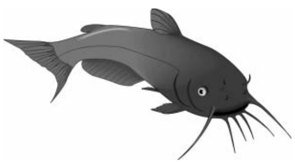
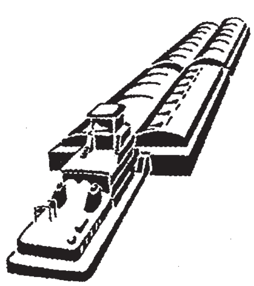
ENV Report 13

Interim Report For The Upper Mississippi River - Illinois Waterway System Navigation Study



Methodologies Employed for Bathymetric Mapping and Sediment Characterization as Part of the Upper Mississippi River System Navigation Feasibility Study



May 1999

US Army Corps of Engineers

Rock Island District
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Upper Mississippi River - Illinois Waterway
System Navigation Study

ENV Report 13
May 1999

Methodologies Employed for Bathymetric Mapping and Sediment Characterization as Part of the Upper Mississippi River System Navigation Feasibility Study

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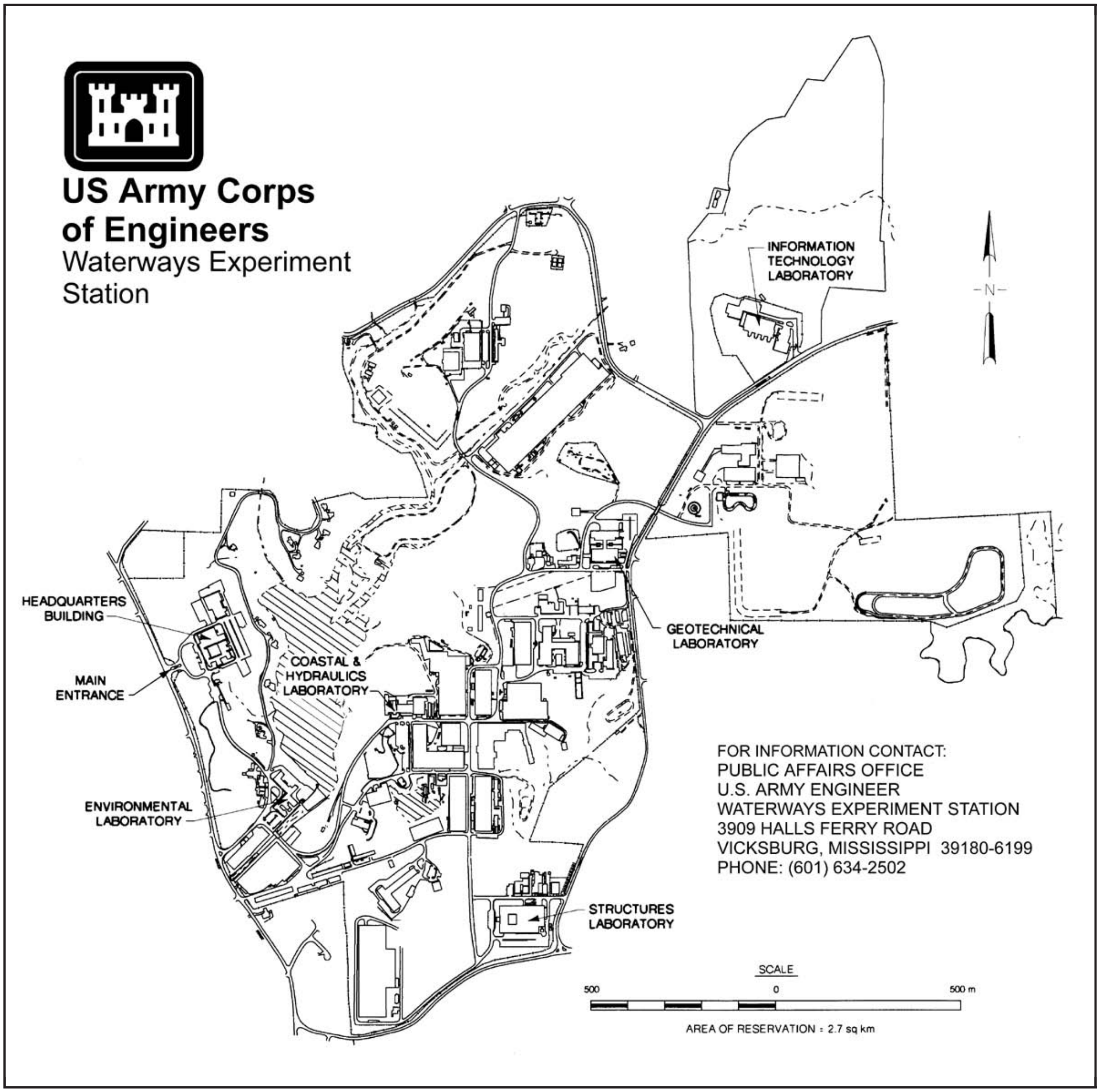
Interim report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Engineer District, Rock Island
Rock Island, IL 61204-2004
U.S. Army Engineer District, St. Louis
St. Louis, MO 63103-2833
U.S. Army Engineer District, St. Paul
St. Paul, MN 55101-1638



Waterways Experiment Station Cataloging-in-Publication Data

Rogala, James T.

Methodologies employed for bathymetric mapping and sediment characterization as part of the Upper Mississippi River System Navigation Feasibility Study / by James T. Rogala ; prepared for U.S. Army Engineer District, Rock Island, U.S. Army Engineer District, St. Louis, U.S. Army Engineer District, St. Paul.

39 p. : ill. ; 28 cm.

“ENV report 13"

Includes bibliographic references.

1. Mississippi River — Bathymetric maps — Methodology. 2. Illinois Waterway (Ill.) —Bathymetric maps — Methodology. 3. Sediments (Geology) — Analysis. 4. Bathymetric maps. 5. Illinois Waterway (Ill.) 6. Mississippi River. I. United States. Army. Corps of Engineers. Rock Island District. II. United States. Army. Corps of Engineers. St. Louis District. III. United States. Army. Corps of Engineers. St. Paul District. IV. U.S. Army Engineer Waterways Experiment Station. V. Upper Mississippi River-Illinois Waterway System Navigation Study. VI. Title. VII. Title: Interim report for the Upper Mississippi River-Illinois Waterway System Navigation Study.

TA7 W3499 R5U7 ENV rept.13 1999

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Preface

The work reported herein was conducted as part of the Upper Mississippi River - Illinois Waterway (UMR-IWW) System Navigation Study. The information generated for this interim effort will be considered as part of the plan formulation process for the System Navigation Study.

The UMR-IWW System Navigation Study is being conducted by the U.S. Army Engineer Districts of Rock Island, St. Louis, and St. Paul under the authority of Section 216 of the Flood Control Act of 1970. Commercial navigation traffic is increasing, and in consideration of existing system lock constraints, will result in traffic delays which will continue to grow into the future. The system navigation study scope is to examine the feasibility of navigation improvements to the Upper Mississippi River and Illinois Waterway to reduce delays to commercial navigation traffic. The study will determine the location and appropriate sequencing of potential navigation improvements on the system, prioritizing the improvements for the 50-year planning horizon from 2000 through 2050. The final product of the System Navigation Study is a Feasibility Report which is the decision document for processing to Congress.

This report was written by Mr. James T. Rogala, U.S. Geological Survey Environmental Management Technical Center. Ms. Sue Fox, AScI Corporation, U.S. Army Engineer Research and Development Center (ERDC), Eau Galle Aquatic Ecosystem Research Facility, Eau Galle, WI, provided detailed documentation of laboratory procedures for sediment analysis. Mr. Stephen O'Connor, U.S. Army Engineer District, St. Louis, provided additional documentation for sediment sieving analysis.

This report was edited and published by the Information Technology Laboratory, ERDC. Mr. Robert C. Gunkel, Jr., Environmental Laboratory (EL), ERDC, was responsible for coordinating the necessary activities leading to publication. Dr. John W. Keeley was Acting Director, EL, ERDC. At the time of publication of this report, Acting Director of ERDC was Dr. Lewis E. Link, Jr.

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1 Introduction

This report documents the general procedures used to collect bathymetric and sediment data for environmental studies conducted as part of the Upper Mississippi River System (UMRS) Navigation Feasibility Study. Several biotic and physical study components of the Navigation Feasibility Study used bathymetric and sediment information. These studies ranged in geographical extent from small areas selected for intense modeling to the entire UMRS for estimating systemwide effects of navigation.

Bathymetric data were obtained at two different levels of spatial resolution. Generation of poolwide bathymetric data from interpolation in a Geographical Information System (GIS) had been completed in three study pools of the Long Term Resource Monitoring Program (LTRMP) prior to initiation of the study. Although poolwide coverage of bathymetry for the entire UMRS could be used by many study components, completion of a systemic poolwide database within the time frame of the study was an unrealistic goal. Therefore, poolwide coverages of bathymetry were completed only for two additional pools, those being previously uncompleted study pools of the LTRMP. To meet the needs of systemic studies, the remaining pools of the UMRS were surveyed along transects at 1.6-km (1-mile) intervals in the main channel and at all connections to off-channel areas. These data were used only to represent long "cells" at 1.6-km (1-mile) intervals and no interpolation of a surface was performed with these data.

Data on sediment composition were also needed at similar levels of resolution. Detailed two-dimensional (2-D) numerical models of sediment transport were developed for selected areas, and existing sediment characteristics within the modeled area were needed. In addition, systemic impacts of navigation were investigated, and sediment characteristics were needed for these investigations. To meet these needs, sailing line and nearshore sediments in the main channel were collected and characterized. The physical characteristics determined for the sediments also varied depending on the scope of the studies, ranging from visual classification for systemic studies to sieving to determine particle size fractions for sediment transport modeling.

