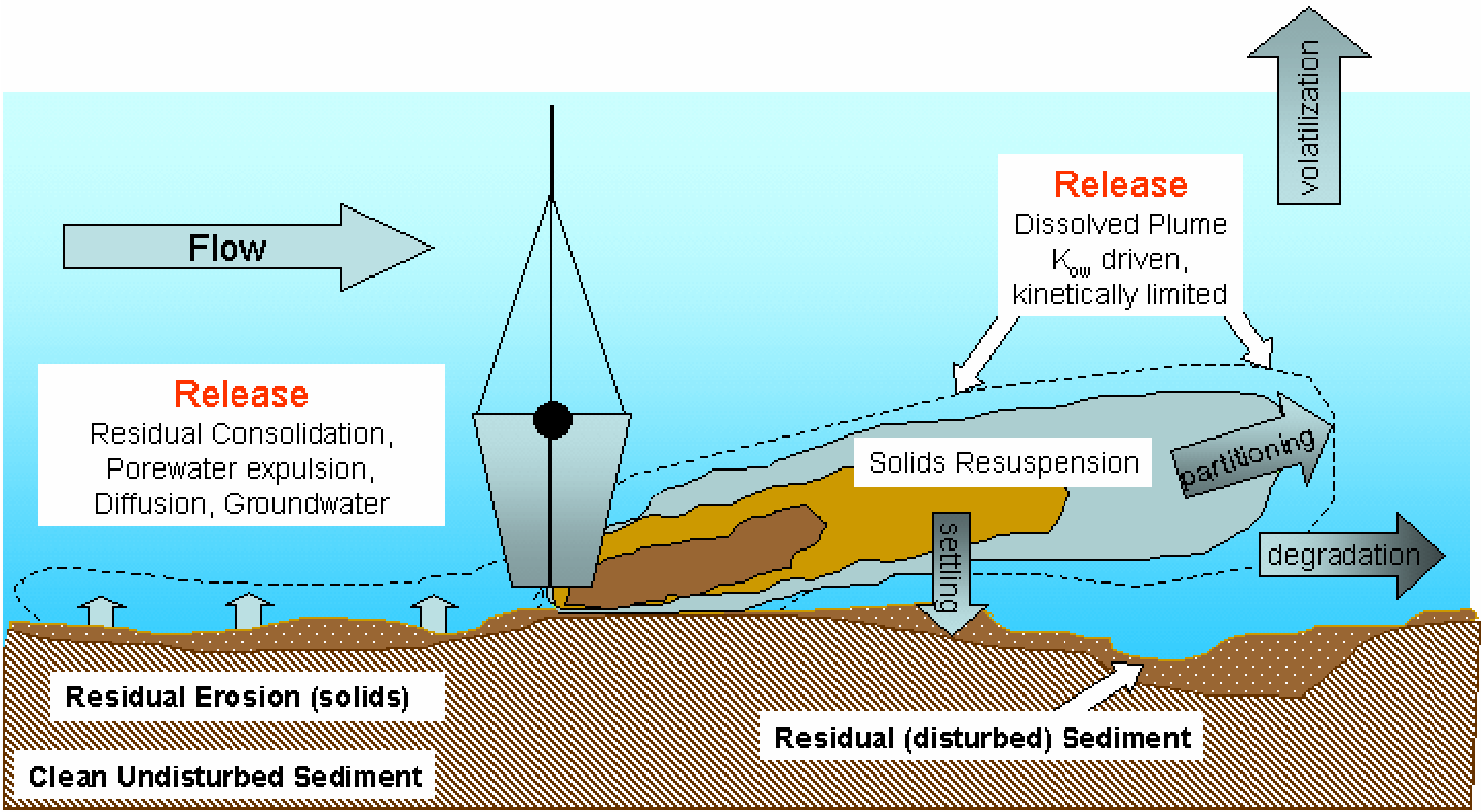
RISK FRAMEWORK



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



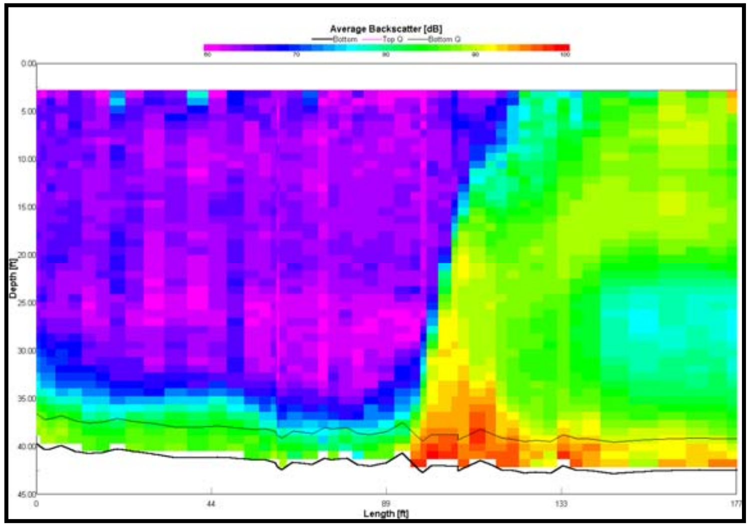
Other Sources

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 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 = Liquid Limit

PL = Plastic Limit

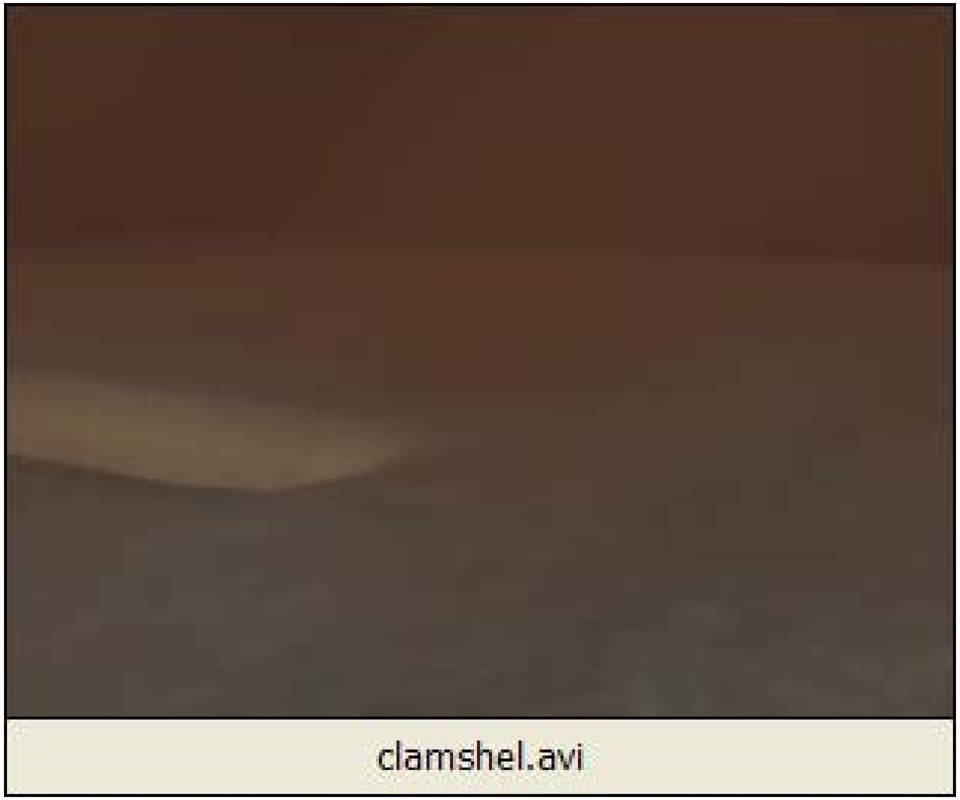
PI = Plasticity Index

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



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**
  - $f_{ta} \leq 1$ $r_3' = [(f_{la} w_{la} + f_{bw} w_{bw} + f_{ea} w_{eb}) f_{ta} + f_{sw} w_{sw}] f_{sed} r_3$
  - for $f_{ta} > 1$ $r_3' = [(f_{la} w_{la} + f_{ea} w_{eb}) f_{ta} + f_{bw} w_{bw} + f_{sw} w_{sw}] f_{sed} r_3$
- **Full Bucket Slewing**
  - $r_4' = f_{so} f_{sed} r_4$
- **Where: $r_1 = 0.01$ $r_2 = 0.09$ $r_3 = 0.15$ $r_4 = 0.25$**
- **Sediment characteristics affect each process**

D. F. Hayes, T. D. Borrowman , and P. R. Schroeder (2007). Process-Based Estimation of Sediment Resuspension Losses During Bucket Dredging. WODCON XVIII, Orlando, FL

Other Contributors

- **Barge Overflow**

For $V_{ds} \leq V_{hb}$ $\qquad R_{OF} = 0$

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

- **Debris** $\qquad R_{debris} = \dfrac{5\ f_{sed}\ N_{debris}}{100}$

- **No predictive measures proposed for bottom sweeping, movement, anchoring, etc.**

Hydraulic Dredge Operation

- **Factors affecting release rate:**
  - Pump rate
  - Cutterhead speed
  - Swing speed
  - Depth of cut
  - Direction of cut
  - Debris
  - Banks / slopes

