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Modeling Resuspension of River Sediments using ARC/INFO

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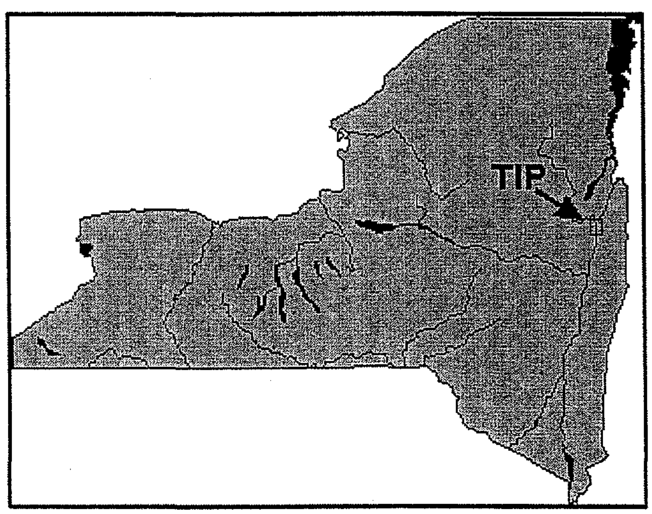
The Upper Hudson River, which is characterized by areas of sediment containing high concentrations of potentially harmful compounds, is currently the subject of an extensive study under the auspices of the Superfund Act. One aspect of this study is the assessment of potential risks to river flora and fauna from the remobilization of contaminated sediments through resuspension. Understanding and quantification of the risks will help involved parties to decide between remediation strategies such as no action, dredging, or in-place containment.

Part of the risk assessment is based on the modeling of bottom sediment scour during different flow conditions. Shear stresses at the sediment-water interface are predicted using a finite-element model and then imported into ARC/INFO as a point coverage. This point coverage is then combined with sediment properties and contamination coverages to predict depth of scour, resuspended sediment mass, and resuspended contaminant mass. Results are visualized with ARCPLOT or summarized as areawide totals.

The approach presented here:

- Provides a scientifically sound method for estimating sediment resuspension due to high-flow events.
- Accounts for spatial variability in model inputs such as sediment type and applied shear stress.
- Highlights resuspension "hot spots" for detailed consideration.
- Allows easy comparison of impacts of different flow scenarios.
- Is extendible to reflect better data and better scientific understanding of processes.

1.0 Introduction



The Thompson Island Pool, or TIP, extends for five miles along the upper reaches of the Hudson River in New York (Figure 1) from the northern tip of Rogers Island to the Thompson Island Dam. Organic compounds and metals entering the river above the TIP travel with the river flow, with portions attaching to solids suspended in the water which in turn may fall out of the water column and add to the sediments on the bottom. The materials attached to the sediments will be then be buried until a high-flow event resuspends the materials (Figure 2).

The remobilized organic compounds and metals in the water may have a significant effect on aquatic life in the Thompson Island Pool and downstream. Buried materials are believed to account for more than 98% of the contaminant mass in the TIP, so resuspension and remobilization during a high-flow event could represent a major source of pollutants to the water column.

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Long-term monitoring data for flow and suspended solids suggest that sediment scour occurs at a flow threshold of about 11,000 cfs. Since this threshold is easily exceeded during moderate- to high-flow events in the TIP (the mean daily flow at Rogers Island is approximately 5000 cfs), a detailed GIS-based study has been undertaken to estimate the risk of sediment scour and associated contaminant remobilization during large flow events.