Several publications include detailed documentation of methods and standards for collecting bathymetric data and sediment analysis. The U.S. Army

Corps of Engineers (USACE) has published a document that discusses extensively the methods and the theory behind the technology for hydrographic surveys (Headquarters, U.S. Army Corps of Engineers, 1994). The general methods reported here can be greatly supplemented by the detail provided in the USACE document. Similarly, standard methods for sediment analysis provided by the American Society for Testing and Materials (ASTM) provide details of analytical procedures. For some laboratory analyses deployed for the study, the ASTM methods were completely followed and methods are simply referenced. Although most of the methods used for the study are in published documents, this report includes specific methodology that needs to be reported to provide the information to data users.

2 Bathymetry

Data Collection Strategy

Methods for generation of poolwide bathymetric data were established as part of the LTRMP mapping prior to the Navigation Feasibility Study. The LTRMP bathymetric data were intended to meet the needs of a variety of users. Details required within specific areas of interest (e.g., dredge sites) were not desired in this bathymetric coverage. Rather, the coverage was to represent poolwide conditions representing bathymetry over a multiyear period. Interpolation between data points is used to generate a continuous surface of bathymetry for poolwide coverages.

Several data types were used to generate the continuous surface of bathymetry. Most of the data was collected by a computerized hydrographic survey system. This was the desired method because of the rapid collection of data and accurate geographical positioning. However, land-based positioning survey systems are very inefficient in some cases. In particular, line-of-sight limitations of the land-based system require many transponder locations in narrow, forested channel areas. Collection of chart recordings along transects was used as an alternative method in these areas. Using information from the chart recordings, contours were hand drawn and then digitized. Another limitation of the automated survey systems is related to the use of soundings to determine water depth. Many of the aquatic areas within the pools are shallow and highly vegetated nearly year-round, and accurate acoustical soundings are difficult to obtain under these conditions. To obtain water depth data in these areas, manually measuring water depth with a sounding pole is required. These spot measurements can be used effectively because these areas are small and have little slope.

Two other types of data were used to assist in the interpolation of the coverage. An existing GIS land/water boundary and assigned water depths based on the location in the pool were used to provide the data needed to interpolate between sounding data and the shoreline. Without these data on the shoreline, extrapolation of values beyond data points would often yield undesirable results. The interpolation to the shoreline was needed because the bathymetric surface was desired to cover all aquatic areas within a pool. The second type of data used to assist in the interpolation of values was break-line data. Break-line data add data points interpolated along individual lines based only on actual data that intersect the line. Break-line data are typically added to maintain slopes and linear features between selected data points where data were sparse. Further discussion on shoreline data and break lines is included in this report in the sections on data collection and GIS database generation.

In contrast to the poolwide data sets, the systemic transects were collected using only the automated survey system. These data were collected bank to bank along transects running perpendicular to the sailing line spaced every 1.6 km (1 mile). Additional transects were surveyed at connections to off-channel areas, except in the impounded area. In large impounded areas, the main channel transects were extended out over the shallow aquatic area of the impounded region for a short distance, and no transect of the connection between the main channel and the impounded area was surveyed. The final data set was a point coverage of water depth, and no interpolation was used between points.

Automated System Configuration

Many hydrographic survey equipment manufacturers have integrated hardware and software into an automated survey system to enable rapid collection of digital geographical positions and depth data. There are three basic components of an automated survey system: a geographical positioning device, a depth sounder/digitizer, and a computer to integrate and store data. The LTRMP has used three survey systems through acquisition and replacement of various components of systems.

In 1988, the first system was acquired from Ross Laboratories of Seattle, WA (Ross Laboratories 1988). This system uses a land-based positioning system. The system computes a position using distances to surveyed locations obtained from a microwave positioning system. The theory behind microwave positioning is discussed in the operator's manual for the system (Del Norte 1986). Typically, four remote transponders are set out at known geographical locations to provide distances to the master transponder on board the survey vessel (Figure 1). The microwave positioning system relies on line-of-sight communication between the master transponder and remotes and typically provides distances accurate to 1 m (3 ft). Positions are calculated using the distances to the known locations in a least squares estimate. Accuracy of positions is dependent on number of transponders used, the geographical arrangement of the transponders, positional accuracy of the transponder locations, and the quality of the signals received.

The computer software merges the calculated position with a digitized sounding of depth obtained from a depth sounder/chart recorder. A minimum digitized water depth of 0.79 m (2.6 ft) is obtainable with this system, and depths are recorded to the nearest 0.03 m (0.1 ft). Nominal accuracy is dependent on depth, with shallow survey accuracy as low as ± 0.03 (0.1 ft) and less accurate recordings of ± 0.12 m (0.4 ft) for deeper surveys. Other errors during soundings

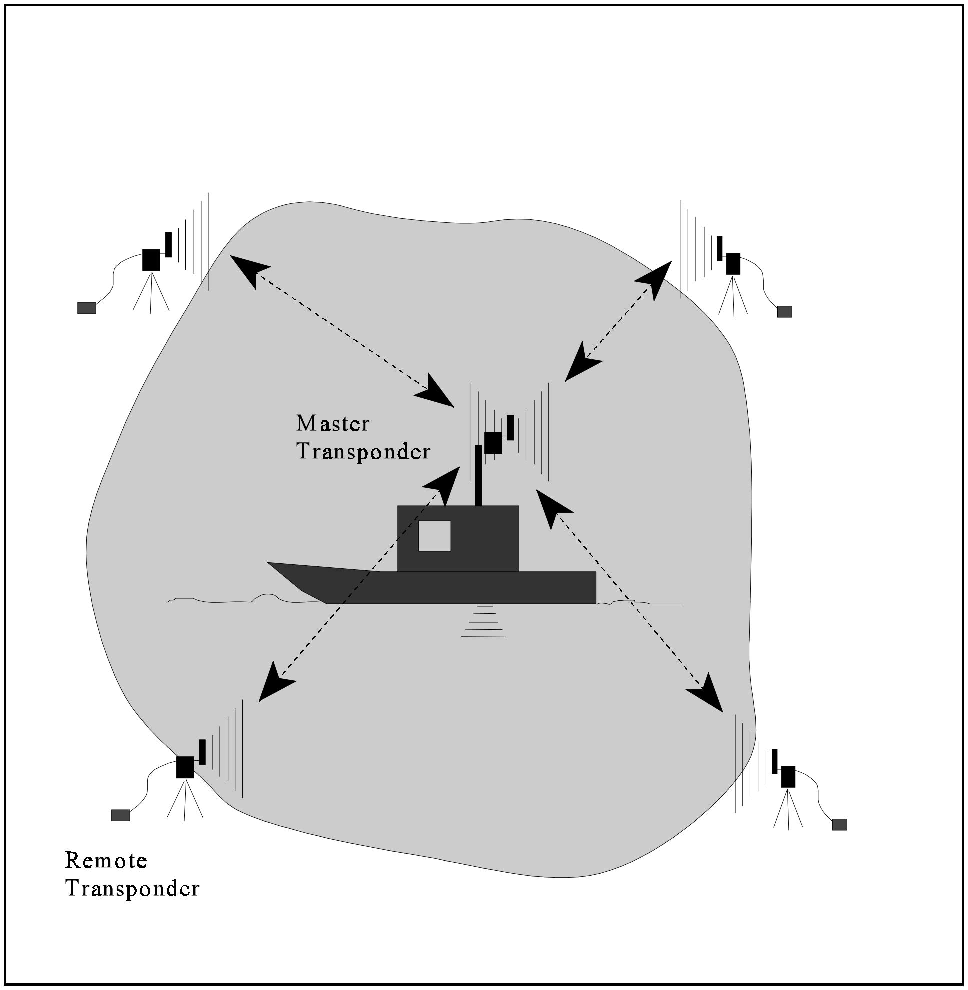

Figure 1. Schematic of land-based positioning survey system

may decrease accuracy of recorded depths. The merged position and depth data are recorded on a computer disc for postprocessing in the office. The majority of the data used to generate poolwide maps for Pools 4, 8, 13, and 26 was collected with this system.

The LTRMP acquired a second automated survey system in 1993 to incorporate Global Positioning System (GPS) technology into LTRMP bathymetric surveys. General information on the theory of GPS is provided in the manual for the GPS unit (Starlink 1997). Because GPS is a satellite-based positioning system, it greatly reduces field surveys by eliminating the need for surveyed locations for transponders. The system was acquired from Innerspace Technology, Inc. (1994), Waldwick, NJ. It includes a two-channel GPS system that can achieve differential GPS. Differential GPS reduces the error by using additional data from a reference GPS receiver at a known position to correct positions obtained during surveys. The position data have an accuracy of <1 m two-dimensional Root Mean Square (2DRMS). The reference stations of the U.S. Coast Guard Beacon system (Figure 2), which has became operational