Empirical Solids Releases

- **Equipment**

  Losses of fine-grained mass of dredged sediment to water column

  - 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

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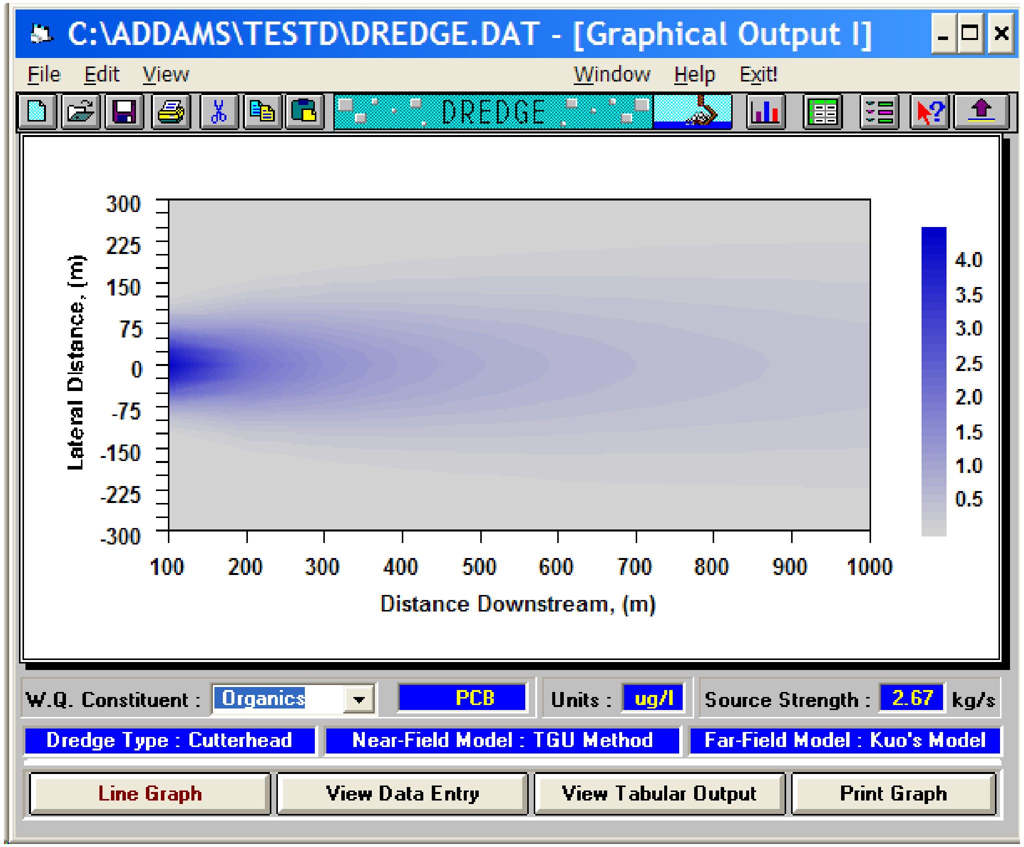
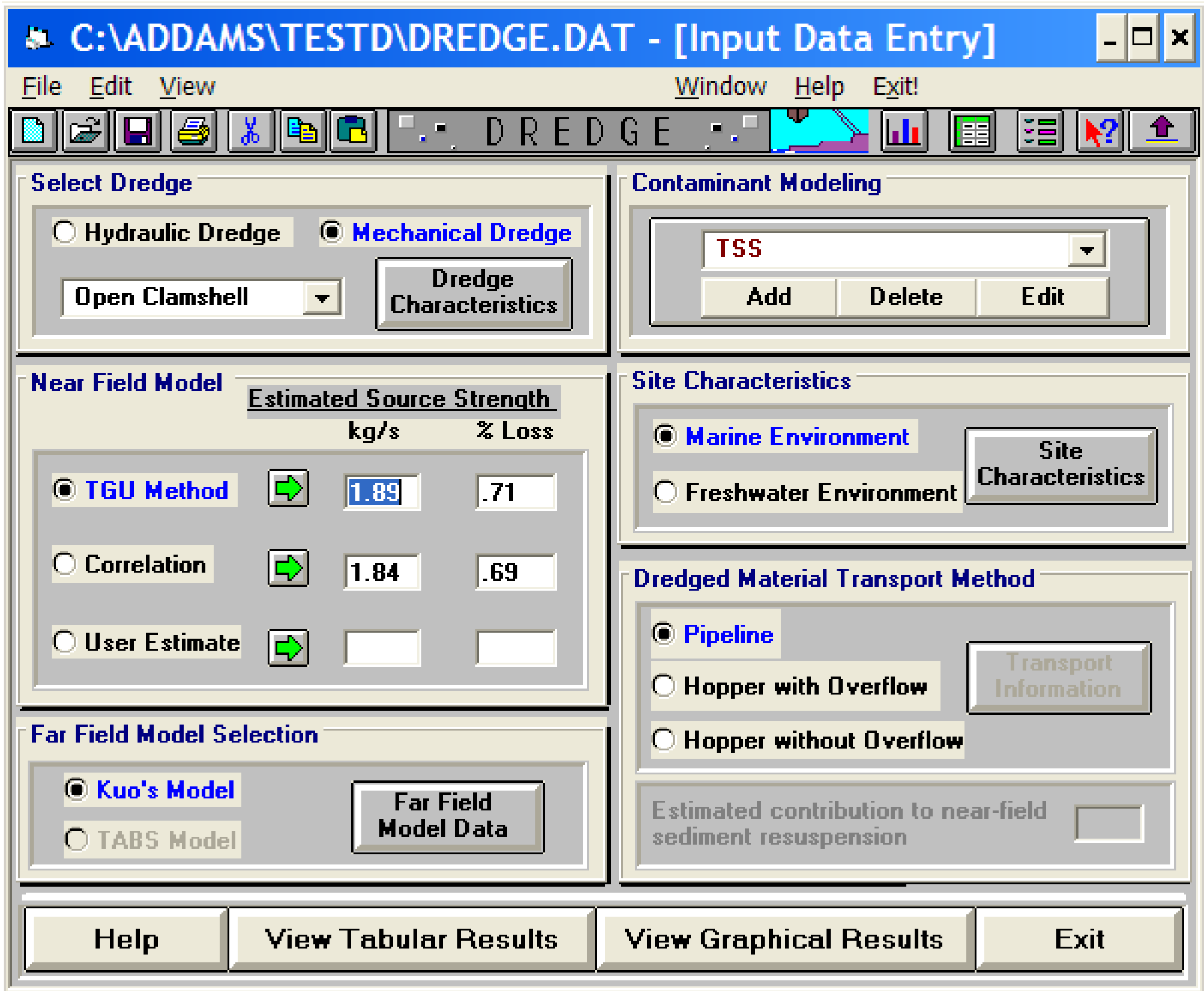
DREDGE



Prediction of Sediment Resuspension and Contaminant Release by Dredging

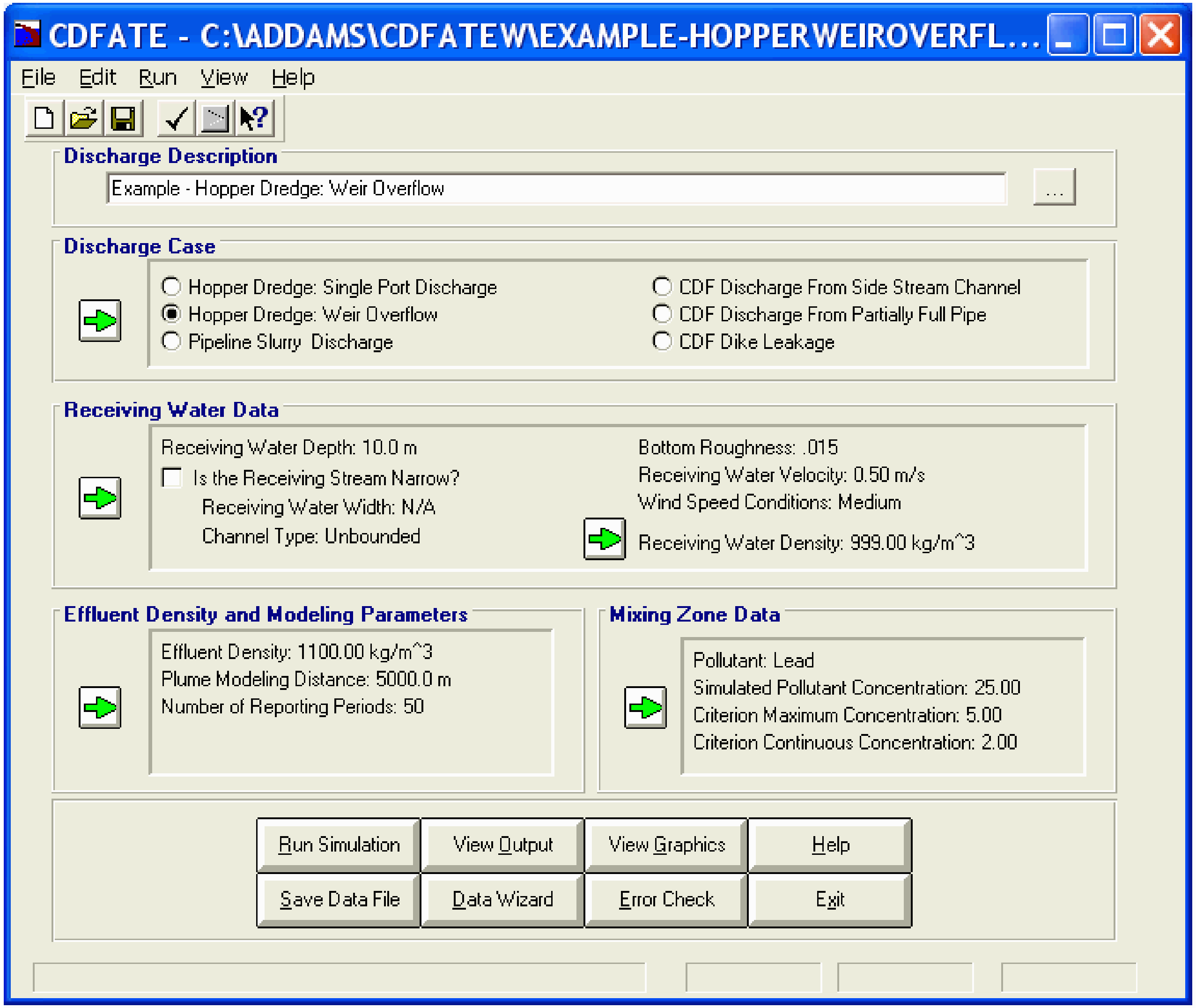
DREDGE Inputs



CDFATE

Computation of Mixing Zone Size or Dilution for Continuous Discharges or Overflows

CDFATE Inputs



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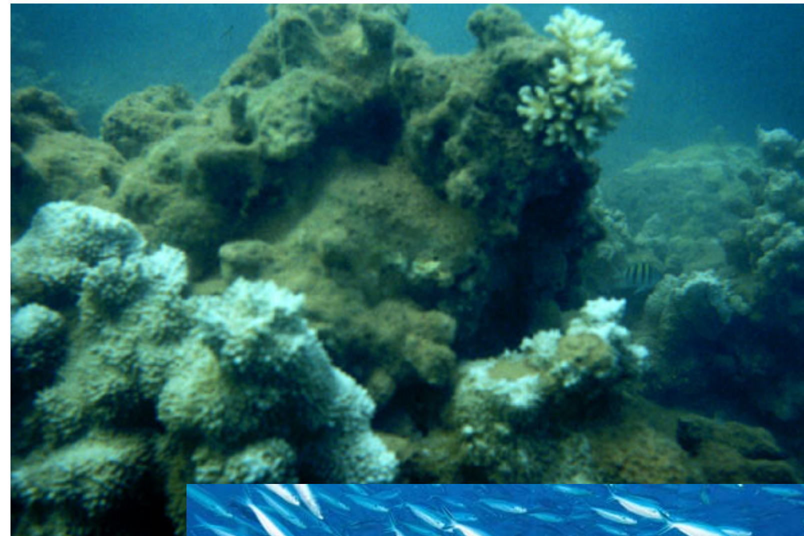
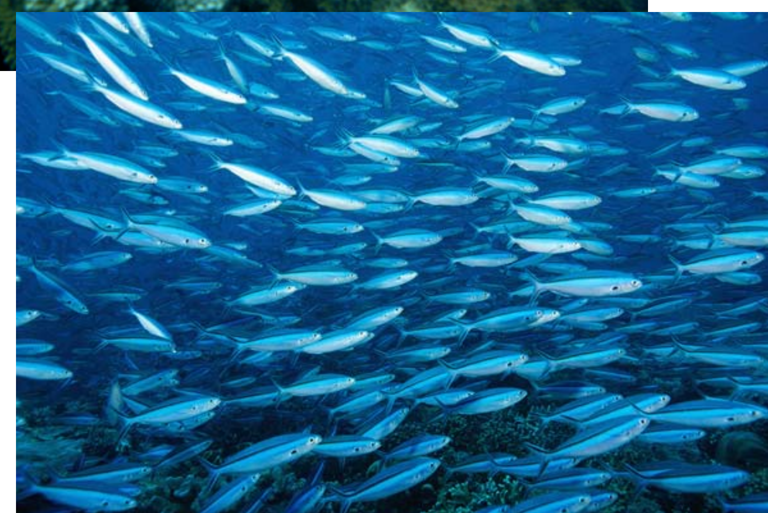
Estimating Exposure Using PTM