2.0 Approach

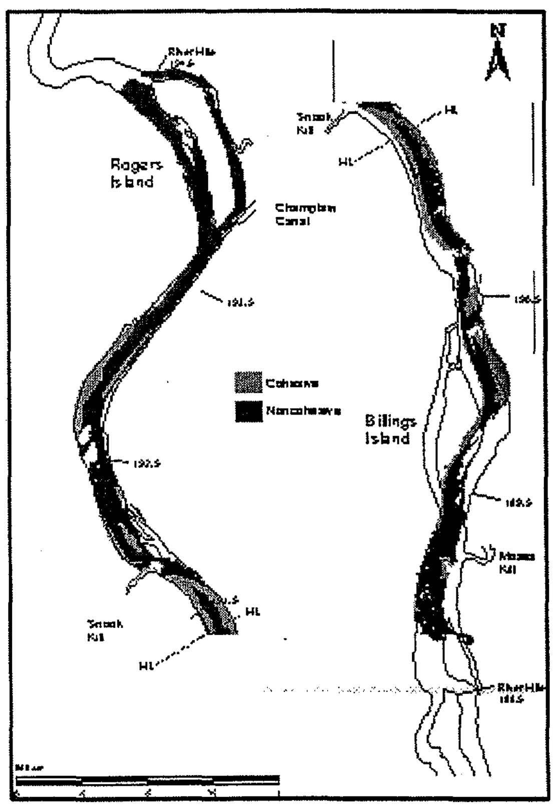
Estimating the total mass of contaminant remobilized during flow events requires three sets of calculations, as briefly described below.

2.1 Hydrodynamics calculations

The RMA-2V finite element model, developed by the U.S. Army Corps of Engineers, was used to model flow fields in the study area under conditions corresponding to low flow, springtime flow, and exceptional flow events such as 5-year and 100-year high flow events. Bathymetry data provided in ARC/INFO coverages were combined with elevation data digitized from USGS quad sheets to provide an accurate depiction of the river channel and flood plain areas for use in the model. A commercial software package, FastTabs by the Boss Corp., was used to help develop and evaluate a 2-D 6,000 node finite element grid (Figure 3) on a Pentium-equipped microcomputer running MS-DOS 6.22 and Windows for Workgroups 3.11. Model-predicted shear velocity at steady-state conditions was predicted throughout the study area.

2.2 Sediment resuspension

The bed sediments in the TIP range from coarse non-cohesive areas to fine-grained sediments in depositional areas along bends and shore lines (Figure 4). The area of non-cohesive sediments is approximately five times larger than the area of cohesive sediments.



In this study, resuspension was calculated differently for cohesive sediments (fine grain, high clay content with extensive interparticle effects) and non-cohesive sediments (no interparticle effects). Resuspension of cohesive sediments was modeled directly using an erosion equation proposed by Lick [Lick 1994] which provides a depth of scour, while resuspension of non-cohesive sediments was estimated using the Ackers-White formulation [Ackers 1973].

The Ackers-White formulation predicts the cross-sectional transport of non-cohesive solids transported in the water column, which in this application is related only empirically to resuspended mass. Mass transport in the water column is integrated at 24 equally-spaced lateral transects, and the median transect result is used to represent water column concentrations of non-cohesive sediments throughout the TIP.

2.3 Contaminant resuspension

The amount of attached contaminant resuspended with the sediments is calculated by multiplying the total mass of sediments resuspended during the modeled event by the concentration in the sediment of the material of interest.

3.0 Use of ARC/INFO

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ARC/INFO version 6 running on a Sun SPARCstation 20 was used for data management, resuspension calculations, and for visualization of model results (Figure 5).

3.1 Data management

One important role for ARC/INFO in this project was the management of spatial data for the application. Available data sets included:

- ARC/INFO polygon coverages for sediment types based on side-scan sonar investigations.
- ARC/INFO point coverages for contaminant sediment core sampling locations.
- Tabulated analytical data for sediment cores.
- Tabulated bathymetry data (transects every 100 feet, data spacing about 5').
- AUTOCAD drawings depicting shorelines and islands.

The analytical data was converted into an INFO file linked with the sediment core point coverage, and the bathymetry data was filtered and entered as a point coverage. In addition, Limno-Tech digitized elevation information from USGS quad sheets for the floodplains adjacent to the TIP.

3.2 Resuspension calculations

This section describes the procedure for estimating the resuspended mass of cohesive sediments and attached contaminants (non-cohesive sediments are not discussed because the modeling approach is still under discussion). Example AML for this calculation is included in the Appendix.