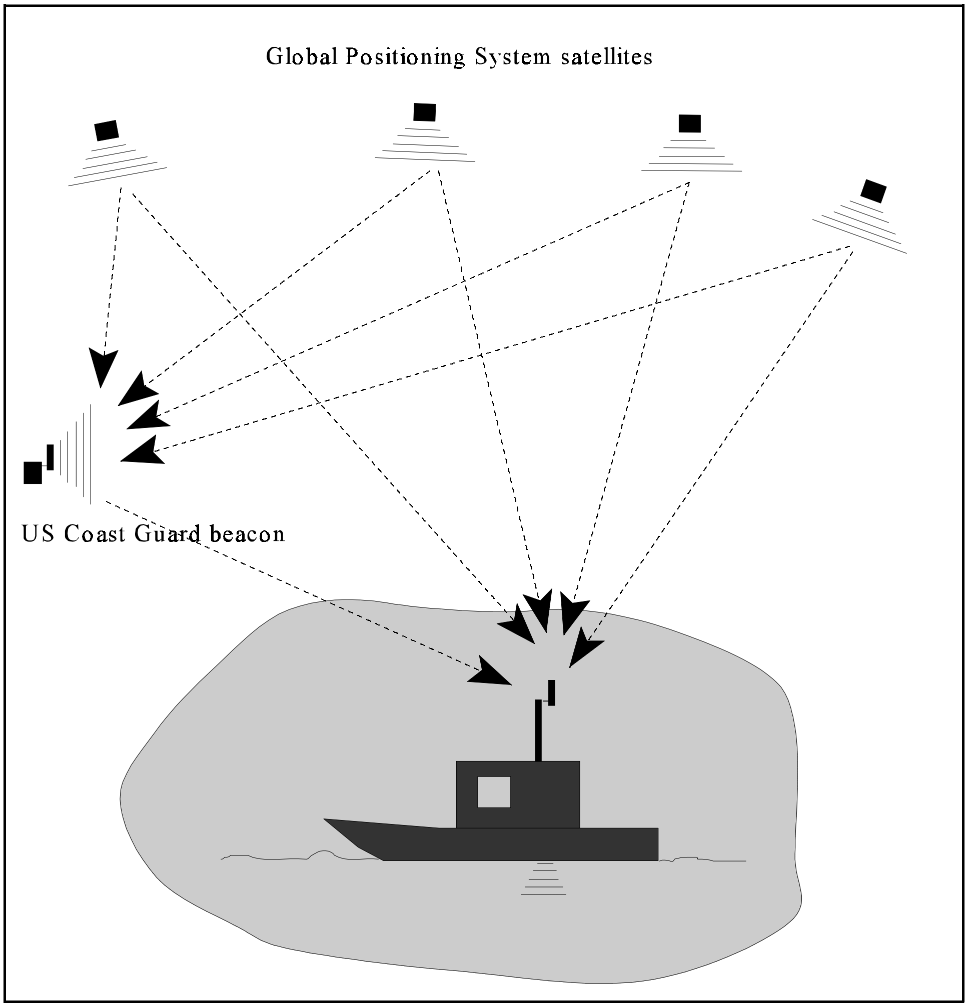

Figure 2. Schematic of GPS positioning survey system

along the entire UMRS, are used. The beacon system transmits signals for performing corrections in real-time; therefore, no postprocessing for corrections is necessary. Position data are used in a manner similar to that described previously for the land-based positioning system. A new depth sounder/digitizer was also obtained that allows for shallow-water surveys to depths of 0.5 m (1.7 ft) with accuracy similar to the previously used sounder. This system was used to conduct surveys in the LaGrange Pool and to collect the systemic transect data.

In 1997, the LTRMP acquired several new components for the survey system: a new 12-channel GPS receiver and beacon signal receiver and new software from Coastal Oceanographics, Inc. (1995), Middlefield, CT. The accuracy is similar to that of the previous GPS unit (<1 m 2DRMS), but the increased number of channels provides for better tracking of satellites under conditions of signal interference. The new software, Hypack, is a more user-friendly Windows application. The Hypack software improves the efficiency of data collection by allowing the boat operator to display shoreline data and maps of previously collected bathymetry data while collecting data. The Hypack system was used to collect data in the LaGrange Pool. Specifications for all three systems are included in Appendix A.

Data Collection

The data collection procedures described in the following paragraphs are meant to be used in conjunction with the user's manuals for the three software packages (Ross Laboratories 1988; Innerspace Technology 1994; Coastal Oceanographics 1995) used by the LTRMP bathymetric survey component. The general procedures presented here were written specifically for the type of work performed by the LTRMP. Although specific language and procedures differ among the three software packages, the methods are somewhat similar. The methods given here use generic text and a common language to describe the three different procedures.

In preparation for conducting surveys, geographical boundaries were established for each survey. The boundaries were based on manageable size of files, acceptable geometry of transponders for range positioning systems, and river mile lengths to simplify adjustment to the reference water surface elevation. Reference transect lines and line spacing intervals were established (Figure 3). These transect lines were displayed during the survey to assist the boat operator in navigating along lines where data collection is desired. For the Hypack system, background coverages such as shorelines are brought into the system as DXF files.

Before data were collected with the depth sounder, the sounder was calibrated to account for variability in water quality parameters. The calibration was performed by anchoring the boat over a location with a bottom of uniform depth. The water depth was acquired with a calibrated sounding pole. With the sounding equipment on, the speed of sound was adjusted until the digitized depth equaled the measured water depth. This calibration was performed at a water depth similar to the mean water depth within the survey area. For example, if a survey was conducted only within shallow backwaters, then the calibration was performed within the shallow backwater. This adjustment of the speed of sound accounts for variability in water quality parameters that affect the speed of sound in water, which is needed to calculate distance (water depth) based on the travel time of the reflected pulse.

To initiate a survey, the survey setup and a reference line were selected. When a line was started, the automated survey system began data collection by recording geographical positions and depths in computer data files as the survey boat was operated along the transect line. The chart recorder was turned on whenever digital data were acquired to generate a hard copy profile of the soundings. Distance off the transect line (offset) and distance along the transect line were displayed on the boat video display to guide the boat operator. For the systemic 1.6-km (1-mile) transects, each transect was established as a reference line and no data were collected other than along reference lines. For poolwide

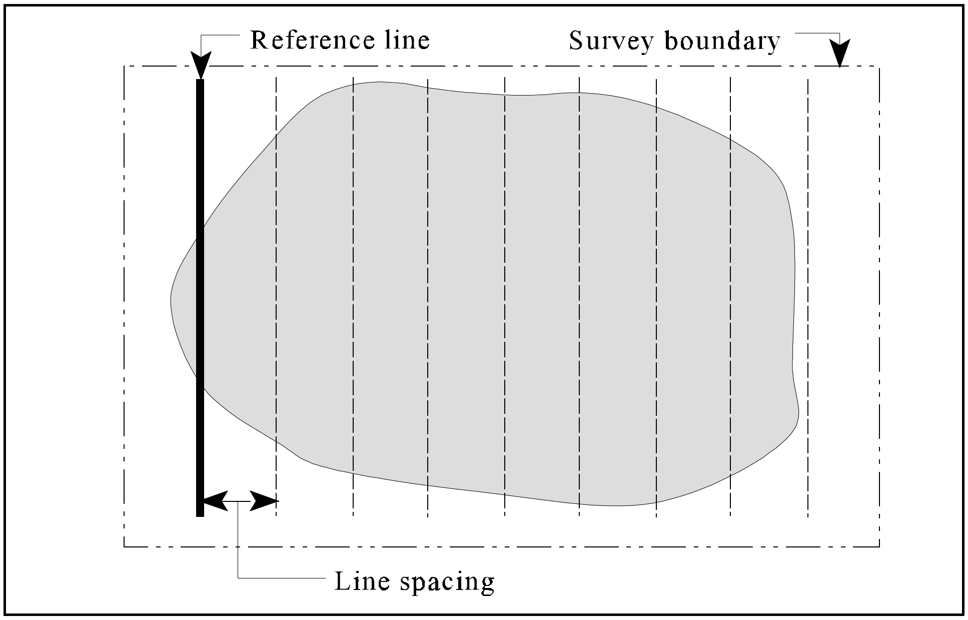

Figure 3. Schematic of parameters used to set up a survey

mapping, data were collected along offsets from the reference line, either as transects spaced along the selected spacing interval or "free-form" lines based on the offset displayed.

For the poolwide mapping, the track line arrangement used differed depending on the type of aquatic area, as defined by Wilcox (1993), where the survey was conducted. Main channel, side channel, and backwater areas were surveyed using a combination of different types of track lines (Figure 4). In the main channel, north-south and east-west track lines were surveyed at regular intervals over the entire area. Track lines were 61 m (200 ft) apart on the lines most parallel to the flow and 152 m (500 ft) apart on the lines most perpendicular to the flow. Data were also collected along the shorelines at two or three distances offshore. When structures (i.e., wing dams) were present, data were collected along two or more lines above, two or more lines below, one line on top of, and four to eight lines across the structure. Side channel track lines included one or more shoreline runs, lines run approximately 61 m (200 ft) or less apart perpendicular to the flow, and a line along the thalweg. Data collection in backwaters included track lines on north-south or east-west lines at 61-m (200-ft) intervals, lines at one or two distances from the shoreline, and channel type track lines in channels if they existed within the backwater.

Data were collected within the survey area until the desired coverage was obtained, as described previously. Areas with depths less than the minimum depth limit of the digitizer were avoided. The recorded files contained geographical position and depth data in a series of x-, y-, and z-values. A record was obtained every 0.33 to 1.5 s, depending on the system and the setting of the time interval in some software. Point data density along track lines was dependent on boat speed, and data points usually ranged between 3 and 9 m