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**





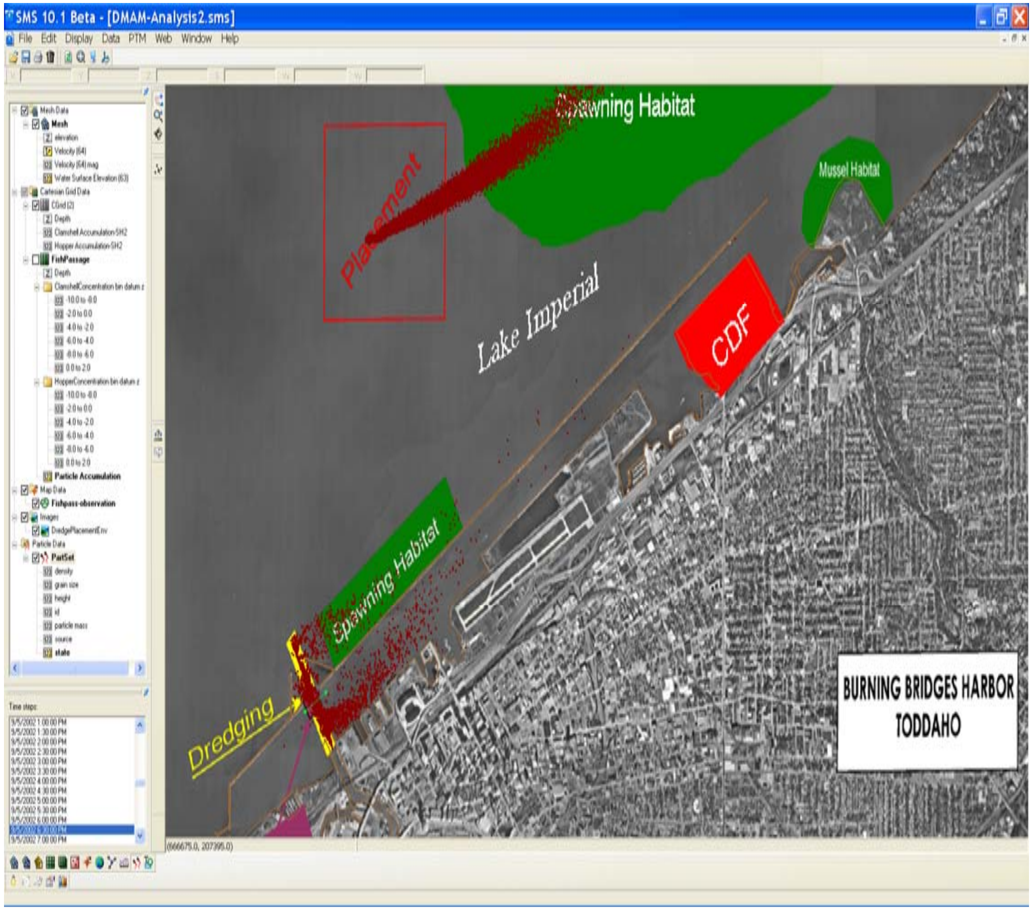
Estimating Exposure Using PTM

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**

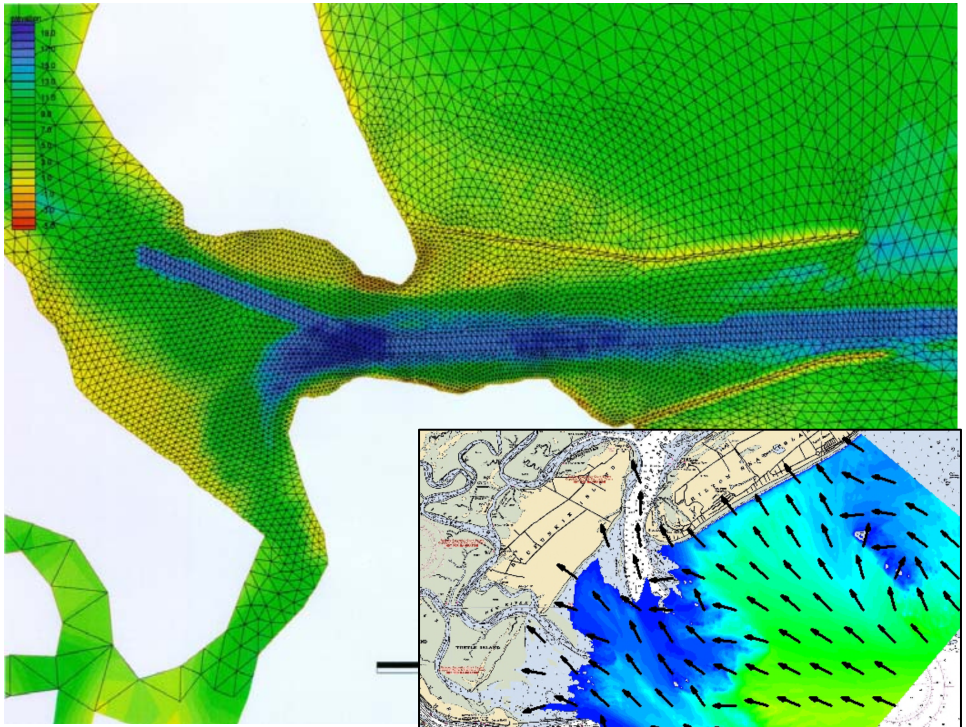
Estimating Exposure Using PTM

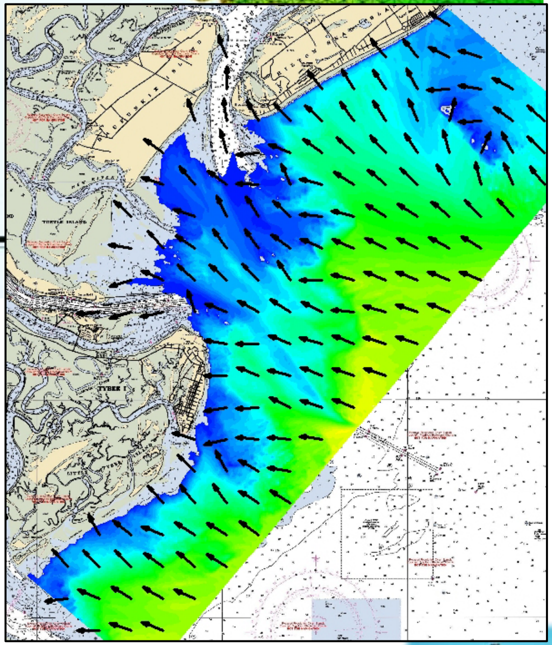
- PTM is a Lagrangian model specifically designed to monitor dredge sources.
- Efficient simulation of multiple scenarios, sources and constituents
- User-defined or model generated source strengths for sediments and constituents
- Isolate and monitor fate of designated sources for exposure estimates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



PTM Hydro/Waves

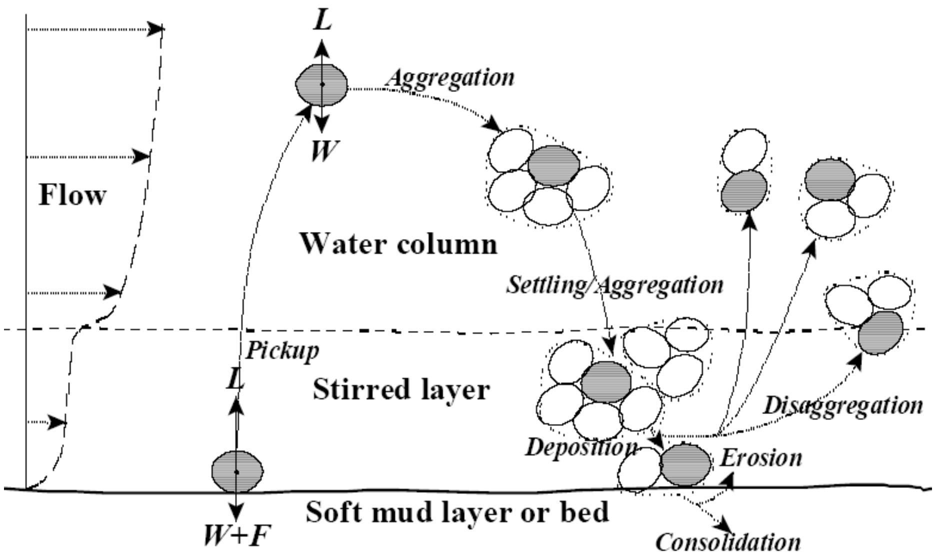
- **PTM hydro input directly from large-domain model:**
  - ADCIRC
  - EFDC
  - ECOM/POM
- **Wave input (optional) from wave transformation model:**
  - STWAVE
  - SWAN
- **Hydro and wave forcings drive particles**
- **Hydro and wave models are mature, demonstrated**
- **Generally, field data insufficient to define hydro for complex domain**
- **Exposure is dependent on accurate predictions of wave and hydrodynamics**



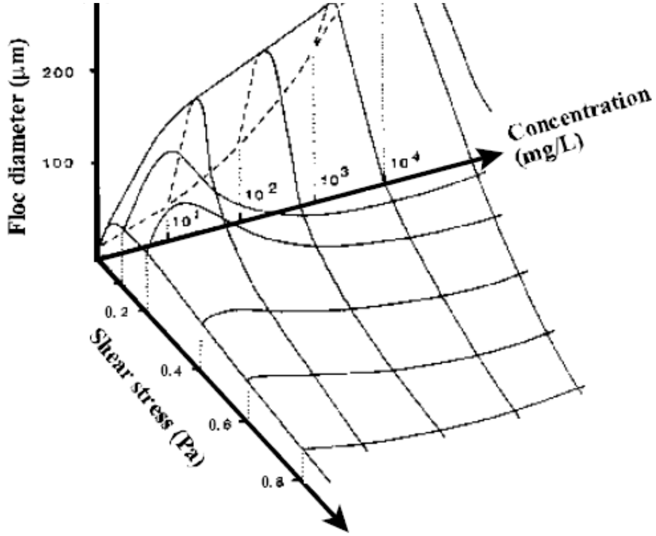


PTM Sediment Processes

- **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**

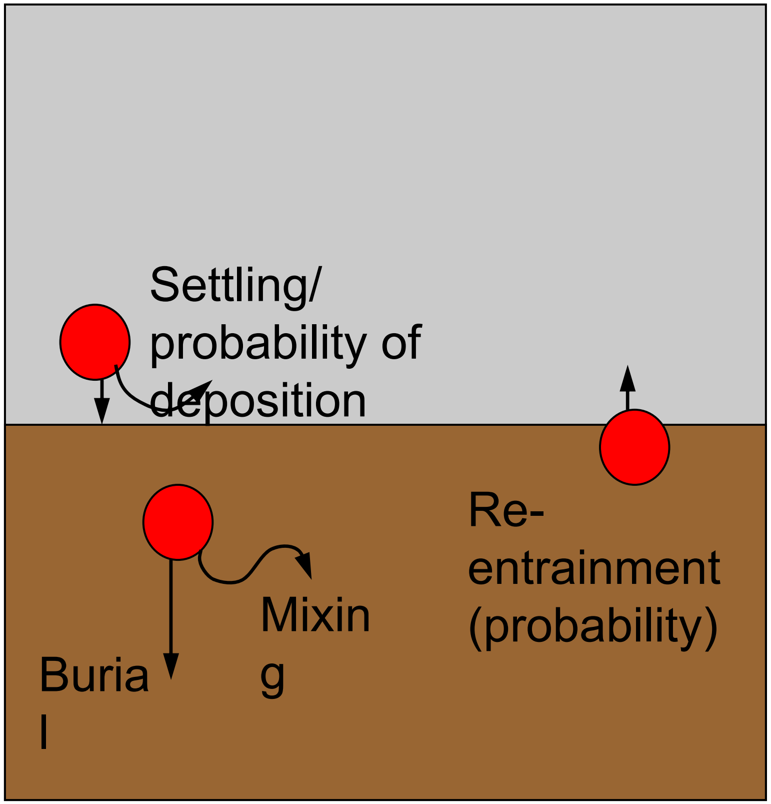


McAnally (1999)



