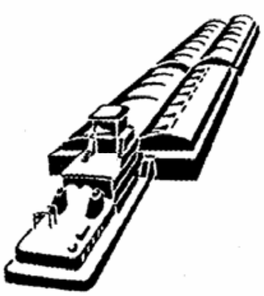
ENV Report 42

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

Upper Mississippi River – Illinois Waterway System Models Report — Physical Effects Models



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Rock Island District
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Upper Mississippi River – Illinois Waterway System Models Report — Physical Effects Models

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Interim report

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ABSTRACT: The Upper Mississippi River – Illinois Waterway (UMR_IWW).system model is comprised of the NAVEFF and NAVSED models and determines the physical forces for the entire UMR-IWW reach as well as the fleet of tows using the waterway. This report documents the geographical information system components of the system models, input and output files formats, and assumptions used in the application of the models to the UMR-IWW. The NAVEFF portion of the system model determines the maximum velocity change, tow drawdown of water level, wave height, bed scour, and bed shear stress. Many of these physical parameters provided input to various ecological models used in the System Feasibility study. NAVEFF output is also input to the NAVSED model that provides the time-history of sediment concentration as a result of tow passage. The NAVSED output also serves as input to various ecological models as well as sedimentation of secondary channels and backwaters.

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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 that will continue to grow in the future. The Navigation Study scope is to examine the feasibility of navigation improvements to the UMR-IWW system 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 study was conducted in the Coastal and Hydraulics Laboratory (CHL) and Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, and the U.S. Army Engineer District, Rock Island (CEMVR). The work was conducted under the direction of Mr. Thomas A. Richardson, Director, CHL, and Dr. Beth Fleming, Acting Director, EL. This report was written by Drs. Stephen T. Maynord and Sandra K. Knight, CHL, ERDC; Messrs. Scott Bourne and Mark R. Graves, EL, ERDC; and Mr. Kevin Landwehr, CEMVR.

Commander and Executive Director of ERDC was COL James R. Rowan. Director was Dr. James R. Houston.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	25.4	millimeters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Commercial navigation traffic is increasing on the Upper Mississippi River – Illinois Waterway (UMR-IWW), and in consideration of existing system lock constraints, will result in traffic delays that will continue to grow in the future. The UMR-IWW System Navigation Study evaluated the feasibility of navigation improvements to reduce delays to commercial navigation traffic. Navigation improvements are expected to increase frequency of tow passage. Increased traffic subjects a variety of organisms using the waterway to an increased frequency of potentially damaging physical forces caused by the traffic. Because of the large variation of channel conditions throughout the UMR-IWW, the large number and variability of tow configurations, and the need to address a range of flows and stages, a system model was developed to determine the physical forces generated by tow traffic under the varied conditions. The physical forces system model was primarily used to provide input to ecological models that evaluated the system-wide impacts of navigation capacity increases on fish, mussels, and other macro invertebrates, and aquatic macrophytes. The physical forces system model also provided input to address the potential for commercial traffic to increase sedimentation of secondary channels and backwaters.

To facilitate analysis of the UMR-IWW system, trend pools were selected that were representative of different reaches of the river. On the UMR, trend pools were 4, 8, 13, and 26. On the IWW, Lagrange was the trend pool. The selection of the trend pools was based on their having been used for detailed study in the Environment Management Program (EMP) that began in the 1980's. The Upper Mississippi River Management Act of 1986 (PL 99-662) authorized the EMP to monitor the natural resources of the river. These pools had a significant amount of historical data that was not available on other pools.

The analysis of system-wide impacts begins with the Navigation Effects (NAVEFF) model, which defines the physical forces created by the tow. NAVEFF is run at each cross-section in the pool for 108 different tow combinations, three river stages, and three sailing line locations. Output from NAVEFF includes maximum velocity change, maximum drawdown, maximum wave height, maximum bed scour, and maximum bed shear stress. The physical forces from NAVEFF are input into the Navigation Sedimentation (NAVSED) model, which provides a time-history of sediment concentration for each cell, 108 tow combinations, three stages, and three sailing lines. NAVSED output along with NAVEFF output are primary inputs to the ecological models and the models for sedimentation of secondary channels and backwaters. The staggering amounts of output from NAVEFF and NAVSED were summarized by determining the probability of exceedance of the parameter of interest. The objective of this report is to provide information to document the NAVEFF and NAVSED models, their input and output, and the various assumptions and decisions used in applying these models. This report is not intended to be a summary of the results of the UMR-IWW study.