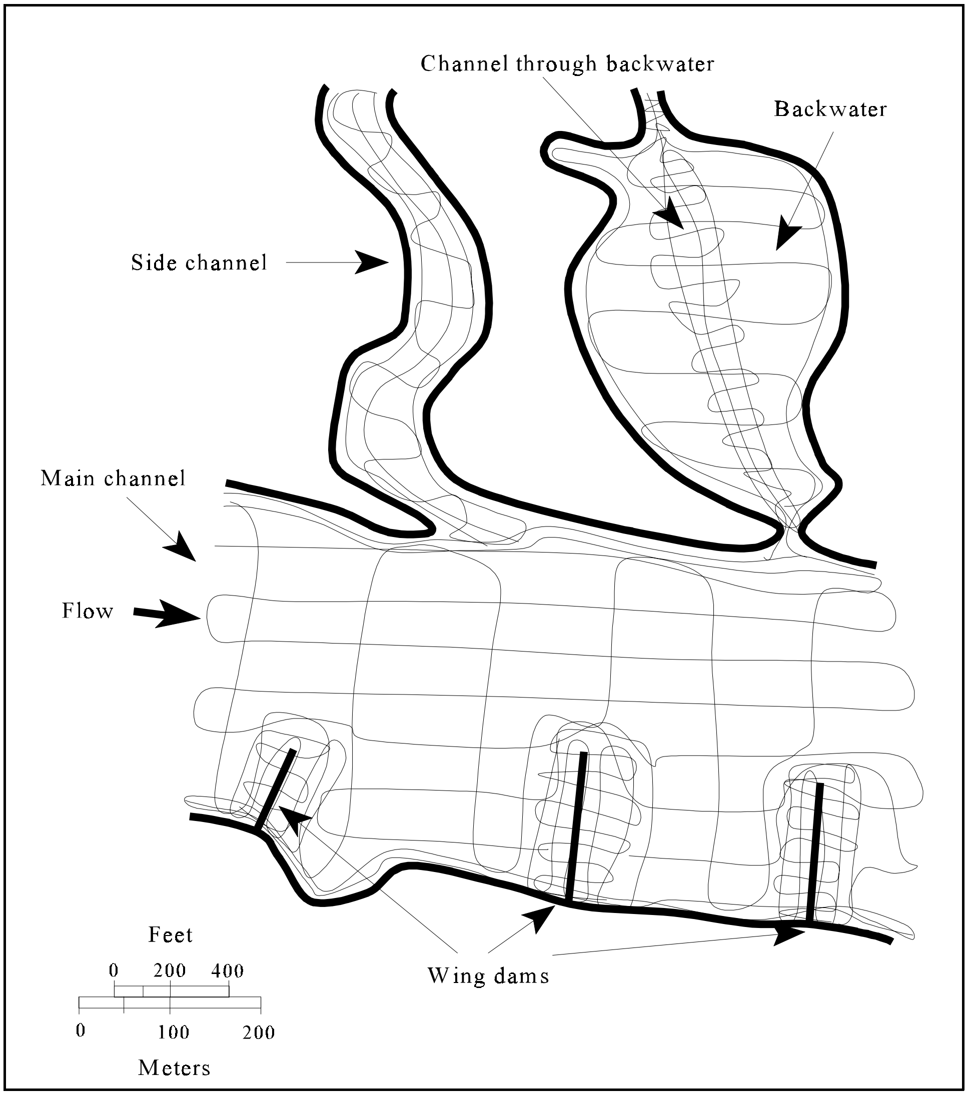

Figure 4. Typical arrangement of track lines for various aquatic area types

(10 and 30 ft) apart. Hard copies of depth soundings in the form of chart recordings of the profile data along the track line were labeled with the survey name and line number. Line numbers increased by one each time a new line was started. These chart recordings are used during editing to evaluate potential errors in digital recordings of depths.

In addition to the automated data collection, data were collected by chart recordings along transects where automated collection was not efficient with the land-based positioning system. Shore-to-shore transects were selected to provide adequate information to hand-draw contours. Typically, transects were spaced farther apart than those of the automated survey because contours were hand drawn rather than computer interpolated. Calibration of the depth sounder was performed daily prior to surveying, as described previously. A transect location was selected and drawn on copies of aerial photography (1:15,000 natural color) in the field. The boat then traversed the transect at a constant speed while the chart recorder was running. The distances to the shore at the beginning and end points were recorded, as well as the direction of the transect.

Manual water depth measurements using a calibrated sounding pole were collected to fill in gaps in the coverage of data from other sources. Locations for measurement were selected using a GIS by displaying locations of actual data points collected with other methods. The x- and y-coordinates of the selected locations and maps of the locations were produced in the GIS. Using the field maps and a real-time differential GPS unit, the survey crew navigated to each of the selected locations and obtained a water depth reading to the nearest tenth of a foot. Data were entered into a computer spreadsheet.

Data Editing

All water depth data were adjusted to a constant reference water surface elevation for each navigation pool. This was necessary because surveys collected water depth data at varying water levels. The use of a constant reference elevation for each pool provided for easy conversion of depth data to elevation data referenced to the National Geodetic Vertical Datum (NGVD), which is the most commonly used reference surface. The water surface elevations for each pool are in feet above mean sea level, with an NGVD of 1912 for the St. Paul and Rock Island District portions of the Mississippi River and an NGVD of 1929 for the St. Louis District portion of the Mississippi River and all of the Illinois River.

The selection of the reference water surface elevation was based on pool elevations used by the USACE. However, the three districts (St. Paul, MN, Rock Island, IL, and St. Louis, MO) in the UMRS use different methods for establishing reference elevations for bathymetric surveys. Only the Rock Island District uses a method of constant water surface elevation within each pool, which is referred to as flat pool elevation. The LTRMP has adopted this method and uses the USACE flat pool elevations as provided in the Master Reservoir Regulation Manual (U.S. Army Engineer District, Rock Island, 1981) for reducing depth data to a reference water surface elevation in the Rock Island District.

Methods in the other two districts were modified to obtain flat pool elevation values. In the St. Paul District, the project pool elevation (maximum lowest controlled pool elevation), as described in the Master Regulation Manual (U.S. Army Engineer District, St. Paul, 1969), for most pools is used as the reference water surface elevation. The exception is Pool 7, for which an elevation of 638.5[1] is used as the flat pool elevation to match the water surface elevation used for hydrographic surveys within the St. Paul District. Similarly, the greatest minimum pool stage used for hydrographic surveys by the St. Louis

[1] To convert elevations given in feet to meters, multiply by 0.305.

District is used as the reference water surface elevation in Pools 24, 25, and 26. These elevations differ slightly from the elevations reported in the Master Water Control Manual (U.S. Army Engineer District, St. Louis, 1980) for those pools. The flat pool reference elevations used by the LTRMP for each pool in the UMRS are included in Table 1.

Table 1
Water Surface Elevations Used as Flat Pool Depths in the UMRS

Pool	Elevation	Pool	Elevation	Pool	Elevation
1	725.1	13	583.0	Brandon Road	538.5
2	687.2	14	572.0	Dresden Island	504.5
3	675.0	15	561.0	Marseilles	483.2
4	667.0	16	545.0	Starved Rock	458.7
5	660.0	17	536.0	Peoria	440.0
5A	651.0	18	528.0	La Grange	429.0
6	645.5	19	518.0	Alton	419.0
7	638.5	20	480.0		
8	631.0	21	470.0		
9	620.0	22	459.5		
10	611.0	24	449.1		
11	603.0	25	434.2		
12	592.0	26	418.5		

In most cases, water surface elevation for a survey site on the day of the survey was estimated by linear interpolation between elevations from USACE main channel gauges above and below the survey as illustrated in the equation:

$$swse = dwse + (srm - drm)\ [(uwse - dwse)/(urm - drm)] \qquad (1)$$

where

swse = survey water surface elevation

dwse = downstream gauge water surface elevation

srm = survey river mile

drm = downstream gauge river mile

uwse = upstream gauge water surface elevation

urm = upstream gauge river mile

These estimates of water surface elevations were more accurate at low-water conditions than at high-water conditions, particularly for contiguous off-channel areas farther from the main channel. However, a more accurate estimate of water surface elevation was obtained during high-water surveys by setting a temporary gauge near the survey area. The elevation of the gauge was then later approximated during relatively flat pool conditions when the slope of the water surface was nearly linear, thus providing a better estimate of the water surface elevation at the time of the survey. Nonetheless, linear interpolation of water surface elevations provides a source of error because the water surface slopes between gauges is often nonlinear.

The adjustment to flat pool was calculated by subtracting the water surface elevation on the day of the survey from the flat pool elevation for the pool where the survey was located. In most cases, a single adjustment value was used for the entire survey. However, if the survey extended over many miles during high water surface elevation slope conditions, then several adjustment values were used along the length of the survey. After water depth data were adjusted to the reference water surface elevation, negative depths representing height above the reference elevation sometimes resulted for surveys conducted in very high water. These negative depths represent nearshore or terrestrial areas.

Errors in both geographical position and water depth can occur during data collection. Positional errors generally occur due to loss of suitable communication with remote transponders or satellites. Errors in depth soundings occur when interference by something in the water column (i.e., fish, turbulence) causes a return signal or loss of signal prior to the signal reaching the river bottom. Errors are detected by plotting the positions or depths in 2-D (Figure 5).

Data collected with the Ross system were edited with the Ross editing software (Ross Laboratories 1988) by altering positions or depths of errant data. Position data were edited by either using a smoothing function or altering x- and y-coordinates. A smoothing function efficiently corrects “spiked” position errors without manually altering x- and y-coordinates. However, the smoothing function was used only on lines where observed errors could be corrected without altering positions of other data points along the line. Errant depths were detected by a screening process that identifies large changes in depths at adjacent positions. These depths were changed if the chart recordings verified that the depth was truly an error. No records were deleted while editing using the Ross software.

The Innerspace and Hypack data were edited in a GIS using a menu-driven program written in Arc Macro Language (AML) for Arc/Info (Environmental Systems Research Institute, Inc. (ESRI) 1991a). In contrast to the Ross editing package, the GIS editing program allows only deletion of errant records, and no smoothing of the position data is performed. Using the Arcedit module of Arc/Info (ESRI 1991b), the depths are displayed as illustrated in Figure 5. Errant depths are identified by visual observation and confirmed by comparison with the chart recording. Those depths in error are selected and deleted. Similarly, positions are plotted and errant positions are selected and deleted.