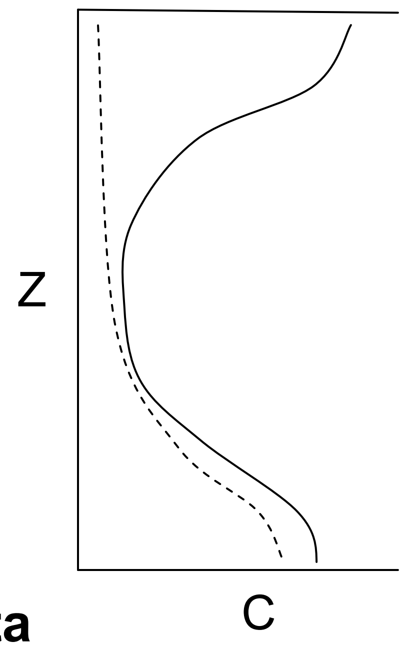
PTM Deposition/Sedimentation

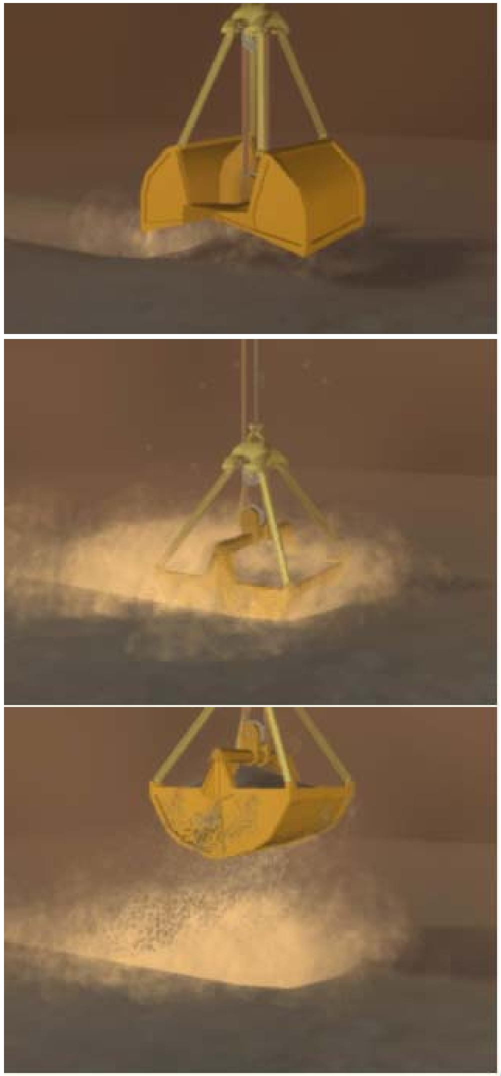
- **Temporally varying fate (deposition) of dredged material is critical to many exposure estimates**
- **Deposition and re-entrainment are highly dependent on native bed dynamics**
- **PTM does not account for transport of native sediments**
- **PTM deposits particles and includes interactions with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



PTM Dredging Processes

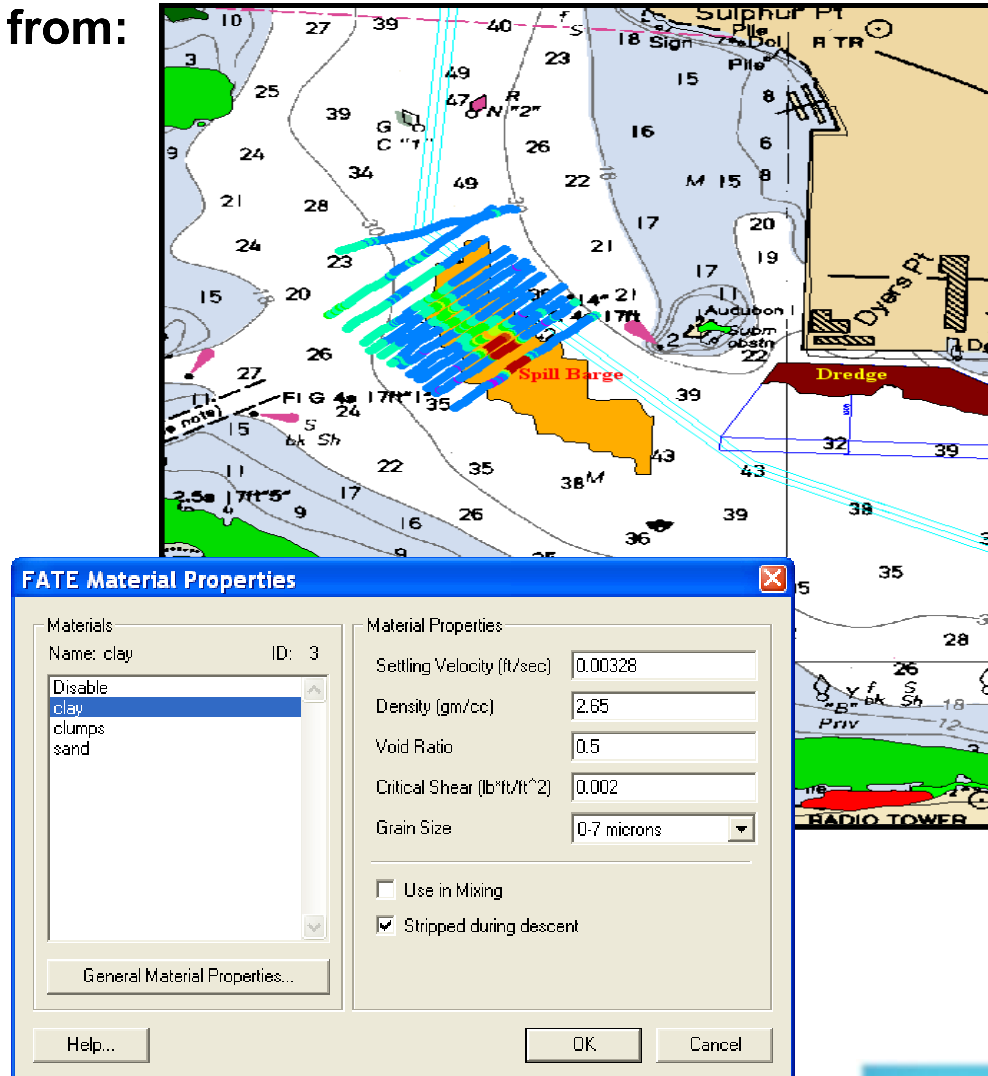
- **Release (source term) from dredging operation dependent on:**
  - Dredge plant
  - Sediment bed
  - Hydrodynamic/waves
  - Operating practices (rates)
  - Debris, etc
- **Source term models developed for various dredging conditions**
- **Highly empirical – additional data are being incorporated**
- **Dredge and placement source terms**





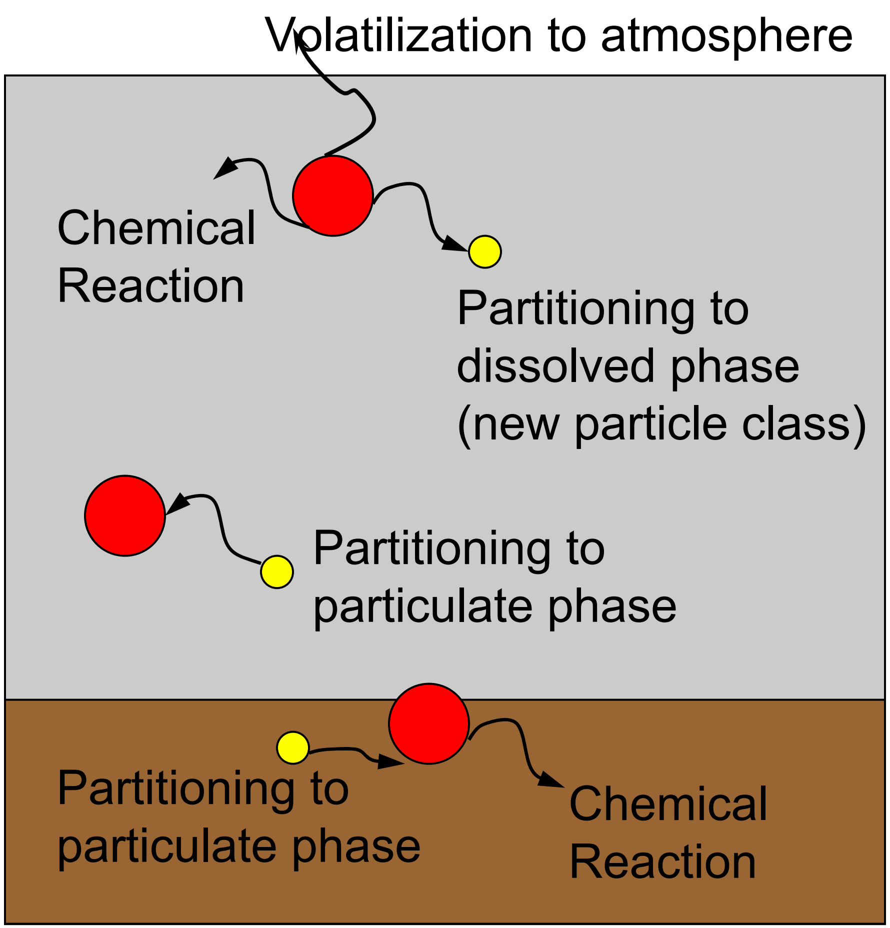
PTM Source Description

- **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**



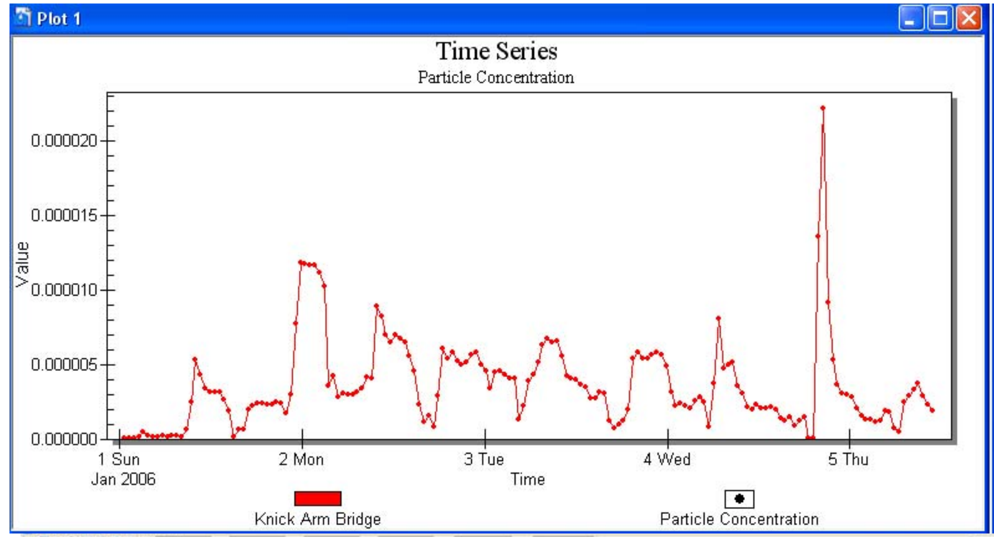
PTM Constituent Processes

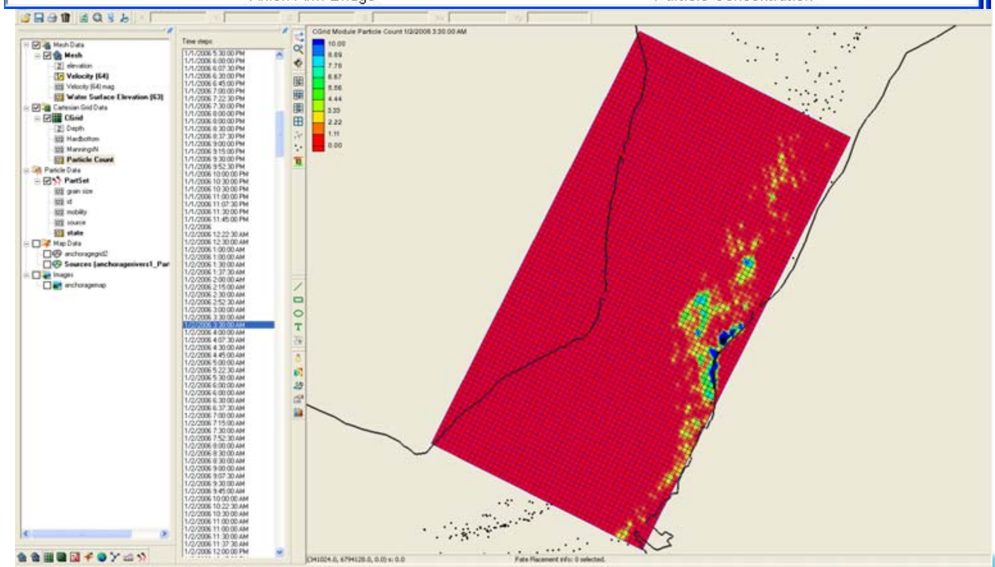
- **Particles can simulate ammonia, DO, contaminant, or other non-conservative substance**
- **Process descriptions include**
  - Non-equilibrium partitioning
  - Volatilization
  - Chemical Reactions
  - Settling/Buoyancy
- **Address contaminant, WQ, and species issues associated with dredging**
- **Modular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