2 Geographical Information System Description Including Bathymetry and Bed Sediment Data Used in System Models

Scientific research and investigation of the UMR-IWW systems have generated a wide variety of environmental data. Numerical modeling output, maps, field measurements, and existing GIS data layers are the types of data used to characterize and understand the UMR-IWW systems. The Navigation Effects GIS database was developed from these different data types using ESRI ArcInfo GIS and mapping software. The objective of developing the UMR-IWW geospatial database was to design a database suitable for numerical and spatial analysis of the UMR-IWW systems. From the beginning of the database design, study team members decided that input files for NAVEFF and some of the biological models would be generated using the GIS. With over 1,000 river miles to be processed, using the GIS was the only efficient and cost-effective way to generate these input files. In addition, the database was also developed to serve as an archive for data collected during the Navigation Effects study. During the mitigation planning and public meeting phases it was vital to illustrate the areas that were subject to potential environmental impacts caused by increased tow traffic. In order to display areas where potential environmental impacts may occur, model output from physical and biological models were attached to the geospatial database. Digital and hardcopy map products were generated displaying these areas.

The GIS database is organized into coverages associated with a single navigation pool that corresponds to a lock and dam on the UMR-IWW system. Also, system layers were developed that cover all or a large portion of the UMR-IWW system. Figure 1 illustrates the lock and dam locations of the UMR-IWW. The GIS database layers developed for the Navigation Effects are discussed below.

Figure 1. Navigation locks and dams on the UMR-IWW

The UMR-IWW database was developed on a UNIX platform using ArcInfo GIS software version 7.0.4. ArcInfo links sets of features and their attributes and manages them together in units called "coverages." Coverages contain a set of related features, such as river miles, hydraulic features, backwaters, and wing dams, along with the attributes for those features. All the coverages for the UMR-IWW geographic area taken together make up the UMR-IWW geospatial database. The database was moved to Windows NT INTEL 4.0 platform and is currently maintained using ArcGIS 8.1.

Hydraulic Classification Data Set

The hydraulic classification data set consists of polygon features that characterize the hydraulic environment for the UMR-IWW systems. The hydraulic features delineation was based on geomorphic features of the main channel, secondary channel, and surrounding backwater environments. To develop the hydraulic classification data set, the 1989 aquatic areas, 1989 land use/land cover, and the Nation Wetland Inventory (NWI) data sets were acquired from the Upper Midwest Environmental Sciences Center (UMESC). The aquatic areas and land cover/land use data sets were developed under the Long Term Resource Monitoring Program. These three data sets were used as base layers to delineate the hydraulic features in each of the pools on the UMR and IWW. Reclassification of polygon features present in these data sets and interactively editing of the data sets produced the final hydraulic classification.

The 1989 aquatic areas data set was used to produce the hydraulic classification for the UMR system pools 4, 5, 5a, 6, 8, 9, 13, 19, 26, a portion of the open river stretch, and Lagrange Pool on the IWW. The 1989 land cover/land use database was used to generate the hydraulic classification for the UMR system pools 7, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 24, and 25. The NWI database was used to generate the hydraulic coverages for the remaining IWW pools. Figure 2 illustrates the hydraulic classification for pool 8.

Backwater Data Set

The backwater data set consists of polygon coverages that characterize backwater locations of the UMR-IWW. Backwater environments were delineated in the Hydraulic Classification coverages by adding a line around the backwater locations, which included limited amounts of terrestrial environments. These coverages contained the outer boundaries of the backwater units, isolated backwaters located within a backwater, and terrestrial areas located within the backwater areas. Figures 3 and 4 are examples of contiguous and single opening backwaters. Within the backwater areas, calculations were made to determine the size of each backwater unit, the water's surface area at flat pool stage, and the ratio of land to water. Attribute values such as the upper and lower Universal Transverse Macerator (UTM) coordinates and the upper and lower river mile extents of each backwater units were collected by displaying the backwater units and reading the information from the screen. Other attribute values measured were length of the backwater unit, width of the backwater unit, number of inlets, number of outlets, number of through channels, number of islands, and whether the backwater unit is located east or west of the main channel.