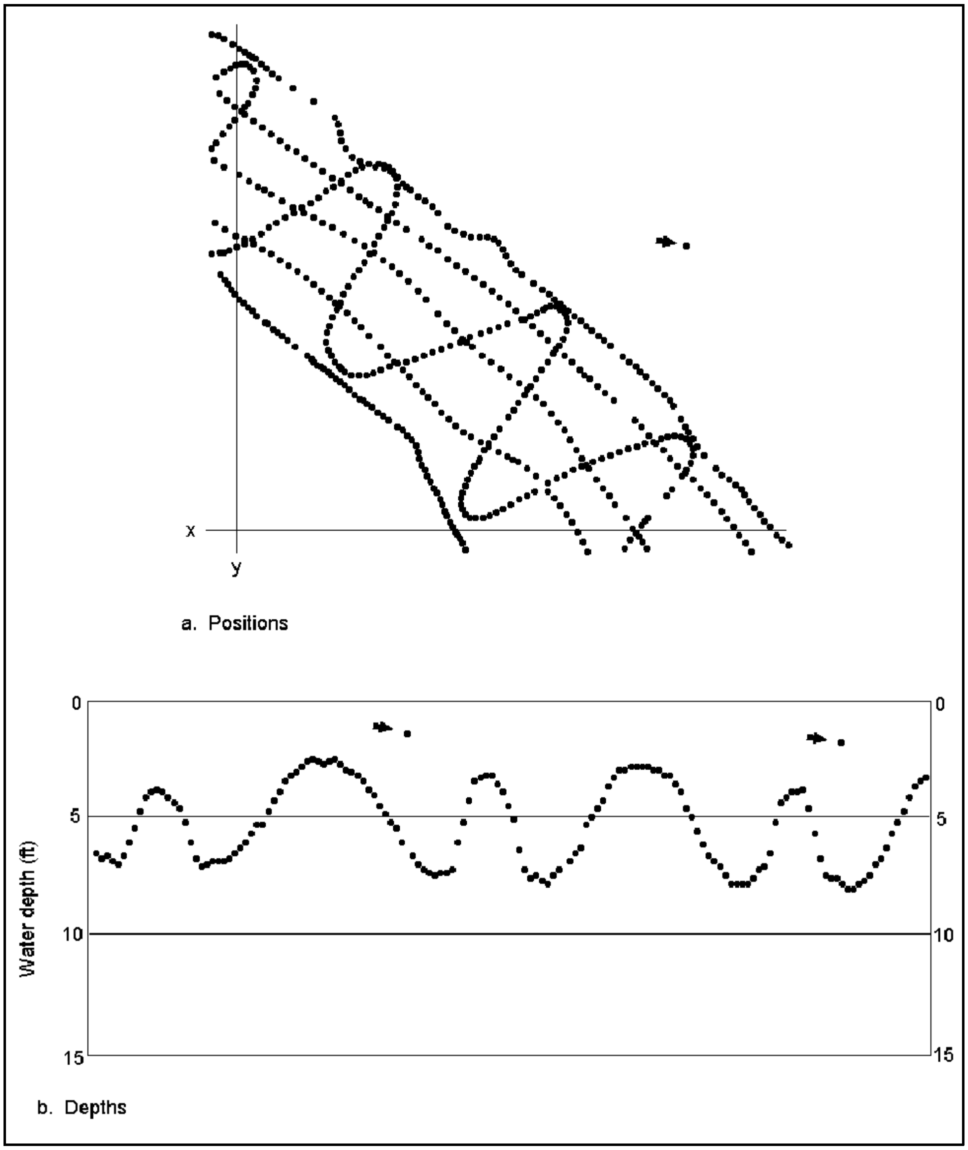

Figure 5. Plots of data used to edit errors in positions and depths. Arrows identify points to be edited

GIS Database Generation

Both the poolwide coverage and the systemic transect data were transformed from the various data types to a GIS coverage in Arc/Info. For the systemic transects, which were collected only with an automated system, the method was simply to output the automated survey system data into an ASCII file containing records of x- and y-coordinates and water depth. A point coverage was generated from an ASCII file after the file was reformatted into the format required by the Arc/Info GENERATE command. The generation of Arc coverages from the files was automated by a menu-driven AML program. The systemic transect data were not altered geographically by editing positions of points to fit existing GIS land cover data; therefore, some points may overlay with land rather than water.

Arc/Info coverages were also generated from ASCII files for some data types used to generate a poolwide coverage. The automated system data and the spot elevation survey data were converted to Arc point coverages. Points in these coverages were compared to the GIS coverage of land/water and positions altered to assure that water depths occurred in aquatic areas. The shoreline data were obtained from an existing Arc polygon coverage of photo-interpreted land cover types by grouping aquatic and terrestrial land cover types. Water depth of the shoreline was determined by interpolating between USACE gauge readings on the date of the photography as described previously. The shoreline arcs were split at each river mile, and the interpolated shoreline depth for each river mile was assigned to the arcs. The photography was collected in low-water conditions, so the interpolated shoreline depths were near flat pool condition and therefore nearly linear. This minimized the potential for error as a result of linear interpolation of the water surface elevation.

The contours drawn from hydrographic chart recordings were digitized directly to create Arc/Info line coverages and attributed with the contour water depth. Base maps of shorelines at a scale of 1:4,800 or larger were created for survey areas. The transect location was transcribed from the aerial photo to base maps. Distances of the nearshore portion of each transect that was not surveyed were scaled off, leaving the remaining distance across the transect equaling the distance of the chart recording. The depths that were used to draw contours on the chart recording were then marked, and their location plotted on the base map by scaling the distance across the transect. Contours were drawn on the base map on the basis of depth locations plotted along the transects. Contours were digitized and georeferenced using identifiable locations on the shoreline for which coordinates were acquired from the GIS shoreline coverage. Adjusting contour depths to the reference water surface elevation was done either prior to or after drawing contours.

A triangulated irregular network (TIN) was used to generate an initial surface of water depth. The TIN is a set of adjacent, nonoverlapping triangles created using Delauney triangulation between the data points (ESRI 1991c). Data points from the automated system surveys and spot elevation surveys were used along with data points for vertices of the contour and shoreline arcs. All data were projected into a common projection of Universal Transverse Mercator Zone 15. Vertices along the arcs were placed at an interval of between 5 and 10 m to increase the number of data points the contours provided to the surfacing procedure. Some reduction of data was done by setting a minimum proximity between data points to 1 m. A TIN was created, and then a raster coverage was interpolated for 2-D viewing.

The raster coverage was displayed and examined for problem areas. The problems were generally associated with the insufficiently dense data to maintain slopes, such as in submerged channels and nearshore areas. To maintain the correct slope, break lines were added to the problem areas

(Figure 6). Break line data were generated from an AML program written to interpolate values for regularly spaced points along lines based on the data that intersected the lines (Figure 7). The lines were added as arcs traversing the problem areas. The break line points of water depth were included in the creation of a TIN, along with the four types of data described previously. A new TIN and raster coverage were created for review and additional break lines added, if needed. This process was repeated until no obvious problem areas were found in the raster coverage.

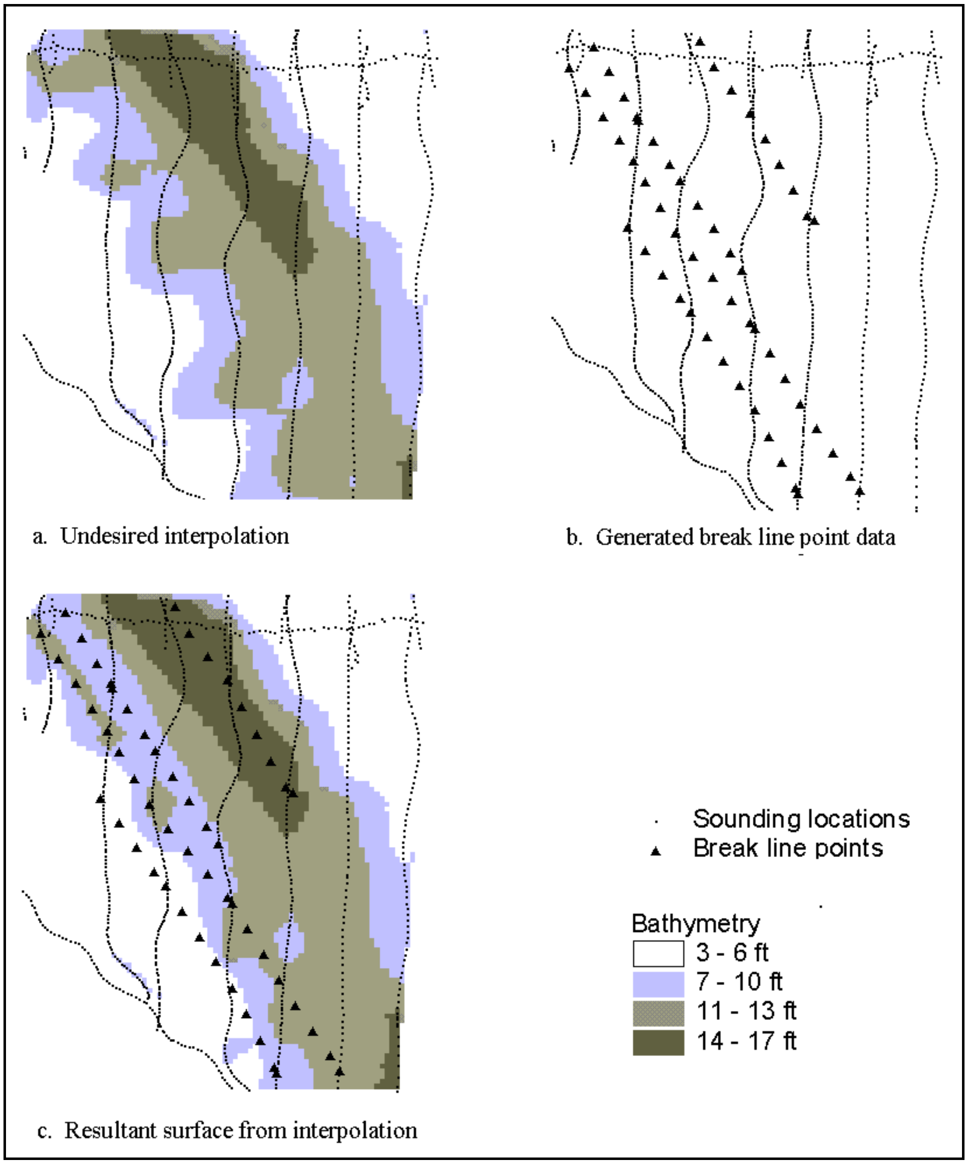

Figure 6. Example of the undesirable interpolation, break line point data generated to maintain the channel slope, and resultant surface from interpolation with the break line data added