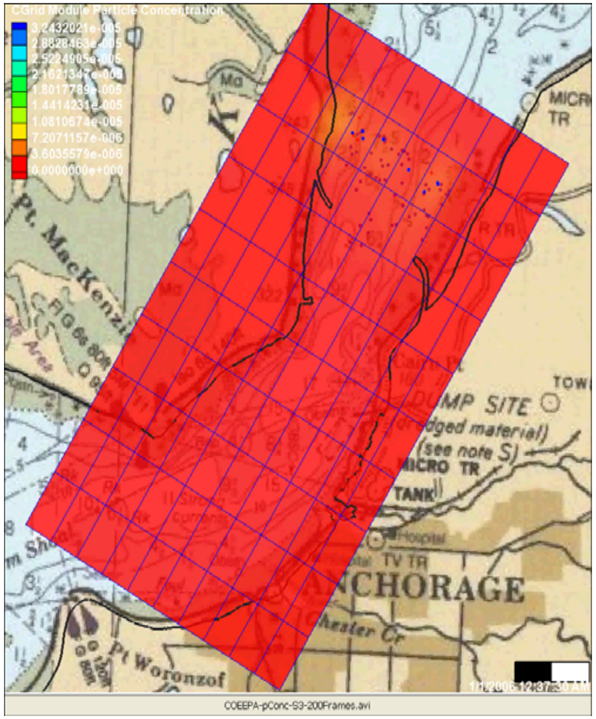
PTM Concentration Predictions

- 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



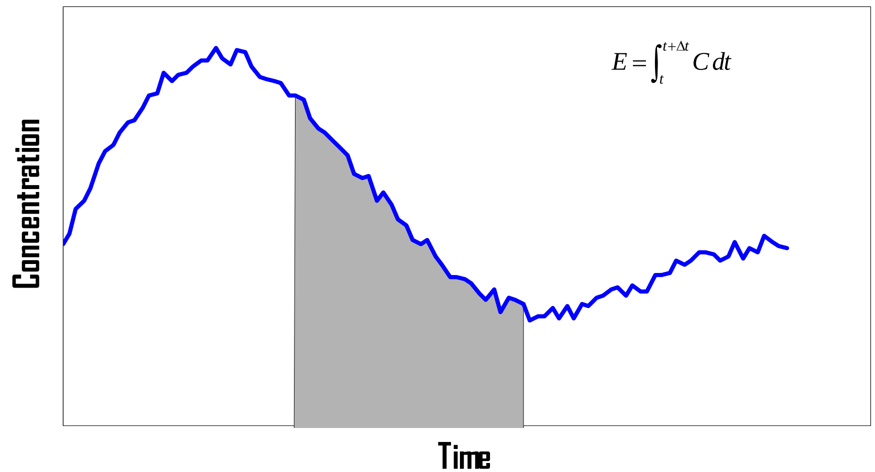


PTM Concentration Predictions



Estimating Exposure

- Effects of sediment or constituent on organisms is both concentration and time dependent.
- Quantifying total exposure is first step towards determining dose or effects.
- Exposure estimates used directly in Risk Assessment

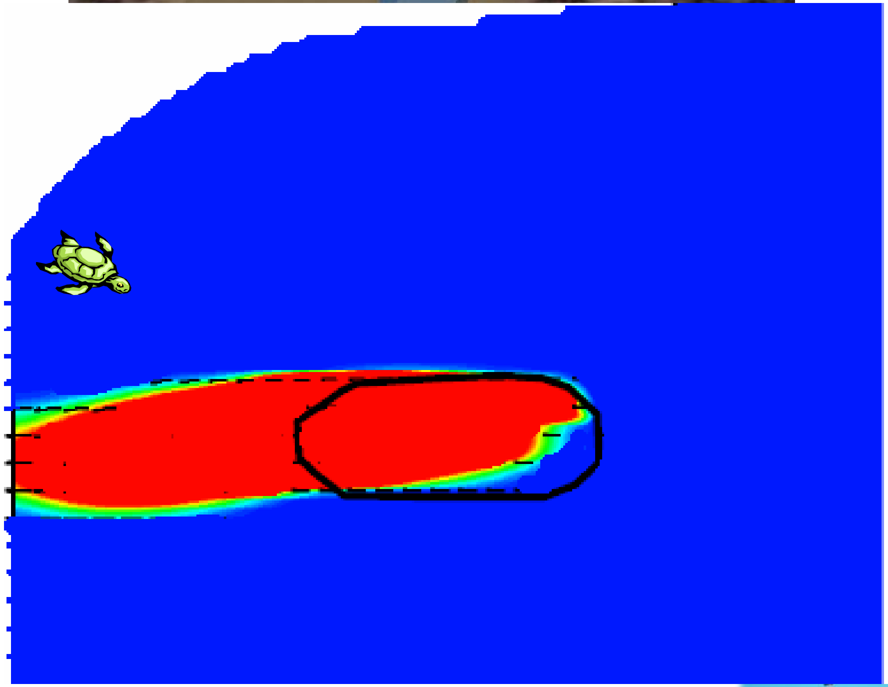


Species[a]	Exposure C	Exposure D	Stress index ($\log_e$ [C × D])
Arctic grayling	25	24	6.397
	23	48	7.007
	65	24	7.352
	22	72	7.368
	20	96	7.560
	143	48	8.834
	185	72	9.497
	230	96	10.002
	20,000	96	14.468

Newcombe and MacDonald (1991)

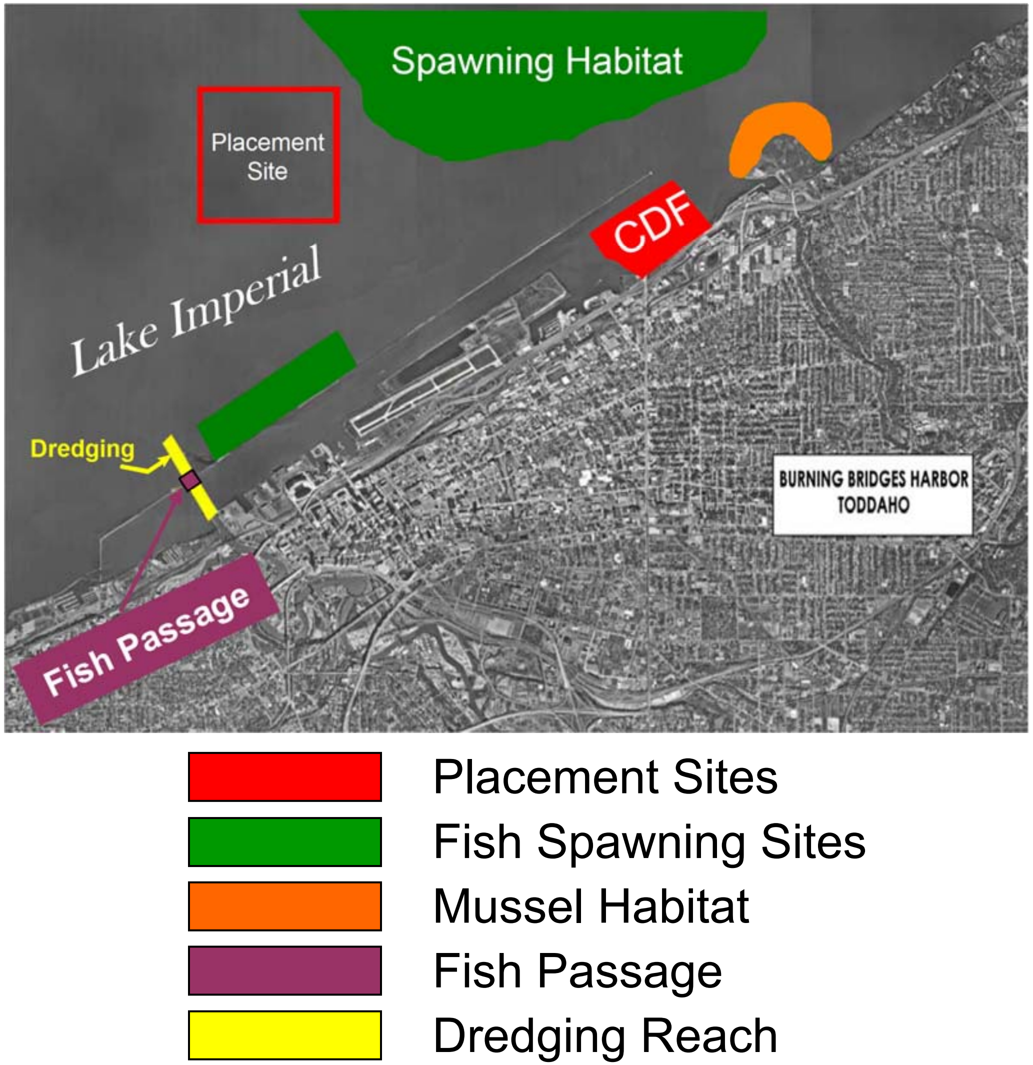
Estimating Exposure in PTM

- **Virtual Gages**
- **Present (fixed space)**
  - point
  - volume
- **Present (moving)**
  - passive larvae
  - characteristic larvae behavior
- **Future**
  - behaviors
  - advanced chemical processes



Hypothetical Example: Exposure

- **Ebb Shoal Environment**
- **Three resources of concern for exposure**
  - Mussel Habitat
  - Fish Passage
  - Spawning Habitat
- **Dredging Operations**
  - Hopper Dredge – OWP
  - Clamshell Dredge – OWP
  - Clamshell Dredge – CDF
- **13-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)**



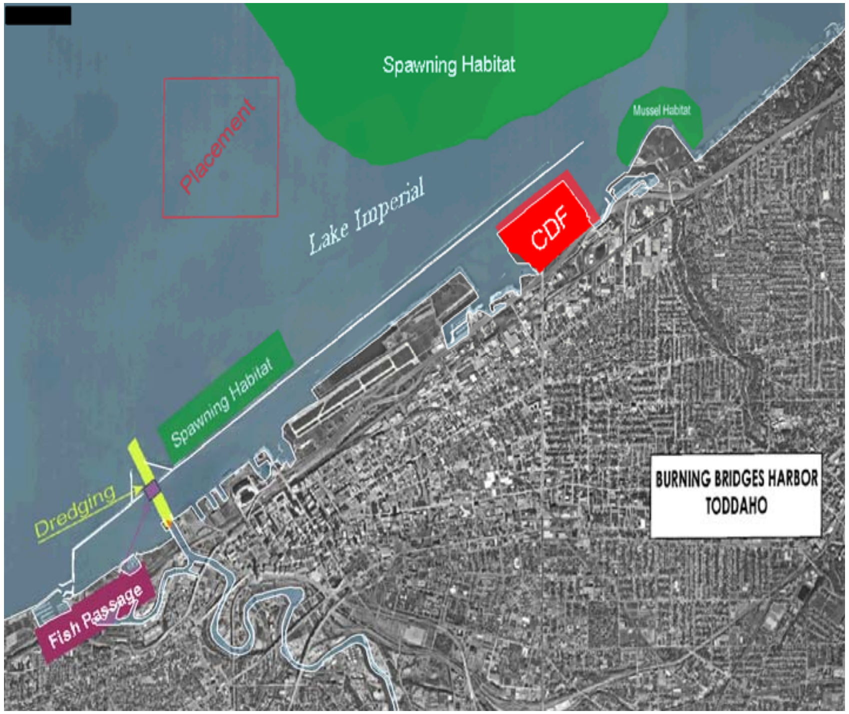
Hypothetical Example: Exposure

Understanding time-varying concentration and wave conditions over complex regions requires validated wave and hydrodynamic models