1. Export bathymetry and floodplain elevation data from ARC/INFO to RMA-2V and develop finite element grid. This step occurs only once.
2. Determine shear velocities at steady-state conditions in the TIP for the flow condition of interest, and import the results into ARC/INFO as a point coverage.
3. Create a 10m grid of shear velocities using the imported point coverage.
4. Apply Lick's erosion equation to create grids characterizing cohesive sediment mass resuspended and depth of scour (Figure 6). Based on statistical analysis of laboratory and field data, Lick proposed an erosion equation of the following form which approximated his experimental data:

   epsilon = a0 / td^n * ((tau - taucrit)/taucrit)^m

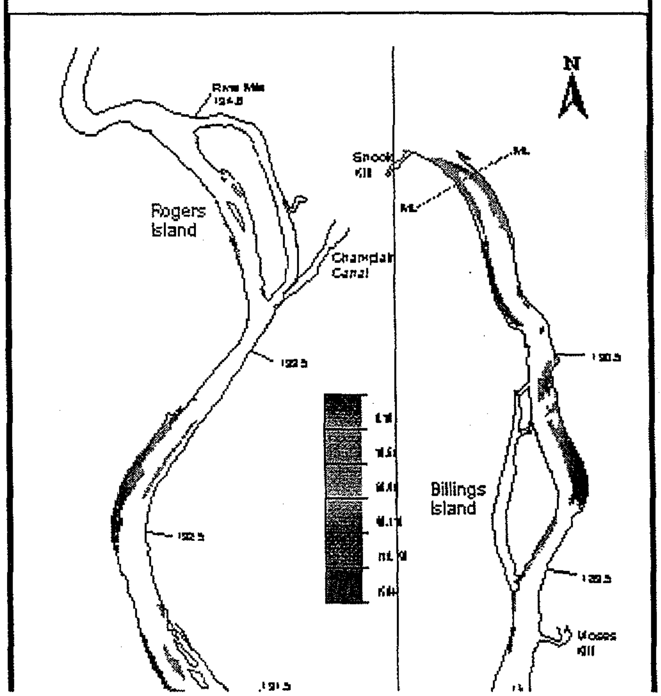
   where epsilon is the total amount of material resuspended (g/cm^2), td is the time after deposition, tau is the shear stress, taucrit is the critical shear stress, and and a0, n, and m are empirical constants. The depth of scour can be calculated as:

   zscour = epsilon / Cbulk

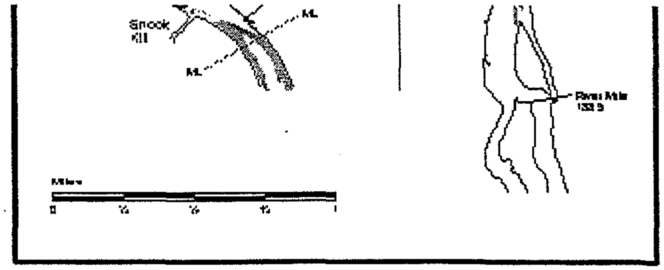
   This equation has been applied and results validated to several rivers (e.g. Fox River, WI; Detroit River, MI; Buffalo River, NY).
5. Use kriging to smooth the resuspension grid, then clip to TIP boundaries and mask out islands.
6. Multiply resuspended sediment mass by

Mass eroded (kg/s), cohesive sediments

Thompson Island Pool, 100-year event (Q = 47,300 cfs)



6. Multiply resuspended sediment mass by contaminant concentration to create a grid of contaminant mass remobilized (Figure 7).
7. Convert result grids to point coverages and operate on the PAT to get systemwide totals.



Preliminary results show that, as expected, the mass of solids and contaminants eroded increases as the magnitude of the flood increases. We found, however, that many "hot spots" - areas of sediment with high contaminant concentrations - are not likely to experience significant erosion due to their location in areas of the river bed subjected to relatively low shear velocities. This finding was aided by the fine-scale GIS approach used in this study.