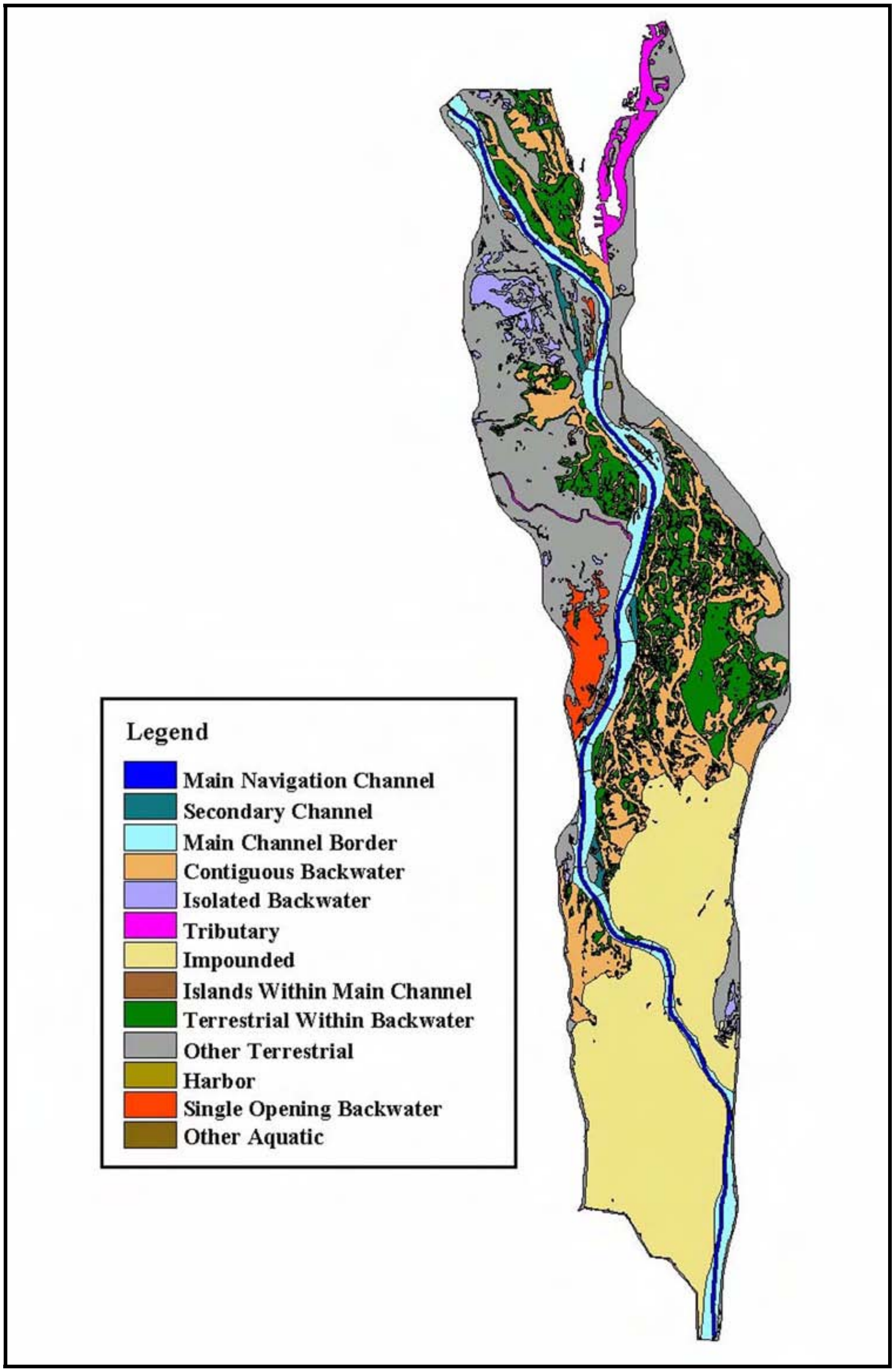

Figure 2. Example of a hydraulic classification used for all the pools on the UMR-IWW

