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Characterization of Sediments in the Clinch River, Tennessee, Using Remote Sensing and Multi-dimensional GIS Techniques

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Remotely-sensed hydro-acoustic data were used as input to spatial extrapolation tools in a GIS to develop two- and three-dimensional models of sediment densities in the Clinch River arm of Watts Bar Reservoir, Tennessee. This work delineated sediment deposition zones to streamline sediment sampling and to provide a tool for estimating sediment volumes and extrapolating contaminant concentrations throughout the system.

The Clinch River arm of Watts Bar Reservoir has been accumulating sediment-bound contaminants from three Department of Energy (DOE) facilities on the Oak Ridge Reservation, Tennessee (see map in the paper by Hargrove et. al., in these Proceedings, page 553). Public concern regarding human and ecological health resulted in Watts Bar Reservoir being placed on the National Priorities List for SUPERFUND. As a result, DOE initiated and is funding the Clinch River Environmental Restoration Program (CR-ERP) to perform a remedial investigation to determine the nature and extent of sediment contamination in the Watts Bar Reservoir and the Clinch River and to quantify any human or ecological health risks. The first step in characterizing Clinch River sediments was to determine the locations of deposition zones. It was also important to know the sediment type distribution within deposition zones because most sediment-bound contaminants are preferentially associated to fine particles. A dual-frequency hydro-acoustic survey was performed to determine: 1) depth to the sediment water interface, 2) depth of the sediment layer, and 3) sediment characteristics (density) with depth (approximately 0.5-foot intervals). An array of geophysical instruments was used to meet the objectives of this investigation. The basic suite of systems included: a 3.5 kHz high resolution "pinger" system, a high definition broad spectrum acoustic profiling "chirp" system, and a dual-frequency side-scan sonar system. A real-time-differential Global Positioning System was used to navigate along predetermined survey lines and to obtain precise locations of data points. Approximately 80 linear miles of survey lines were navigated to cover a 22 mile length of river. On-board display of sediment density data in real-time was instrumental for CR-ERP personnel to delineate further sampling areas.

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Surface Sediment Data Analysis

Surface sediment density data were created for 5642 points from the hydro-acoustic survey. Because the hydro-acoustic instrumentation could not operate in water shallower than about 10 feet, the survey data were augmented with density data from 400 near-shore sediment samples that were analyzed physically. Both these data sets were used to create GRASS site files which were used iteratively as input to a program that performed a regularized spline with tension interpolation technique to generate bathymetric and surface sediment density surfaces. The parameters used in each of the following spline interpolations were always 120 for tension with a smoothing of 0.1. Significance of the tension and smoothing parameter values are discussed in the following paper (Hargrove *et al*). The density data were reported in increments of 0.1 grams per cubic centimeter and values ranged between 1.0 (density of water) to about 2.5 for solid rock.

Five sediment density surfaces were generated by varying what data the program used and how it used each of the data sets. These spline interpolations were performed iteratively until a surface that best fit the data and our knowledge of the system was created. The 5 density surfaces were as follows:

1. Only the hydro-acoustic survey data were used.
2. The hydro-acoustic survey data and a density of 1.6 assigned to the shoreline.
3. Hydro-acoustic data and physically measured samples, no shoreline density value.
4. Same as 3 with shoreline areas with rock escarpments were assigned a density value of 2.5.
5. Same as 2 but the spline was performed in two separate passes. A surface for the river channel was generated and then a surface for the overbank was generated and the two were pasted together.

A two-pass spline was used because the reservoir has a distinctive channel which is defined by steep sides and a flat, shallow overbank. Depositional forces and patterns are very different in these two areas and thus provided a logical break point for interpolation.

Table 1: *Sediment types as related to density ranges*

Density (grams/cubic cm)	Sediment Type
1.0 - 1.2	Fluid Mud
1.2 - 1.4	Clays, Silty Clays
1.4 - 1.6	Clayey Silts, Silt
1.6 - 1.8	Coarse Silt, Clayey Silty Sands, Very Fine Sands
> 1.8	Sands, Gravel, Stiff Clays, Rock

Each of the spline surfaces were reclassified into five sediment type categories based on Hamilton (1970, Table 1) and are summarized in Figure 1. The surface from scenario 1 created more soft sediments than were believed