3.3 Visualization

ARC/INFO was an excellent tool for viewing model results, giving the capability to produce graphics which accurately conveyed large amounts of information with some style. Graphic depictions of other spatial information was also useful in gaining an understanding of unique site features, such as the spatial distribution of sediment types and contaminants throughout the TIP, and for diagnostic examination of intermediate calculations like shear stress. The only significant difficulty faced in producing graphics was the development of an effective standard layout which could fit the entire area of interest on tabloid (11"x17") sheets for inclusion in bound reports.

4.0 Future Development

Several areas have been identified for the future enhancement of the modeling system described here, including the development of more accurate formulations for non-cohesive sediments, inclusion of vertical variability in contaminant and sediment properties, and generalization of the AML for use on other sites.

4.1 Non-cohesive sediments

One of the major concerns in the calculation of resuspension is the treatment of non-cohesive sediments. The depth of scour is not directly calculated; it is instead estimated from a sediment transport term based on the Ackers-White formulation. An alternative, more conceptual, statistically-based method is under consideration. The expected depth of scour would be directly calculated based on the particle size distribution in the bed, the critical shear stress by particle type, and the observed shear stress. This approach will lead to a more credible process parameterization by minimizing the number of calibrated parameters.

4.2 Vertical variability

The current implementation of the sediment resuspension calculation acts does not use all of the available information about sediment stratification and vertical distribution of contaminants in the sediment. This may lead to inaccuracies when the calculated depth of scour exceeds the thickness of the first layer of sediments, exposing a new layer with different characteristics which may not resuspend at the same rate. Similarly, contaminant concentrations in the sediments are represented in the model by the depth-averaged concentration, even though they actually change with depth. In addition, new data has been collected providing a more accurate description of depth-varying characteristics. We plan to develop additional AMLs to model the resuspension of sediments and remobilization of contaminants by layer, thereby increasing the accuracy of the model and taking advantage of newly available data.

4.3 Generalization

Most of the AML and linkage code developed for this application were created on a somewhat ad-hoc basis to meet project-specific needs. It is therefore not highly suitable for re-use on other sites. We plan

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to restructure the existing code to make it easy to re-use and to improve the user interface through the judicious application of menus and forms.

5.0 Conclusion

The application of state-of-the-art formulations for sediment resuspension offers an effective tool for predicting contaminant resuspension under different flow conditions. Combining these formulations with GIS allows their application in heterogeneous systems where contaminant concentrations and sediment type and grain size vary spatially in two or three dimensions. GIS also helps the modeler by providing effective depictions of site characteristics and model results.

Finally, the results of the application described here can be used to model contaminant resuspension effects on aquatic life forms and to decide what remediation strategies are necessary and appropriate for consideration.

Appendix - Example AML

The following is excerpted from the AML code used to calculate the mass of resuspended cohesive sediments and the associated contaminants.

```
/* Create 10 m grids directly from shear velocity
pointgrid t100 t100-sv shearvel;10;y;nodata

/* Calculate shear stress, depth of scour, mass resuspended
grid
t100-str = sqr(t100-sv) * 1000 * 0.929
t100-cm = 3.048 * 3.048 * (1.3 / 1000 / 7) * pow(t100-str - 1,2.5) * 100 * 100 / 100
t100-csc = t100-cm / 3.048 / 3.048 / 715.5 * 100
quit

/* Convert results back to points
gridpoint t100-cm t100-cmp mass
gridpoint t100-csc t100-cscp scour
gridpoint t100-str t100-strp stress
kill t100-cm
kill t100-csc
kill t100-str

/* Use kriging to smooth resuspension estimates, then clip to TIP
/* and mask out islands.
grid
setcell 10
t100-amk = kriging(t100-cmp,mass)
t100-amk2 = selectpolygon(t100-amk,tip.seg)
t100-amk3 = t100-amk2 + isl-grid
t100-cmk = t100-amk3
kill t100-cmp
kill t100-amk
kill t100-amk2
kill t100-amk3
quit

/* Get contaminant resuspension by multiplying mass by concentration
grid
setcell 10
t100-cpcb = t100-csck / 30.48 * pcbsurfgr * 3.048 * 3.048
quit
```

Acknowledgments

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