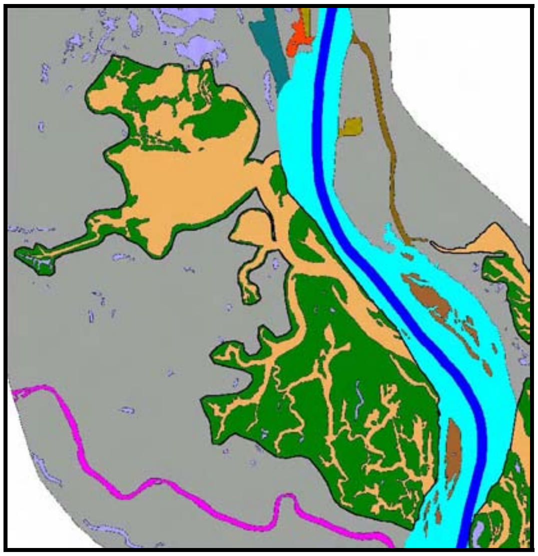

Figure 3. Contiguous backwater

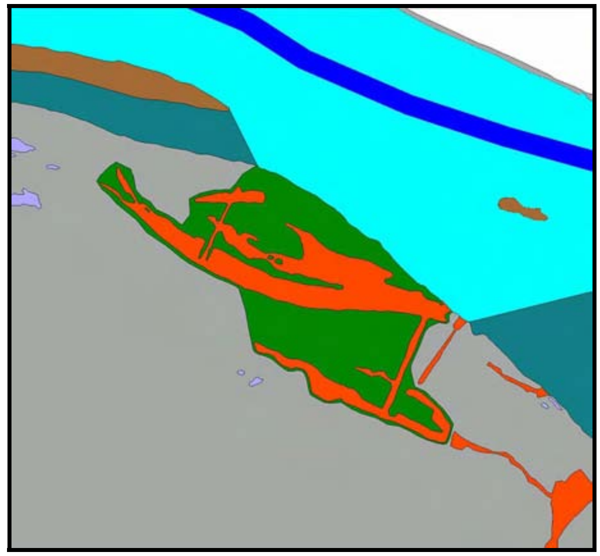

Figure 4. Single backwater

Midpoints Data Set

In trend pools on the UMR, cross-sections were selected every 0.5 river mile. At Lagrange and all of the nontrend pools, cross-sections were selected at every 1.0 river mile. Each cross-section is divided into 10-m-wide cells. Most regions of a cross-section did not require such a detailed resolution of the channel width. The two exceptions were the region near the vessel where the magnitude of physical forces varied significantly with distance and the region near the shoreline where the depth varied significantly with distance.

The midpoints data set consists of a point in each 10-m-wide cell across each cross-section that represents locations within the UMR-IWW at which physical forces were determined. The midpoints are evenly spaced at 10 m across the main channel and main channel borders. The midpoints represent the attributes of the entire 10-m-wide by 0.5- or 1.0-mile-long cell.[1] The lateral extent of the midpoints includes areas outside the main channel border that are inundated during high water stage. Figure 5 illustrates the 10-m spacing and lateral extent of midpoints at a single river mile. Each midpoint contains the attributes listed in Table 1. Attribute values for each midpoint were exported to an ASCII file and used as inputs to the NAVEFF model. Only midpoints within the main channel and main channel border include sediment values since these were the only areas where the sediment data were available. A unique cell ID that will be described subsequently in the section under "Reference Line" uniquely identifies each midpoint. Output results from the NAVEFF model and other models retain this unique value. This allows all model results to be included and displayed in the geospatial database.

[1] A table of factors for converting U.S. customary units of measurement to metric (SI) is presented on page viii.