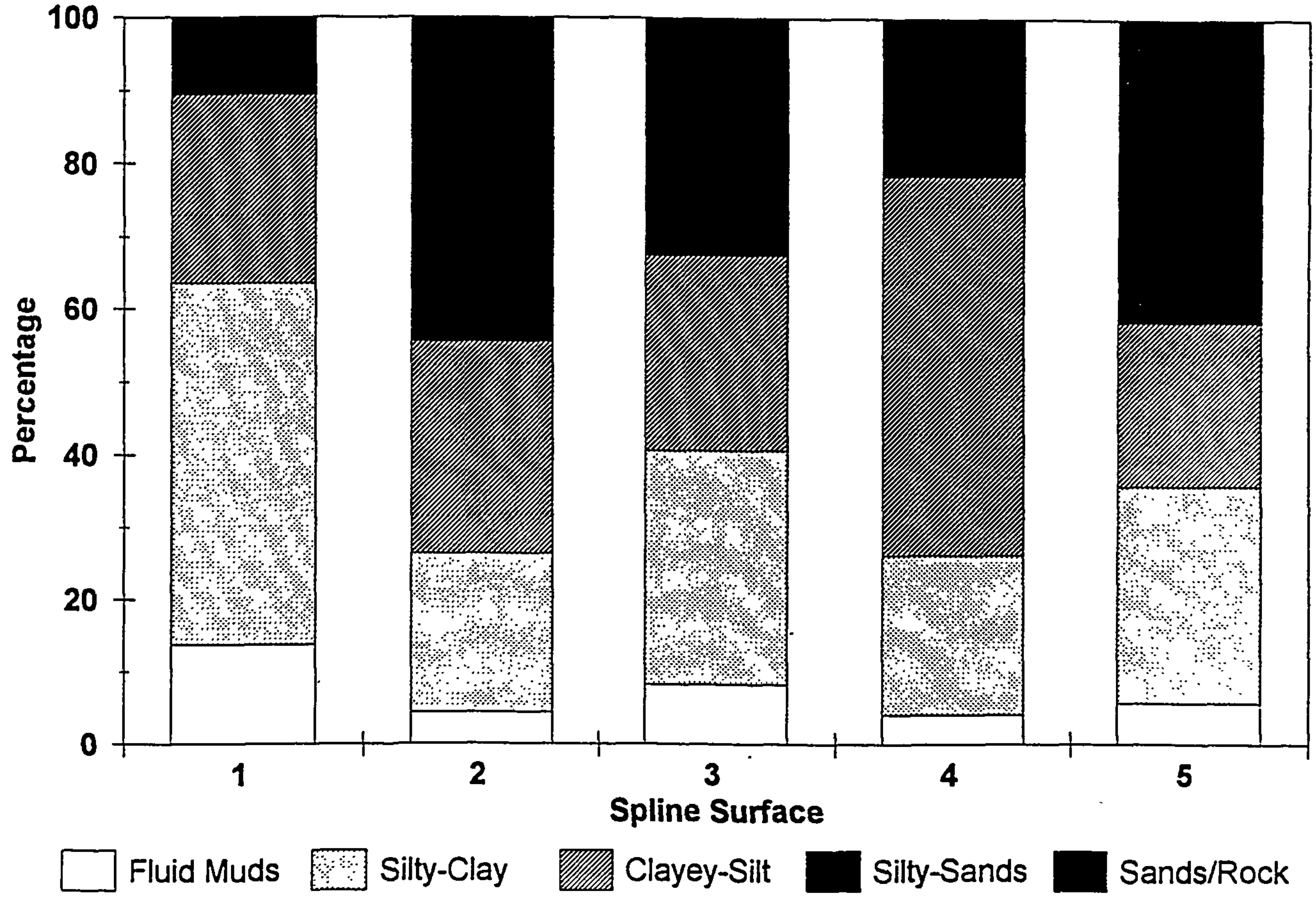

Figure 1: *Surface sediment types for each spline scenario*

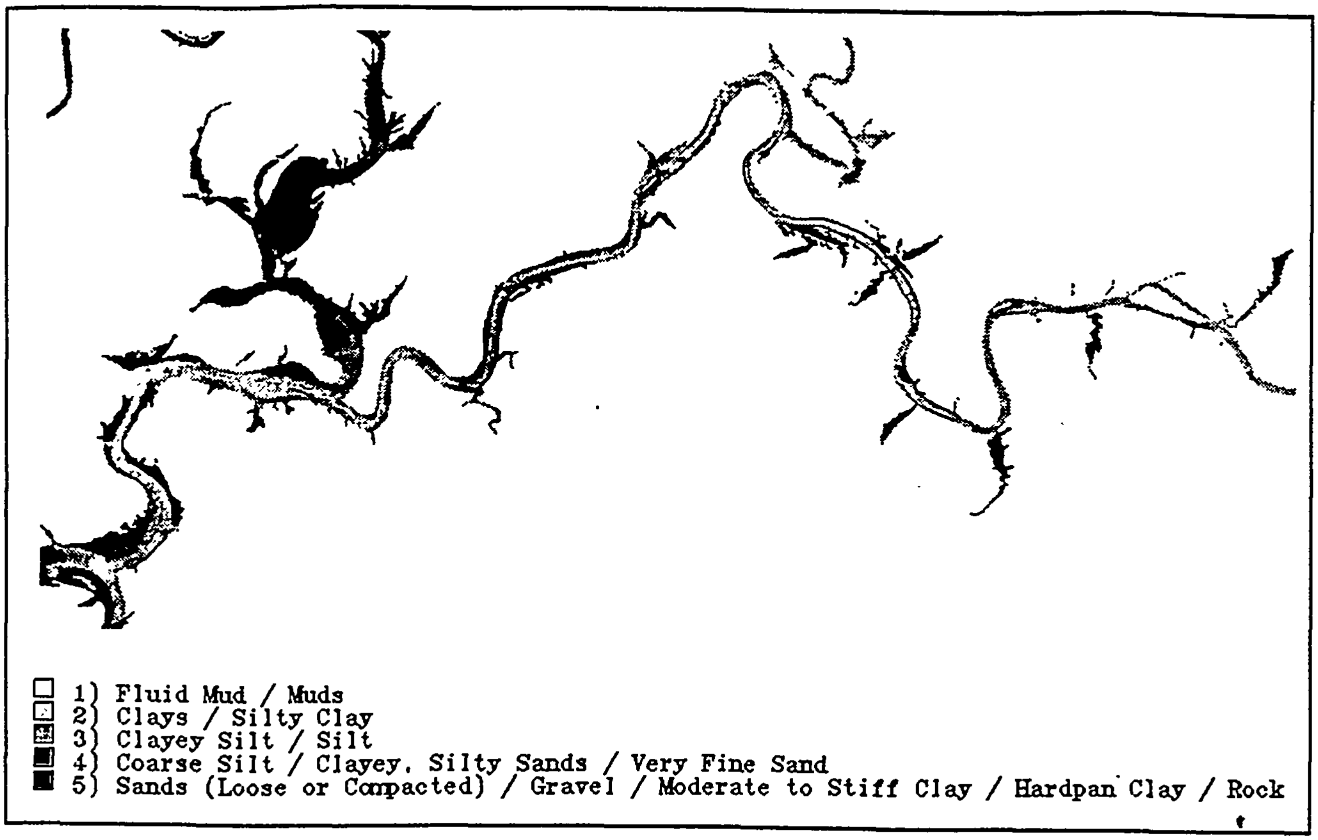

Figure 2: *Gray-scale representation of surface sediment types in the Clinch River resulting from scenario 5*

to be present in the system. This is because the hydro-acoustic data were only collected from the channel where softer sediments are typically found. By setting the shoreline points to a density of 1.6, (scenario 2) which is the breakpoint between the soft and hard sediment types, we increased the hard type dramatically. However, the surface was not representing the near-shore areas well because the channel varies in distance from the shoreline. When the channel is adjacent to the shoreline the 1.6 value was over-influencing the interpolation. Scenario 4 was a variation of 2 with the addition of the rock cliffs as input. This scenario was unsatisfactory for the same reason as 2. Improvements in the surface resulted by adding the physically measured samples, scenario 3, and removing the synthetic shoreline value. Nearly all of the physical samples were collected in the shallow areas that the hydro-acoustic survey did not measure.

Scenario 5 seems to be the best model of the surface sediment. The amount of hard sediment types is about what was expected and the distribution of the sediment types matched our knowledge of the system (Fig. 2). Scenario 5 produced the best result because the data were separated by a hydrologically sensible breakline; sharp lines between sediment types were expected with drastic changes in depth; splining across those logical breaklines resulted in poorer results.

Even with a relatively large amount of data the resulting surface can vary tremendously, even with the same spline program parameters. Knowledge of the system being modelled is critical to obtain a reasonable representation.

3-Dimensional Sediment Data

Sediment densities, in 6 inch depth increments, from approximately 4000 points within the main channel were used as input for a three-dimensional spline technique to generate a volumetric model of the sediment densities. Figure 3 portrays a section of the river with the sub-bottom density data represented by stacked balls on a pole. The darker the ball the denser the sediment. Volumetric representations resulting from the splines will be discussed in the presentation. The volumetric model of sediment types will aid the CR-ERP to calculate volumes and types of sediment requiring remediation as well as evaluate appropriate types of remediation techniques.