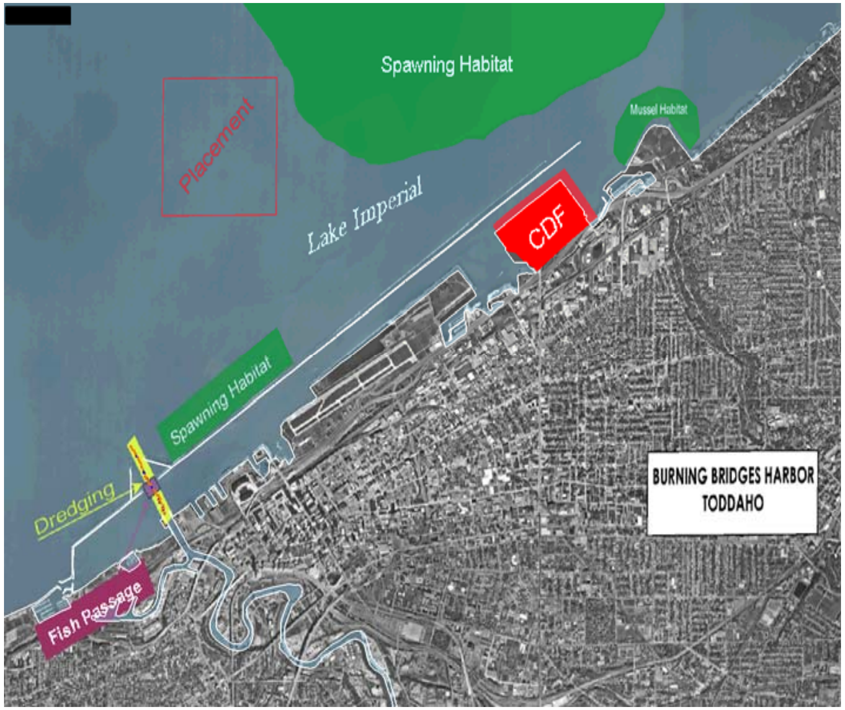
6 day simulation – Maximum Velocity ≈0.25m/s

Hypothetical Example: Exposure

PTM 6-day hopper simulation with no overflow indicates most sediment remains in channel with some north and east of channel. Very little near mussel bed.