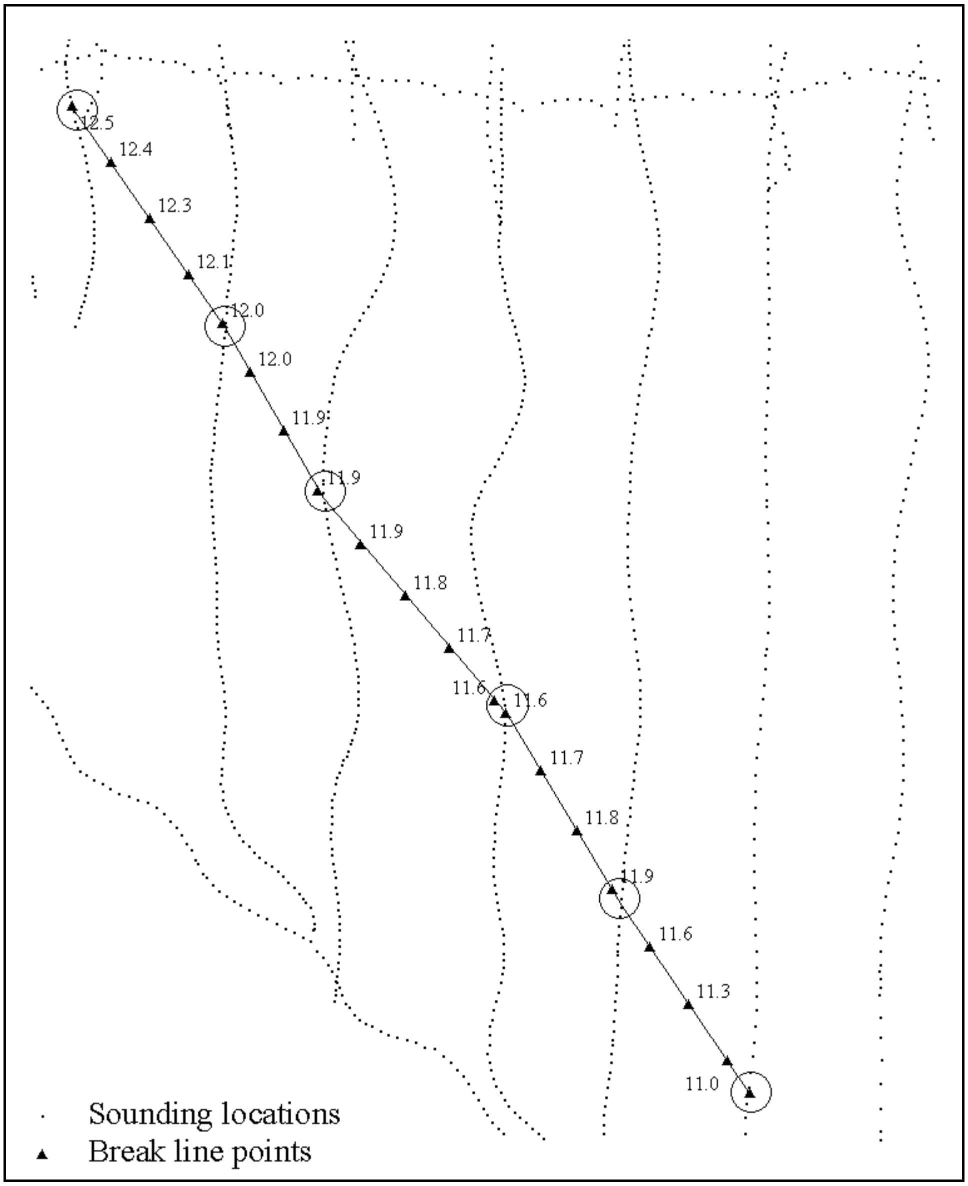

Figure 7. Example of values interpolated along a break line based on the depth values that intersect the line (circled)

The interpolation of an Arc/Info GRID raster coverage from the TIN surface included several processes. First, a lattice of points was generated by linear interpolation between the nodes of the TIN surface. The depth values in the resultant lattice contained more significant figures than the collected data could justify. Therefore, the vertical resolution of the lattice was reduced to better match the significant places beyond the decimal place of the recorded depths. A unit of centimeters was selected for depth because it adds one place to the tenths of feet collected during surveys. In the process of reduction, the lattice was converted to an integer GRID coverage, which is a more efficient method of data storage. Because the GRID coverage included data extrapolated in areas beyond the actual data, the spatial coverage of the GRID coverage was reduced by using a land/water grid to eliminate elevation data in nonaquatic areas. In addition, data were insufficient for reasonable interpolation of depths in some aquatic areas. Values in the bathymetry grid were replaced in these areas with a unique value to represent the unreliable interpolated values.

A related GRID coverage was generated by filling cells of a GRID coverage where actual data were located. The cells were filled with values representing the source of data (e.g., automated surveys, break lines) used in the TIN. This coverage can be used to assess the spatial density of data used to generate the bathymetric GRID coverage. Errors in the interpolated values can be generally assessed by evaluating the gaps between data and the heterogeneity of the depths of adjacent data points.

The data in the final grid coverage included items with depth expressed in meters and feet below flat pool elevation. These data can be transformed into feet above mean sea level by subtracting the water depth from the flat pool elevation. Flat pool elevations for each pool were reported previously in the "Data Editing" section of this chapter.

3 Sediment Characterization

Data Collection Strategy

Sediment data were needed at a high resolution for selected areas in which sediment transport modeling was conducted and at a lower resolution for the systemic analysis of navigation impacts. Within the selected areas for sediment transport modeling, modelers selected locations based on the model needs. All of these sediments were analyzed in detail for particle size distribution.

The systemic sampling was conducted along transects spaced at 8-km (5-mile) intervals in the study reach of the UMRS. The study reach was from Pool 3 to Pool 26 on the Upper Mississippi River and Brandon Road Pool to Alton Pool on the Illinois Waterway. Along each transect, sampling locations were selected laterally as follows: (a) in the center of the navigation channel, (b) at the location of 1.0 m at low-water conditions on both sides of the channel, (c) at the location halfway between the 1.0-m location and the shoreline on both sides of the channel, (d) at both shorelines at low-water conditions, and (e) at a terrestrial site 0.5 m above low-water conditions on both shores. Samples at the terrestrial location and the location halfway between the 1.0-m depth and the shoreline were not taken if the locations were within 10 m of other sampling sites. A maximum of nine locations and a minimum of five locations were sampled along each transect.

Although a sample of the sediment was retained at all systemic sampling locations, only sediments for every other transect (16-km (10-mile) intervals) were sent to the laboratory for analysis. All samples were classified by visual/tactile techniques in the field. The visual classification was to be used to extrapolate to the transects for which no laboratory analysis on the sediments was performed. The classification system included estimates of the dominant particle size for samples containing all sediments larger than silt (>63 µm). Those samples containing particles of size less than fine sand (<63 µm) were classified by both dominant and subdominant particle size. All sediments less than 63 µm were grouped into a silt/clay class because distinguishing between silt and clay was not possible using the visual/tactile techniques.

Sediments containing silt/clay were also classified into consolidated or unconsolidated sediments. This distinction was included because the systemic sampling was to be used for sediment resuspension predictions, and both particle size and cohesive properties determine the potential for resuspension of fine sediments. Several of the sites with consolidated cohesive sediments were selected for obtaining large amounts of sediments for laboratory testing of the potential for resuspension.

Sediment Collection

For the systemic transects, surficial sediment (top 10 cm) was obtained with a Wildco KB Sediment Core Sampler (Wildco Wildlife Supply Company) containing a plastic core liner (with approximate 5-cm inside diameter and 50-cm length) at the nearshore sites. A 23- × 23-cm (0.052-m^2) standard Ponar grab sampler (Wildlife Supply Company) was used to obtain sediment in the navigation channel. Nearshore sites were found based on the depth criteria described previously. This required obtaining an estimate of the water surface elevation by interpolating between elevation gauging stations prior to field sampling. The difference in the estimated water surface elevation on the day of the survey and the low-water condition of flat pool elevation in Table 1 was used to adjust water depths on the day of the survey. The sediments obtained were homogenized by mixing thoroughly. The sediment was subjectively classified by visual/tactile techniques into classes as previously described and listed in detail in Table 2.

Table 2
Classes used for Visual/Tactile Classification

Class	Description
1	Consolidated silt and clay
2	Predominantly consolidated silt and clay with some sand
3	Predominantly sand with some consolidated silt and clay
4	Silt and clay
5	Predominantly silt and clay with some sand
6	Predominantly sand with some silt and clay
7	Predominantly fine sand
8	Predominantly medium sand
9	Predominantly coarse sand
10	Predominantly gravel
11	Predominantly boulder
12	No sample obtained

A sample of the homogenized sediment from each sampling location was placed in a 0.5-L (16-oz) bag. The vertical depth of sediment sent for laboratory analysis differed for the nearshore sites (10 cm) and main channel sites (depth of sediment depended on the depth of the Ponar grab). Sediment from every other transect was sent to the laboratory for analysis and the remaining sediment retained for analysis in the future, if needed. Geographical coordinates were obtained with a real-time differential GPS unit for all sampling locations. A GIS coverage of the sampling locations was generated from the coordinates obtained and attributed with sediment characteristics.

Laboratory Analysis

All laboratory analyses performed by the U.S. Army Engineer Waterways Experiment Station (WES) were completed using modifications to published methodologies. Moisture content and bulk density were determined using gravimetric methods; organic content was determined as the loss of sediment mass on combustion at 550 °C; and particle size distribution for most samples was determined by hydrometer methods. Detailed procedures, including references, for analytical methods used by WES are included in Appendix B.