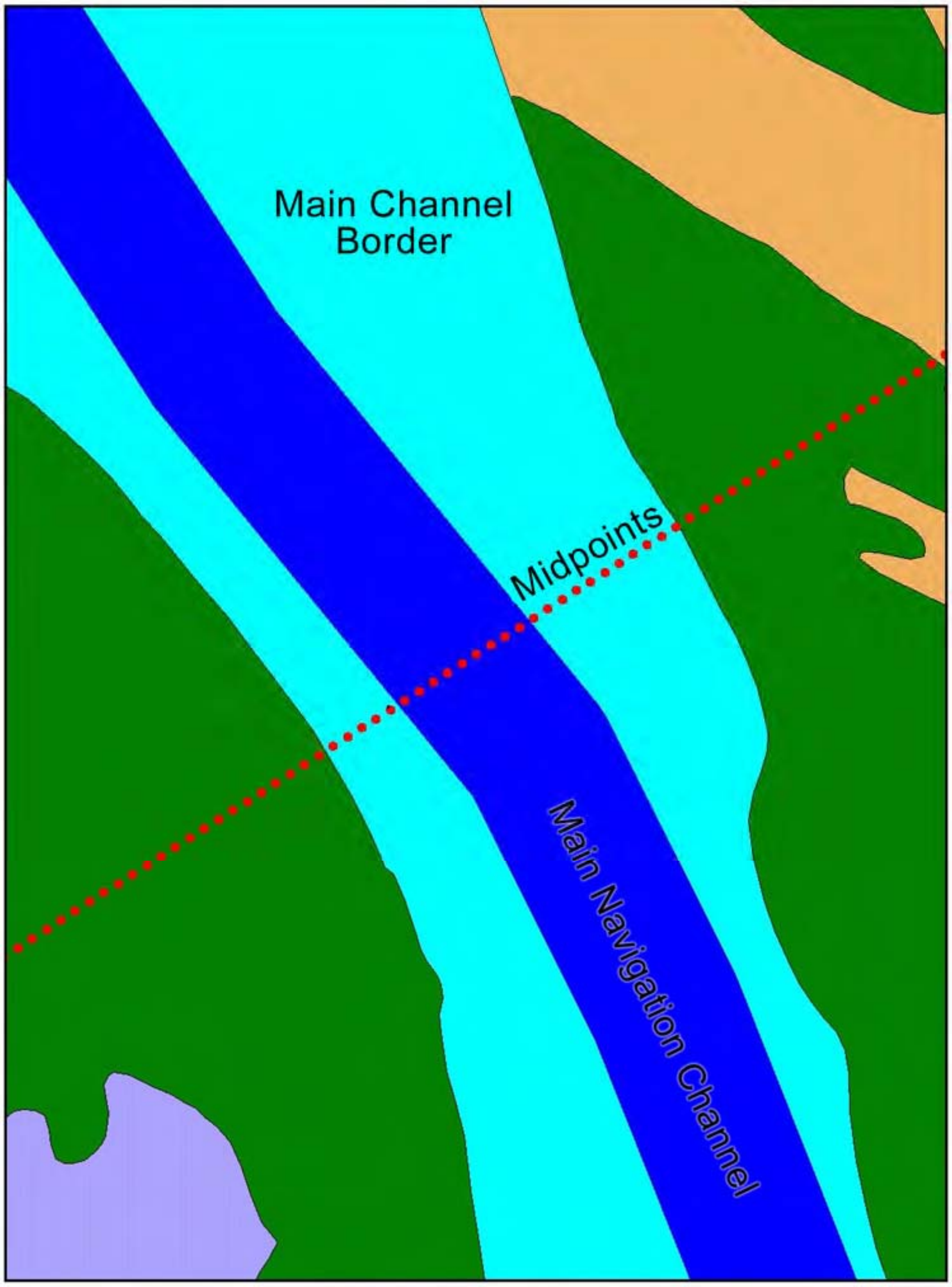

Figure 5. Midpoints at a single river mile

Table 1 Midpoints Attributes	
Attributes	**Description**
RIVER_MI	River mile
XCOORD	X-coordinate location measured in UTM's
YCOORD	Y-coordinate location measured in UTM's
POLY_TYPE	Measured distance from sailing line to midpoint
CELL_ID	Point identification number
REFL_DIST	Reference distance from sailing line to point
MSL_M	Mean sea level of point measured in meters
FPD_M	Flat pool depth measured in meters
DEPTH_L	Depth of point at low water stage
DEPTH_M	Depth of point at medium water stage
DEPTH_H	Depth of point at high water stage
AMBVEL_L	Ambient velocity at low stage
AMBVEL_M	Ambient velocity at medium stage
AMBVEL_H	Ambient velocity at high stage
COH_SED	Cohesive sediments 1. Cohesive 2. Silt mixture 3. Sand mixture
D50_GSZ_MM	D50 grain size measured in millimeters
D50_VEL_CMS	D50 fall velocity measured in centimeters/second
COH_CLASS	Bottom classification of silt mixtures (Group 2) 1. Soft 2. Medium 3. Hard

Cross-Sections (Bathymetry) Data Set

The cross-sections data set consists of points that represent channel geometry of the UMR-IWW. The within bank cross-section data points were collected in the field using global positioning system technology. These data were collected by the UMESC. These bathymetry points were combined with out of bank elevation points that were digitized from 7.5-min quadrangles. The out of bank elevation data were needed to produce a complete cross-section of the river channel geometry at all three water stages. The cross-sections data set was used to generate profiles of the UMR-IWW river channel geometry. From these profiles, left and right bank points were selected for high, medium, and low water stages. The within bank and out of bank elevation points were used to define the elevation at each of the 10-m-wide cells in NAVEFF.