Conclusions

Immediate results from the survey and GIS analysis allowed sediment sampling to focus in areas where fine particles had been identified and therefore were most likely to have contaminated sediments. Therefore, a reduction in total number of samples was realized and minimal time was lost in the field trying to locate sediment deposits. The surface sediment map, combined with the bathymetry data, provided a tool for estimating total area of exposed soft sediment during winter drawdown of the reservoir. The three-dimensional model of the sediment densities provides a tool for estimating sediment volumes potentially requiring remediation as well as the characteristics of that sediment; an important factor in selecting remediation techniques.

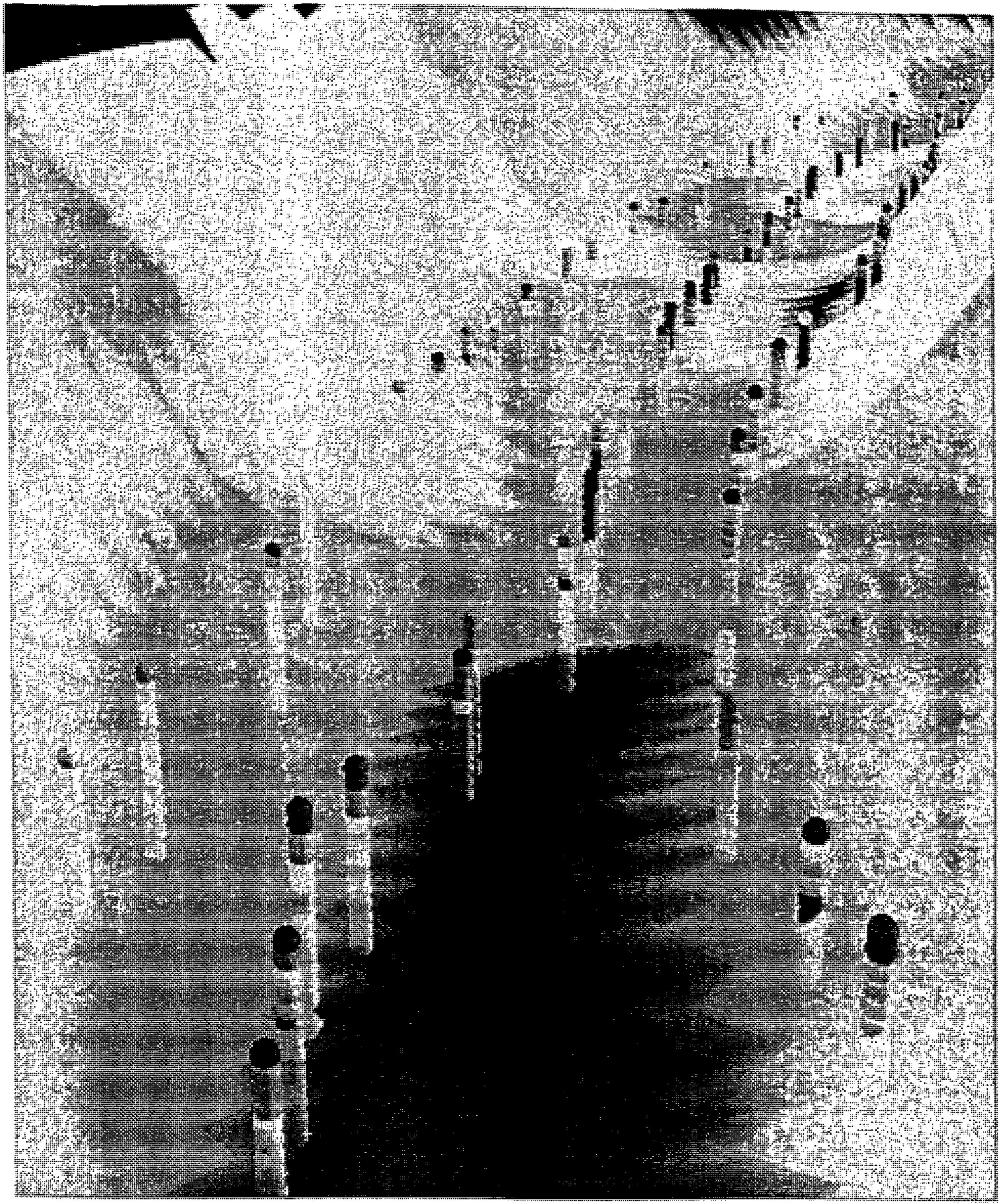

Figure 3: *Gray-scale representation of sediment density with depth at sample locations plotted on top of river bathymetry*

All of the resulting sediment surfaces and volumes discussed can be viewed as images or movies via the World Wide Web at the following URL:

http://www.esd.ornl.gov/programs/CRERP/INDEX.HTM

Key words: hydro-acoustic survey, sediment, three-dimensional, bathymetry, SUPERFUND

References

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