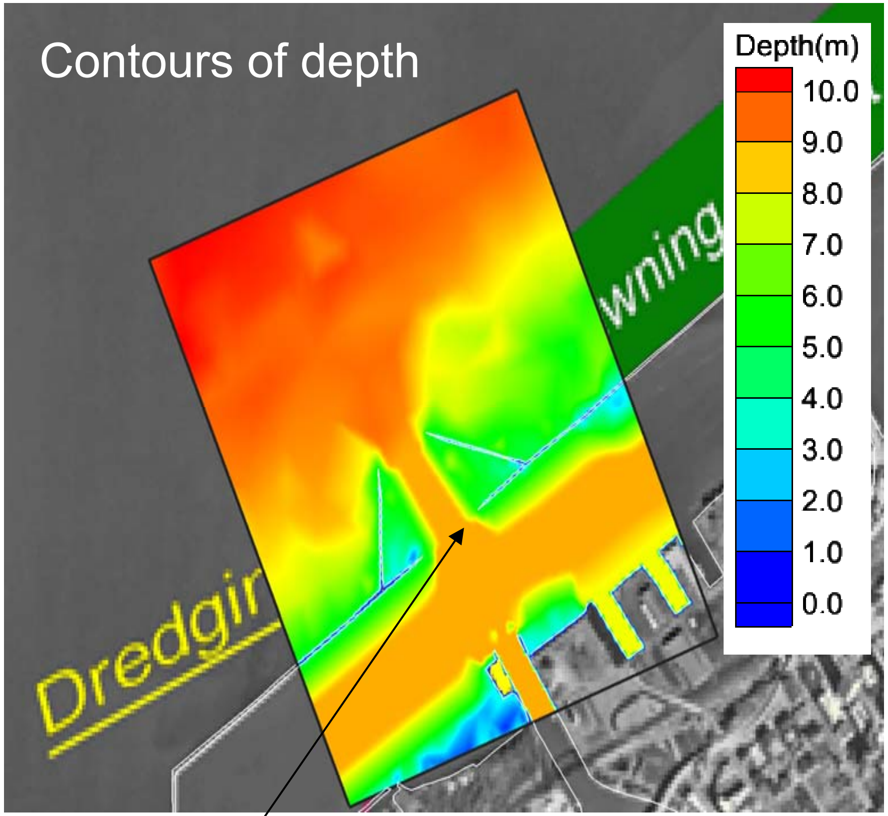


Clamshell Dredge

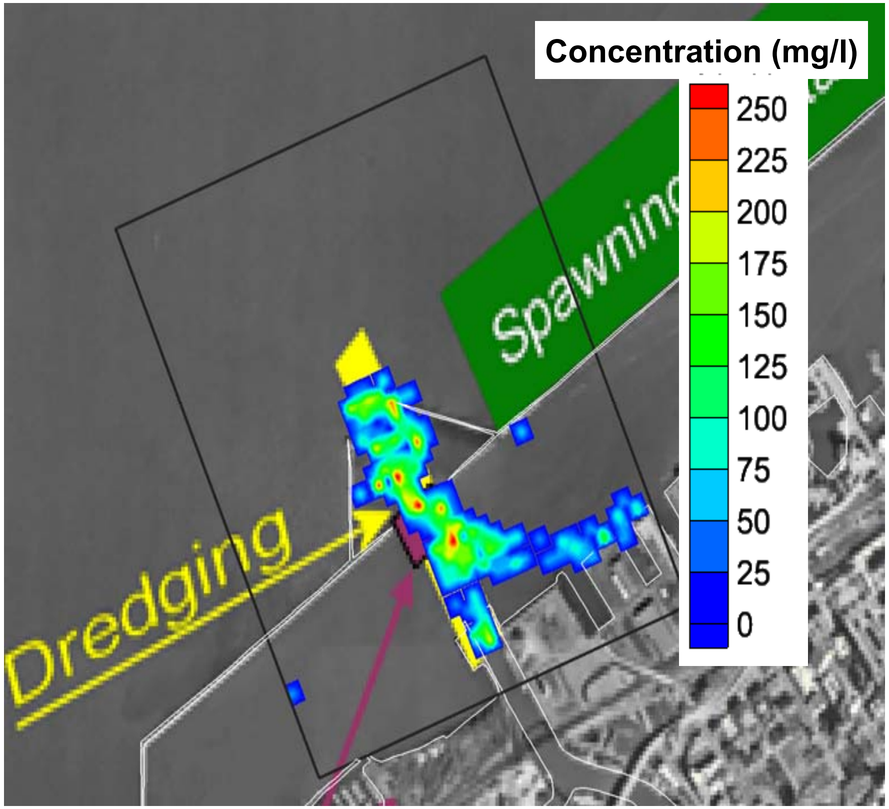


Hopper Dredge

Exposure: TSS in Fish Passage

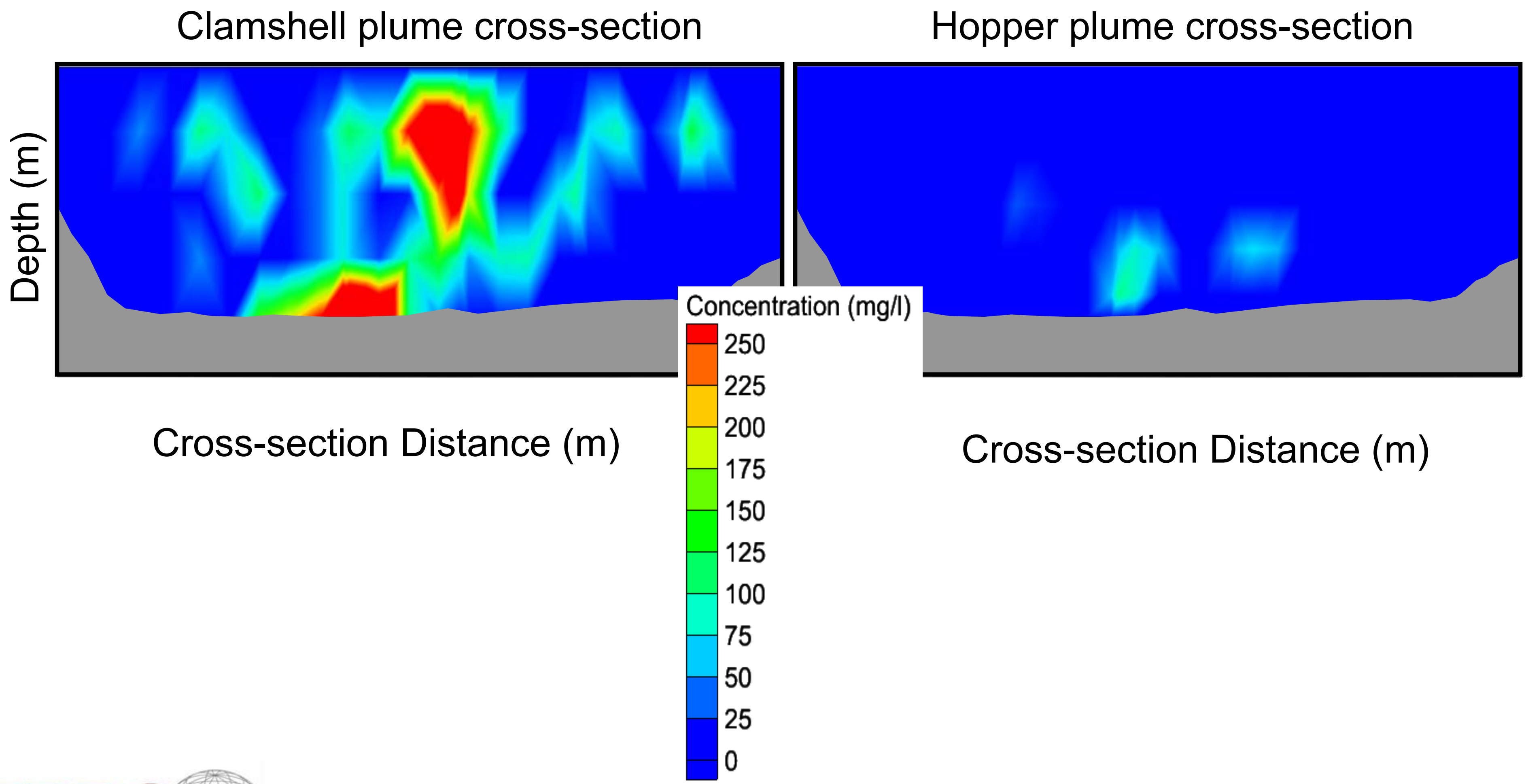


Fish passage

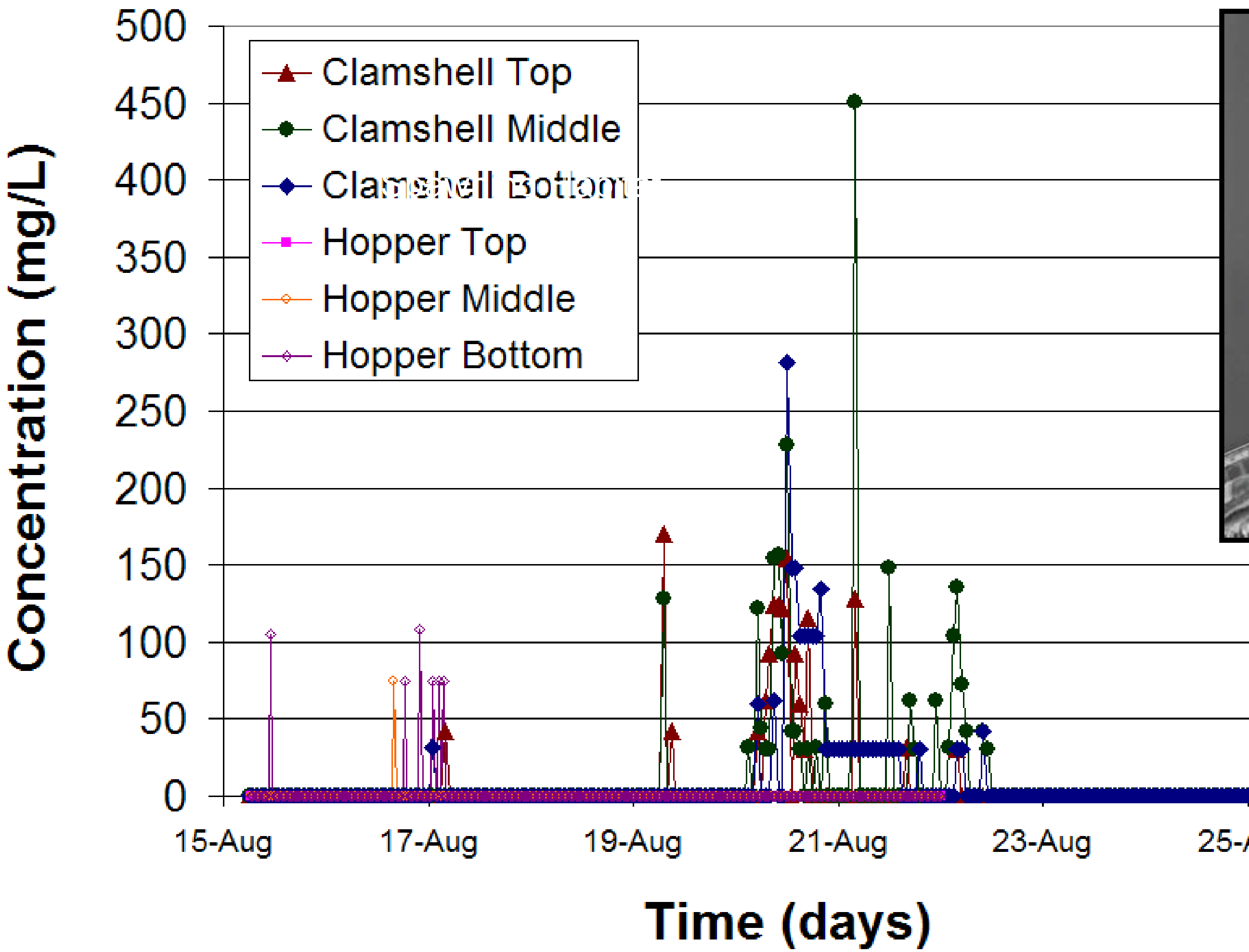


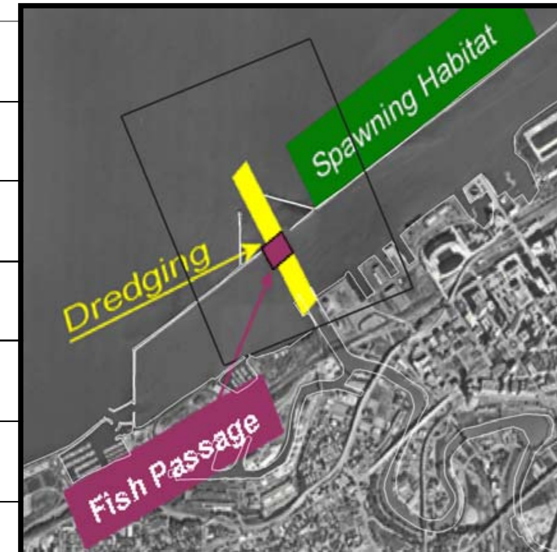
Clamshell Dredge

TSS Distribution at Fish Passage



Time Series of Concentration → Dose





$$D = \int C dt$$

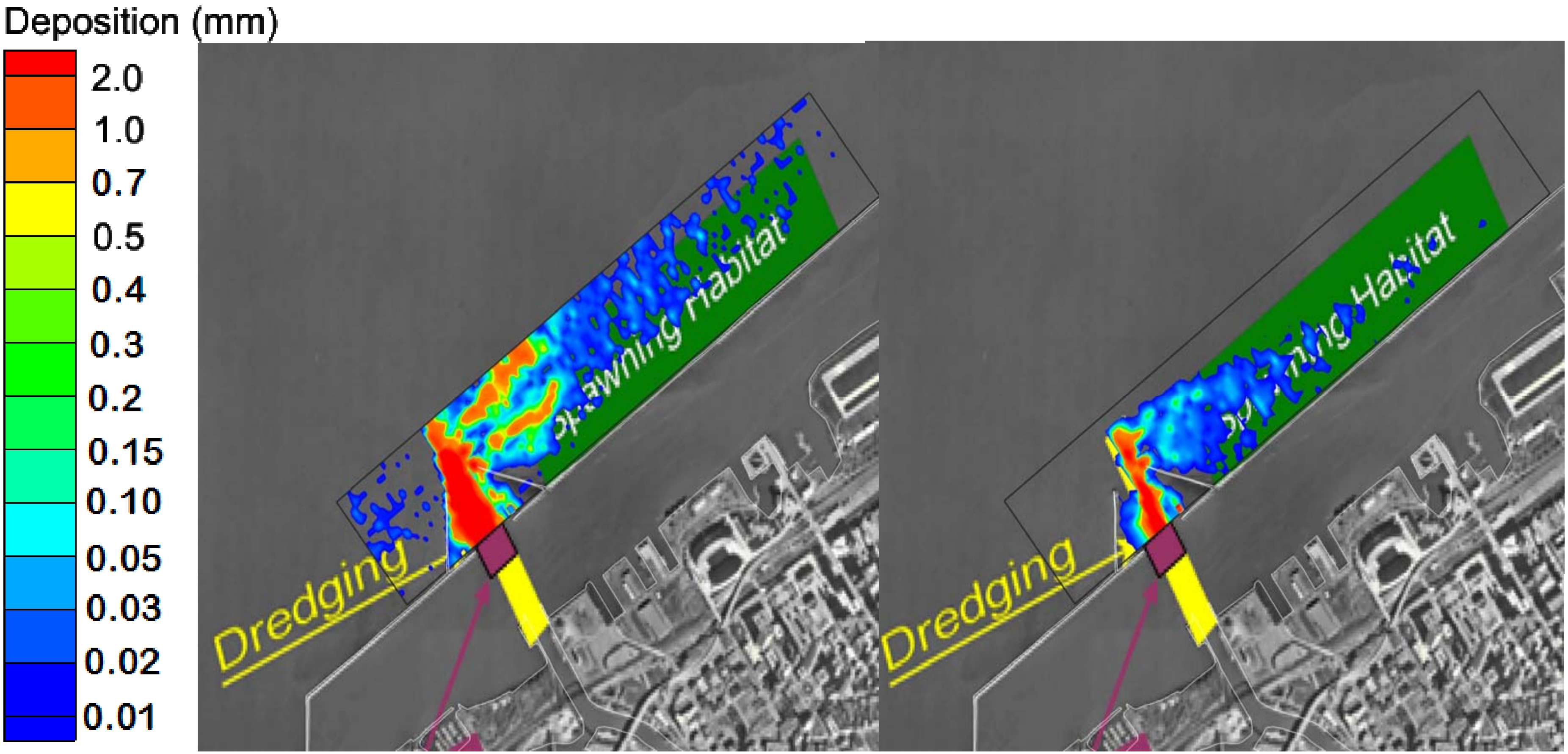
Clamshell -
2.2 kg*hr/m^3

Hopper -
0.3 kg*hr/m^3

Hypothetical Example: TSS Exposure

- **Concentration is highly variable both spatially and temporally**
- **Significant TSS difference between clamshell and hopper**
- **Hopper dredging**
  - Less TSS near fish passage
  - Higher TSS at spawning habitat near open water placement site
- **PTM maintains all data for each particle: mass, location, properties**
- **Translate particles to TSS – quantify exposure**