Inlets Data Set

The inlets data set consists of cross-section points that represent the geometry of inlets and outlets of backwaters and secondary channels along the UMR. These data were used to calculate the average depth and cross-sectional area of each of the backwater and secondary channel inlets.

River Miles Data Set

The river miles data set consists of points displayed on the GIS that represent river mile locations for the UMR-IWW. The data set in its entirety includes the UMR from the confluence of the Ohio River (River Mile (RM) 0) to Upper St. Anthony Falls Lock (RM 854) and in the IWW from Grafton, IL (RM 0), to Lake Michigan (RM 330).

Reference Line Data Set

The reference line data set consists of one line that represents the center of the navigation channel for the UMR-IWW. The reference line was based on the sailing line obtained from the navigation charts, but is not the location of the sailing line used in NAVEFF calculations. (Chapter 5 describes how sailing line locations were selected.) All cell ID's were measured relative to the reference line. For example, cell ID 75R5290 was the 10-m-wide cell whose center was 75 m right of the reference line (looking downstream) at river mile 529.0.

Wing Dams Data Set

The wing dams data set consist of single lines representing the wing dams on the UMR-IWW. Each line represents the centerline of the wing dam as detailed on the 1 in. = 400 ft scale hydrographic survey sheets.

Sediment Data Set

The sediment data set consists of points containing sediment data collected in the field by the UMESC. The sediment characteristics used by the NAVEFF model are shown in the last four rows of Table 1 and were determined at each 10-m-wide cell (midpoint data set). Details of the sediment classification are given in Parchure et al. (2001). Detailed description of sediment attributes in the sediment data set are listed in Table 2. Sediment samples were not collected for the area known as Open River that covers the UMR river miles from RM 0-RM 203. Samples of river sediments were taken from each pool at 5-mile increments for all of the pools in the UMR-IWW. Pool 8, however, had sample data collected at 3-mile increments instead of 5-mile increments. These data, through a set of documented procedures, were extrapolated to all of the navigation and main channel borders areas for all pool on the UMR-IWW. Appendix A documents the procedures used for the assigning and extrapolation of sediment data to midpoints of cells.

Table 2 Sediment Attributes	
Attribute	**Description**
SAMPLE_ID	Sediment sample ID
POOL_NAME	Pool name
RIVER_MI	River mile
SAMPLE_LOC	Sample location
SAMPLELOC_STR	Sample location description
FPD	Flat pool depth
SED_CODE	Sediment code
DESCRIPTION	Sediment description
LOSS_OI_PERC	Loss on ignition percentage
BULK_D_G/ML	Bulk density
WET_BLKD_G/ML	Wet bulk density
LT2UM	Less than 2 μ
D16	Grain size, μ
D50	Grain size, μ
D84	Grain size, μ
LT62UM	Less than 62 μ
LAB_CODE	Laboratory code
LABCODE_STR	Laboratory code description
REMARK	Large sediment description
COH_SED	Cohesive sediments 1. Cohesive 2. Silt mixture 3. Sand mixture
BANK	Left bank, right bank
COH_CLASS	Bottom classification of silt mixtures (Group 2) 1. Soft 2. Medium 3. Hard
FALL_VELOCITY	Fall velocity
D50_REMARK	D50 remark
RIVER_SYSTEM	Mississippi River or Illinois Waterway

Metadata

Metadata document the content, data quality, point of contact, entity and attribute data, and source of the geospatial data. The UMR-IWW database has an associated metadata file for every data layer. Metadata are stored as ASCII text, which are identified by a .met extension. Metadata are also stored as an HTML file that can be displayed using a web browser. Metadata data files were developed using SMMS 3 Spatial GIS Metadata/Data Manager version 3.0c.