More detailed particle size analysis on some samples was performed by the St. Louis District using ASTM methods. Standards used include the following:

a. ASTM C117-95 (ASTM 1995)

b. ASTM C136-96a (ASTM 1996)

c. ASTM D422-63(R1998) (ASTM 1963b)

d. ASTM D2487-93 (ASTM 1993a).

The standard procedure ASTM C136-96a was used on the entire sample for about half the samples. The standard procedure ASTM C117-95 was used on the other samples based on the visual observation of the amount of sediment passing through a No. 230 sieve. The gradation of the sediment retained on the No. 230 sieve after washing was then determined by the ASTM C136-96a procedure. The exception was the use of the ASTM D422-63(R1998) procedure for a few samples. When the ASTM D422-63(R1998) procedure was used, the materials retained by a No. 10 sieve were sieved using the ASTM C136-96a procedure and included in the hydrometer results.

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Appendix A
Components of Long Term Resource Monitoring Program (LTRMP) Hydrographic Survey Systems

Dolfin Survey System by Ross Laboratories, Seattle, WA

Ross Laboratories Survey system: Model 5001 recorder, Model 4401 transceiver, Model 6801 digitizer, 200-kHz 3.5-deg transducer, steering indicator

Del Norte 542 Trisponder System: Model 542 digital distance measuring unit, Model 217E master transmitter/receiver with 360 × 19 antenna, Model 217E remote transmitter/receiver with 110 × 7 antenna(4)

HP9000 Model 520 computer

Ross Dolfin System software

Portable Hydrographic Survey System by Innerspace Technology, Inc., Waldwick, NJ

Model 448 Thermal Depth Sounder Recorder with 208-kHz 3-deg transducer, Model 603 Remote Indicator

Model 610 REF Motorola 620 System Interface GPS Receiver with Starlink MRB-2A MSK beacon receiver

486DX computer with EGA display

ITI Field/Office software

Hypack Survey System by Coastal Oceanographics, Middlefield, CT

Model 448 Thermal Depth Sounder Recorder with 208-kHz 3-deg transducer
Starlink DNAV-212G/MBA-2 – 1-m 2DRMS accuracy integrated 12-channel DGPS and 2-channel automatic MSK beacon receiver
Dell Latitude LM M166MMX Notebook with Windows 95
Hypack Lite Hydrographic Survey Software

Appendix B
Methods for Laboratory Analysis of Sediments

Methods for Sediment Physical Analyses (Moisture Content, Bulk Density, and Organic Content

Moisture Content Method: Gravimetric - weight loss on drying at 103-105 °C

Bulk Density Method: Gravimetric - determination of ratio of sediment mass to known volume

Reference: S. E. Allen et al. (1974). *Chemical analysis of ecological materials.* Wiley, New York, 21–22.

Equipment:

a. Analytical balance

b. Air-circulation oven

c. Disposable aluminum weighing dishes

d. Desiccator

Moisture Content/Bulk Density Procedure:

a. Weigh to nearest 0.001 g (1 mg) disposable aluminum weighing dish of known volume, record weight on analysis data form, and label dish vis-a-vis sample. Prepare three replicates of each sediment sample (when sufficient amounts of sediment are available).

b. Homogenize fresh sediment and completely fill weighing dish. Exercise care to exclude all air from sediment by making small additions of sediment while agitating the weighing dish. This can be accomplished by rapping weighing dish on countertop. Note: Be careful not to cause a change in the volume of the dish by denting or bending it.

c. Screed excess sediment from weighing dish to ensure that sediment equals known volume of dish.

d. Weigh sediment and dish to nearest 0.001 g, record weight on analysis data form.

e. Place sediment/dish in the air-circulation oven, set temperature to 105 °C, and dry for at least 24 hours. Note: If oven is being used for drying other type samples, e.g., plant tissues, and temperature setting is 80 °C, dry sediment for at least 24 hours at 80 °C, then transfer samples to muffle furnace set at 105 °C and dry for an additional 24 hours.

f. Remove from oven and place in desiccator, allow to cool to ambient temperature (constant weight is achieved when successive weighings do not differ more than 1 or 2 mg).

g. Weigh and record weight on analysis data form.

Calculations:

$$\text{Moisture content (\%)} = [\text{sediment weight loss (g)} \times 100]/\text{sediment wet weight (g)} \qquad \text{(B1)}$$

where

a. Sediment wet weight = (weight of fresh sediment = weight of dish) - weight of dish

b. Sediment dry weight = (weight of sediment after drying = weight of dish) - weight of dish

c. Loss in weight on drying = sediment wet weight - sediment dry weight

$$\text{Bulk density} = \text{sediment dry weight (g)/volume of aluminum dish} \qquad \text{(B2)}$$

Loss-On-Ignition Methods: Loss of sediment mass on combustion at 550 °C

References:

a. Modification of S. E. Allen et al. (1974). *Chemical analysis of ecological materials*. Wiley, New York, 22–23.

b. Modification of R. H. Plumb, Jr. (1981). "Procedures for handling and chemical analysis of sediment and water samples," Technical Report EPA/CE 81-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 3–59, 60.

Equipment:

a. Analytical balance

b. Muffle furnace for operation at 550 °C

c. Porcelain crucibles

d. Soil grinding mill

e. Desiccator

Loss-on-Ignition Procedure:

a. Combust empty porcelain crucibles in muffle furnace at 550 °C for 1 hour.

b. Place crucibles, after partial cooling, into desiccator until constant weight is achieved.

c. Weigh to nearest 0.001 g and record.

d. Grind sediment used in moisture content analysis to a fine powder using either mortar and pestle or soil mill.

e. Weigh about 1 g of ground sediment to nearest 0.001 g (1 mg) in each porcelain crucible and record total weight (weight of sediment + crucible).

f. Place crucibles containing sediment (uncovered) into muffle furnace. NOTE: DO NOT PREHEAT MUFFLE FURNACE.

g. Set temperature to 550 °C, power up furnace, and allow temperature to rise slowly while combusting samples for 24 hours.

h. CAREFULLY remove crucibles from furnace (DO NOT ALLOW ASH TO BE BLOWN FROM CRUCIBLES DURING HANDLING) and place in desiccator after partial cooling.

i. Allow crucibles to cool to constant weight, weigh, and record.

Calculations:

$$\text{Loss-on-Ignition (\%)} = (\text{sediment weight loss (g)} \times 100)/\text{sediment dry weight (g)} \qquad \text{(B3)}$$

where

a. Sediment weight loss = sediment dry weight (prior to combustion) - sediment dry weight (following combustion)

b. Sediment dry weight = (ground sediment weight = crucible weight) - crucible weight

Particle Size Distribution Analysis (Sand, Silt, and Clay)

Method: Hydrometer

References:

a. William H. Patrick, Jr. (1958). "Modification of method of particle size analysis." *Proceedings - Soil Science Society of America.* 22:366-367.

b. Paul R. Day. (1956). "Report of the Committee on Physical Analyses (1954-1955)." *Proceedings - Soil Science Society of America.* 20:167-169.

Equipment and Materials:

a. ASTM D152H standard hydrometer with Bouyoucos scale in grams per liter

b. Glass sedimentation cylinders with sufficient diameter so that the 1000-mL mark is 36 ±2 cm from the bottom on the inside

c. Rubber stoppers to cover sedimentation cylinders

d. Thermometers, -20 to 50 °C, immersion type

e. Electrically driven mixer

f. Timer with cumulative seconds counter

Reagents:

a. Calgon dispersing agent (10 percent solution): Add about 500 mL distilled water to a 1000-mL beaker and place on stirrer-hot plate. Heat on low until warm, add 100 grams of sodium metaphosphate, and stir to dissolve completely. Remove from heat, allow to cool, then while stirring adjust the pH of the solution to 8.3 with the addition of sodium carbonate solid. Transfer to 1-L volumetric flask and add distilled water to the mark.

b. Amyl alcohol (syn. 3-methyl 2-butanol)

Preparation of Blank Solution/s:

a. Add 50 mL of 10 percent "Calgon" solution to a sedimentation cylinder and make up to 1000-mL mark with distilled water.

b. Stopper and invert several times to mix.

c. Allow to stand overnight to reach ambient temperature (between 20-30 °C).

Preparation of Sample Suspension/s:

a. Weigh out 40.0 grams dry weight equivalent of fresh wet sediment. (Dry weight equivalent can be calculated following the determination of sample percent moisture content (Equation B1).) Record on data sheet in "Wt of Sediment Used (g)."

b. Place sample in a 250-mL beaker and add 50 mL of 10 percent "Calgon" dispersing solution. Mix gently with glass rod and let stand for at least 10 minutes.

c. Transfer to dispersing cup (blender/mixer cup). Sparingly use distilled water from a wash bottle to remove all sediment from beaker.

d. Mix for exactly 5 minutes in a Waring Lab Mixer.

e. Transfer to labeled sedimentation cylinder using distilled water from a wash bottle to remove all sediment from mixer cup.

f. Make up to 1000-mL mark with distilled water, stopper, and allow to stand overnight to reach ambient temperature.

g. Put a piece of tape on the counter by each cylinder for recording the times associated with the analysis on the following day.

h. Let sit overnight to ensure that the solutions in each cylinder are the same temperature.

Calibration of Hydrometer/s (Blank Solution/s):

a. Remove stoppers from the sedimentation cylinder and measure temperature of the blank solution.

b. Carefully lower the hydrometer into the blank solution and determine the scale reading R_L at the upper edge of the meniscus surrounding the stem. All meniscus readings should be made at the upper edge because the bottom of the meniscus will not be evident when examining those samples containing sediment. The position of the meniscus can be determined by viewing it from an angle of 10 to 20 deg above the plane of the liquid.

c. Record on data sheet in "Morning Blank Reading" column.