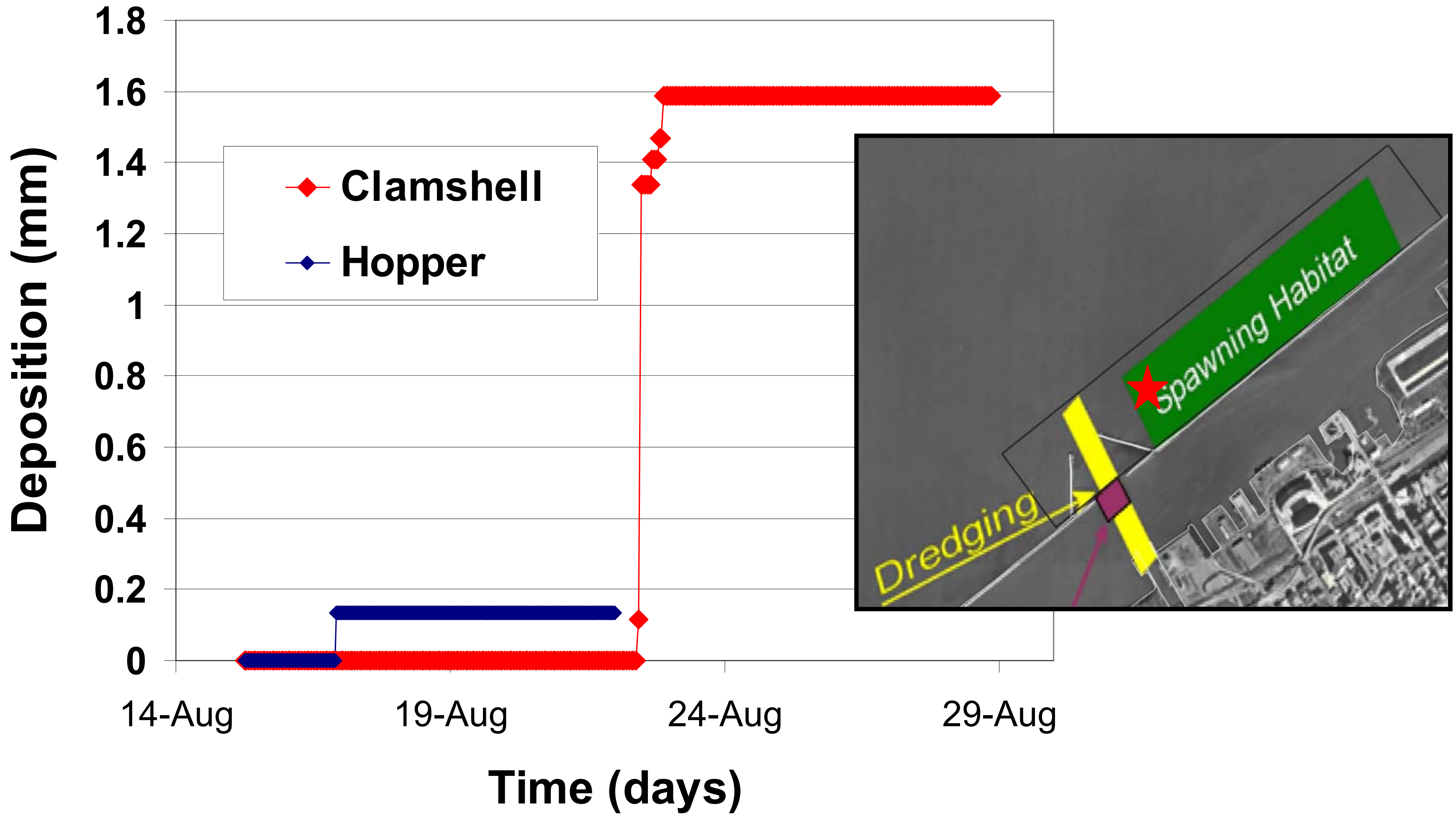
Deposition Near Dredging Site



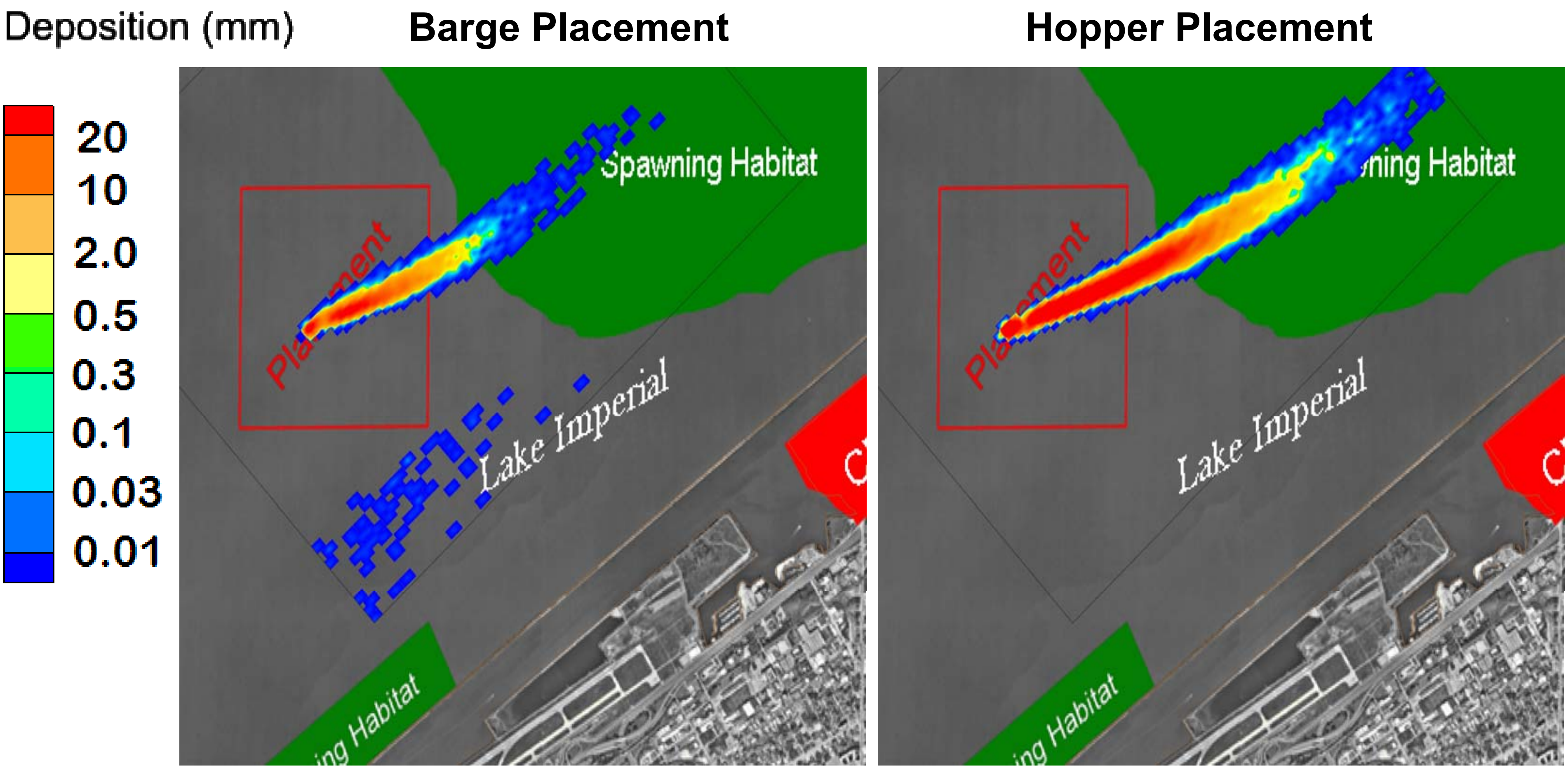
Clamshell Dredge

Hopper Dredge

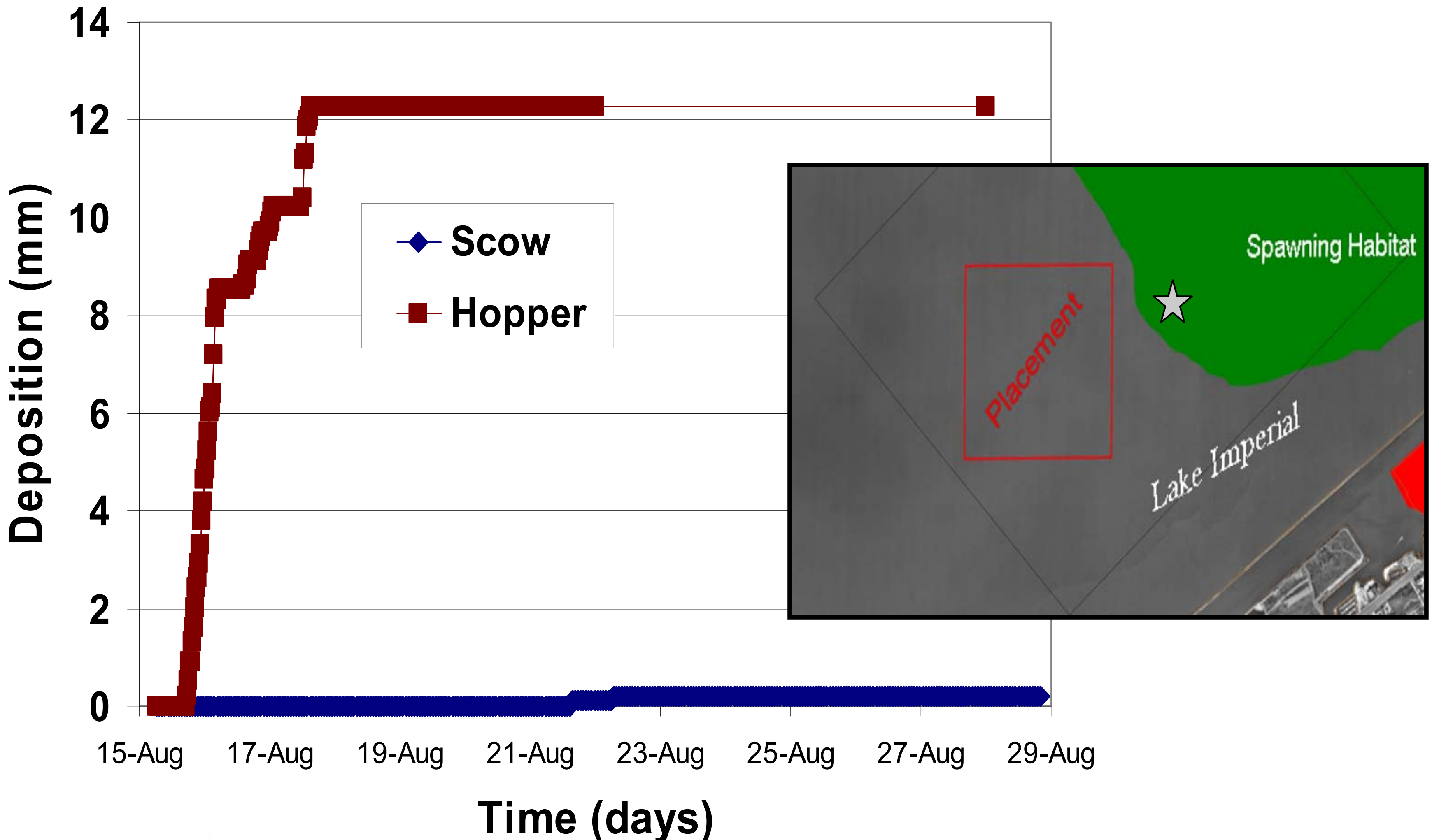
Time Series of Deposition



Deposition at Open Water Placement Site

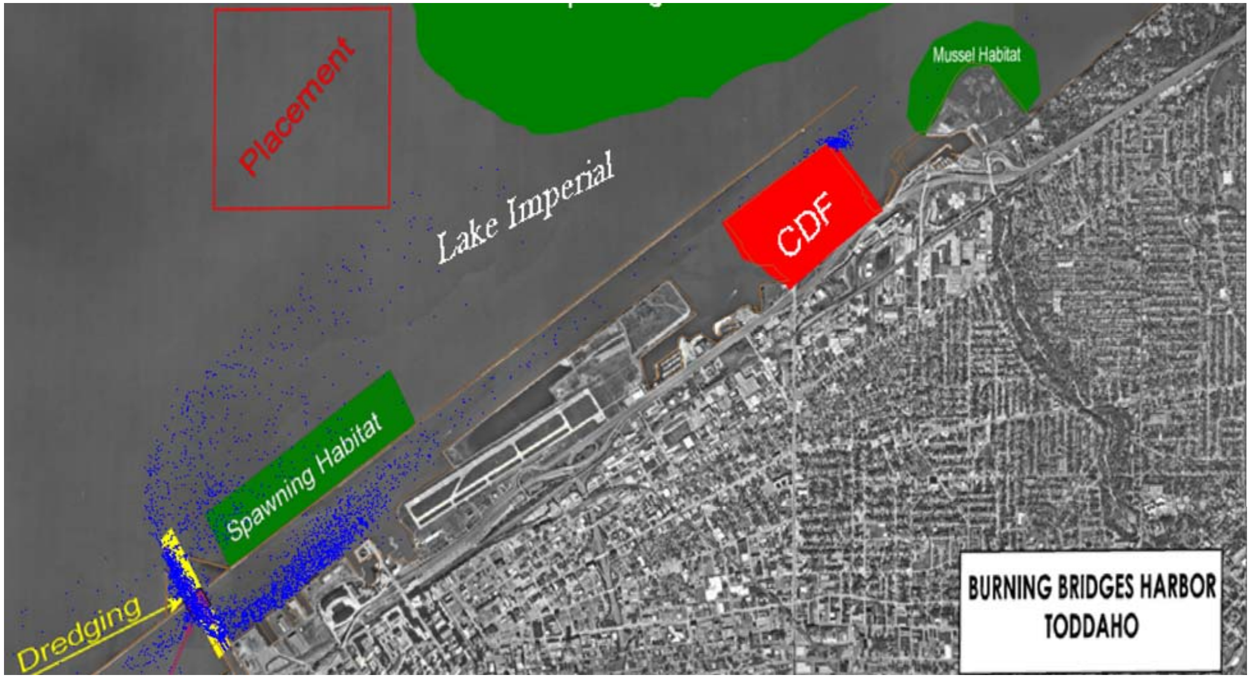


Time Series of Deposition



Case Study: Bed Exposure

- Significantly more deposition from hopper dredging at offshore spawning ground
- Near-Harbor spawning ground deposition is greater from clamshell
- No exposure at Mussel Habitat from either hopper or clamshell operation



Summary

- PTM is used to simulate multiple scenarios of dredging and placement operations
- PTM includes methods to specify dredging operation and sediment types
- Dredging plant is demonstrated to significantly change resulting TSS and deposition time series for this case study
- Exposure, quantified using PTM, is coupled with effects data to quantify and manage risk
- PTM also used for optimizing beneficial use, site capacity studies, infilling, capping, etc
- PTM analysis and post-processing tools expedite exposure/effects assessments.