Determination of 50µ Separation:

a. With a rubber stopper in place on sedimentation cylinder, invert cylinder 10 times to mix thoroughly. After inverting first time, shake cylinder to loosen sediment attached to the bottom.

b. After mixing, return cylinder to upright position on laboratory counter and immediately start timer (counting up).

c. If surface of suspension is covered with foam, add one (1) drop of amyl alcohol to suspension.

d. Carefully lower hydrometer into suspension and read the scale (at the top of the meniscus) at 35 seconds elapsed time.

e. Using Table B1, determine the time corresponding to the measured *R* value and suspension temperature (the nearest whole degree) and make final reading of hydrometer scale at the time indicated. For example:
(1) Suspension temperature = 24 °C
(2) *R* value at 35 seconds = 27
(3) Therefore cumulative time to final reading = 48 seconds

f. Record the final *R* value for the 50µ separation on bench data sheet in "Morning Reading" column.

g. Replace stopper on cylinder, write down the actual time of day on the tape next to each cylinder, and do not further disturb. Any disturbance of cylinders will result in having to remix the suspension and start the process over for the 50µ and 2µ separations.

Determination of 2µ Separation:

a. After 7-8 hours elapsed time, remove the stopper from the blank suspension. Measure the temperature. Carefully place the hydrometer in the suspension, and read the scale at the top of the meniscus.

b. Using Table B2, determine the time corresponding to the measured *R* value and suspension temperature (the nearest whole degree). For example:
(1) Suspension temperature = 24 °C
(2) *R* value at about 6 hours = 19
(3) Therefore cumulative time to final reading = 9 hours and 20 minutes

c. Make final reading of hydrometer scale at the time indicated. Record final *R* value for the 2µ separation on bench data sheet in the "Evening Reading" column.

Table B1
Sedimentation Time for 50μ Separation

	Cumulative Time, sec, to Final Reading for Temperature, °C										
R	20	21	22	23	24	25	26	27	28	29	30
56	32	31	30	30	29	28	28	27	27	26	26
55	32	32	31	30	30	29	28	28	27	27	27
54	33	32	32	31	30	30	29	29	28	28	27
53	34	33	32	32	31	30	30	29	29	28	28
52	35	34	33	32	32	31	30	30	29	29	28
51	35	34	34	33	32	32	31	30	30	29	29
50	36	35	34	34	33	32	31	31	30	30	29
49	37	36	35	34	33	33	32	31	31	30	30
48	37	37	36	35	34	33	33	32	31	31	30
47	38	37	36	36	35	34	33	33	32	32	31
46	39	38	37	36	35	35	34	33	33	32	32
45	40	39	38	37	36	35	35	34	33	33	32
44	40	39	38	38	37	36	35	35	34	33	33
43	41	40	39	38	37	37	36	35	34	34	33
42	42	41	40	39	38	37	36	36	35	34	34
41	43	42	41	40	39	38	37	36	36	35	34
40	43	42	41	40	39	39	38	37	36	35	35
39	44	43	42	41	40	39	38	38	37	36	35
38	45	44	43	42	41	40	39	38	37	37	36
37	46	44	43	42	41	40	40	39	38	37	37
36	46	45	44	43	42	41	40	39	39	38	37
35	47	46	45	44	43	42	41	40	39	38	38
34	48	47	45	44	43	42	41	41	40	39	38
33	48	47	46	45	44	43	42	41	40	40	39
32	49	48	47	46	45	44	43	42	41	40	39
31	50	49	48	46	45	44	43	42	42	41	40
30	51	49	48	47	46	45	44	43	42	41	40
29	51	50	49	48	47	46	45	44	43	42	41
28	52	51	50	49	47	46	45	44	43	42	42
27	53	52	50	49	48	47	46	45	44	43	42
26	54	52	51	50	49	48	47	46	45	44	43
25	54	53	52	51	49	48	47	46	45	44	43
24	55	54	53	51	50	49	48	47	46	45	44
23	56	55	53	52	51	50	49	47	46	45	44
22	57	55	54	53	51	50	49	48	47	46	45
21	57	56	55	53	52	51	50	49	48	47	46
20	58	57	55	54	53	52	50	49	48	47	46
19	59	58	56	55	54	52	51	50	49	48	47
18	60	58	57	56	54	53	52	51	49	48	47
17	60	59	58	56	55	54	52	51	50	49	48
16	61	60	58	57	56	54	53	52	51	50	48

Table B2
Sedimentation Time for 2μ Separation

R	Cumulative Time, hr:min, to Final Reading for Temperature, °C												
	20	21	22	23	24	25	26	27	28	29	30	31	32
45	6:50	6:40	6:30	6:20	6:10	6:05	5:55	5:45	5:40	5:30	5:25	5:20	5:15
44	6:55	6:45	6:35	6:25	6:20	6:10	6:00	5:55	5:45	5:40	5:30	5:25	5:20
43	7:05	6:55	6:45	6:35	6:25	6:15	6:10	6:00	5:55	5:45	5:40	5:30	5:25
42	7:15	7:00	6:50	6:40	6:35	6:25	6:15	6:05	6:00	5:50	5:45	5:40	5:30
41	7:20	7:10	7:00	6:50	6:40	6:30	6:20	6:15	6:05	6:00	5:50	5:45	5:40
40	7:30	7:20	7:05	6:55	6:45	6:40	6:30	6:20	6:15	6:05	5:55	5:50	5:45
39	7:35	7:25	7:15	7:05	6:55	6:45	6:35	6:25	6:20	6:10	6:05	5:55	5:50
38	7:45	7:35	7:20	7:10	7:00	6:50	6:45	6:35	6:25	6:20	6:10	6:05	5:55
37	7:50	7:40	7:30	7:20	7:10	7:00	6:50	6:40	6:30	6:25	6:15	6:10	6:00
36	8:00	7:50	7:40	7:25	7:15	7:05	6:55	6:50	6:40	6:30	6:25	6:15	6:10
35	8:10	7:55	7:45	7:35	7:25	7:15	7:05	6:55	6:45	6:35	6:30	6:20	6:15
34	8:15	8:05	7:55	7:40	7:30	7:20	7:10	7:00	6:50	6:45	6:35	6:25	6:20
33	8:25	8:10	8:00	7:50	7:40	7:30	7:20	7:10	7:00	6:50	6:40	6:35	6:25
32	8:30	8:20	8:10	7:55	7:45	7:35	7:25	7:15	7:05	6:55	6:50	6:40	6:30
31	8:40	8:25	8:15	8:05	7:55	7:40	7:30	7:20	7:10	7:05	6:55	6:45	6:40
30	8:45	8:35	8:25	8:10	8:00	7:50	7:40	7:30	7:20	7:10	7:00	6:50	6:45
29	8:55	8:40	8:30	8:20	8:05	7:55	7:45	7:35	7:25	7:15	7:05	7:00	6:50
28	9:05	8:50	8:40	8:25	8:15	8:05	7:50	7:40	7:30	7:20	7:15	7:05	6:55
27	9:10	9:00	8:45	8:35	8:20	8:10	8:00	7:50	7:40	7:30	7:20	7:10	7:00
26	9:20	9:05	8:55	8:40	8:30	8:15	8:05	7:55	7:45	7:35	7:25	7:15	7:10
25	9:25	9:15	9:00	8:50	8:35	8:25	8:15	8:00	7:50	7:40	7:30	7:20	7:15
24	9:35	9:20	9:10	8:55	8:45	8:30	8:20	8:10	8:00	7:50	7:40	7:30	7:20
23	9:40	9:30	9:15	9:00	8:50	8:40	8:25	8:15	8:05	7:55	7:45	7:35	7:25
22	9:50	9:35	9:20	9:10	8:55	8:45	8:35	8:20	8:10	8:00	7:50	7:40	7:30
21	9:55	9:45	9:30	9:15	9:05	8:50	8:40	8:30	8:20	8:05	7:55	7:45	7:35
20	10:05	9:50	9:35	9:25	9:10	9:00	8:45	8:35	8:25	8:15	8:05	7:55	7:45
19	10:10	10:00	9:45	9:30	9:20	9:05	8:55	8:40	8:30	8:20	8:10	8:00	7:50
18	10:20	10:05	9:50	9:40	9:25	9:15	9:00	8:50	8:35	8:25	8:15	8:05	7:55
17	10:30	10:15	10:00	9:45	9:35	9:20	9:05	8:55	8:45	8:30	8:20	8:10	8:00
16	10:35	10:20	10:05	9:55	9:40	9:25	9:15	9:00	8:50	8:40	8:30	8:15	8:05
15	10:45	10:30	10:15	10:00	9:45	9:35	9:20	9:10	8:55	8:45	8:35	8:25	8:15
14	10:50	10:35	10:20	10:10	9:55	9:40	9:30	9:15	9:05	8:50	8:40	8:30	8:20
13	11:00	10:45	10:30	10:15	10:00	9:50	9:35	9:20	9:10	9:00	8:45	8:35	8:25
12	11:05	10:50	10:35	10:20	10:10	9:55	9:40	9:30	9:15	9:05	8:50	8:40	8:30
11	11:15	11:00	10:45	10:30	10:15	10:00	9:50	9:35	9:20	9:10	9:00	8:45	8:35
10	11:20	11:05	10:50	10:35	10:20	10:10	9:55	9:40	9:30	9:15	9:05	8:55	8:40
9	11:30	11:15	11:00	10:45	10:30	10:15	10:00	9:50	9:35	9:25	9:10	9:00	8:50
8	11:35	11:20	11:05	10:50	10:35	10:20	10:10	9:55	9:40	9:30	9:15	9:05	8:55
7	11:45	11:30	11:15	11:00	10:45	10:30	10:15	10:00	9:50	9:35	9:25	9:10	9:00
6	11:50	11:35	11:20	11:05	10:50	10:35	10:20	10:10	9:55	9:40	9:30	9:15	9:05

Destroy this report when no longer needed. Do not return it to the originator.