3 Discharges, Water Surface Elevations, and Suspended Sediment Concentrations

Selection of Exceedance Events and Monthly Distribution of High, Medium, and Low Flows

Annual exceedance flows of 5, 50, and 95 percent were selected to represent a typical high, medium, and low flow for each month of the year in each pool. In order to define the probability of each flow for a given month, a duration analysis was used to define the percent of time that the low, medium, and high flow conditions occurred. The three flows represent individual points along the annual stage-duration curve; therefore, the low flow (95 percent exceedance) was assumed to be representative of the lower 20 percent of the annual stage-duration curve (as well as representative of the potential impacts occurring during flows in that range). Likewise, the high flow value (5 percent exceedance) was assumed to be representative of the upper 20 percent of the annual stage-duration curve. The balance of the year (60 percent) was represented by the 50 percent duration or median flow value.

Each pool was broken down into the percent of low, medium, and high flow on a monthly basis. Analysis of the breakdown for each pool identified three reaches that exhibit similar patterns: the UMR above the confluence of the Missouri River, the UMR below the confluence of the Missouri River, and the Illinois Waterway. Tables 3-5 show the monthly breakdown of high, medium, and low flows for each of the three groupings.

Water Surface Elevations

The 5, 50, and 95 percent exceedance water surface elevations were determined at each gage location (Tables 6 and 7) using an elevation (or stage) duration analysis. Between gages, straight-line interpolation was used to determine the water surface elevations at each river cross-section.

Table 3
Percent of Low, Medium, and High Flow Percentages by Month for Mississippi River Above Confluence of Missouri River

Month	Percent of Low (95 percent) Flow	Percent of Medium (50 percent) Flow	Percent of High (5 percent) Flow
January	34.2	63.5	2.4
February	30.0	66.7	3.3
March	8.7	66.0	25.3
April	0.8	34.5	64.7
May	3.2	46.2	50.7
June	7.8	57.3	34.8
July	16.7	60.0	23.3
August	30.7	62.8	6.5
September	29.2	63.2	7.7
October	32.5	58.5	9.0
November	21.5	70.0	8.5
December	28.7	68.5	2.8
Annual	20.0	60.0	20.0

Table 4
Percent of Low, Medium, and High Flow Percentages by Month for Mississippi River Below Confluence of Missouri River

Month	Percent of Low (95 percent) Flow	Percent of Medium (50 percent) Flow	Percent of High (5 percent) Flow
January	45.0	50.5	4.5
February	30.0	61.5	8.5
March	9.0	61.5	29.5
April	0.5	48.5	51.0
May	1.5	50.5	48.0
June	3.5	55.0	41.5
July	8.0	69.0	23.0
August	17.5	78.5	4.0
September	25.0	68.5	6.5
October	32.5	59.0	8.5
November	28.0	63.5	8.5
December	41.5	52.5	6.0
Annual	20.0	60.0	20.0

Table 5
Percent of Low, Medium, and High Flow Percentages by Month for Illinois Waterway

Month	Percent of Low (95 percent) Flow	Percent of Medium (50 percent) Flow	Percent of High (5 percent) Flow
January	14.5	66.0	19.5
February	11.4	64.6	24.0
March	2.9	57.6	39.5
April	1.3	50.3	48.5
May	2.4	59.9	37.8
June	7.4	68.6	24.0
July	16.0	71.9	12.1
August	30.4	65.8	3.9
September	49.7	44.8	5.5
October	51.3	41.9	6.9
November	35.5	57.3	7.3
December	21.8	66.8	11.5
Annual	20.0	60.0	20.0

Table 6
Water Surface Elevations, Flows, and Sediment Concentrations on Mississippi River

Mississippi River Gage		River Mile	Elevation[1]			Flow			Weighted Coefficients		
			95%	50%	5%	95%	50%	5%	95% SS Conc.	50% SS Conc.	5% SS Conc.
St Paul District											
L&D 1 at Minneapolis – St. Paul	Pool	847.6	724.2	725.5	728.3	2,200	7,200	25,200	4	7	14
	Tail	847.6	690.3	695.3	707.4	2,400	10,200	44,400	4	9	18
St. Paul at Robert St. Bridge	Gage	839.3	687.3	687.7	694.5	2,400	10,200	44,400	4	9	18
So. St. Paul (Control Point 2)	Gage	833.7	687.2	687.2	692.4	2,400	10,200	44,400	4	9	18
L&D 2 at Hastings, MN	Pool	815.2	687.1	686.7	686.5	2,400	10,200	44,400	4	9	18
	Tail	815.2	675.2	676.4	684.7	4,800	15,000	55,200	6	11	21
Prescott, WI (Control Point 3)	Gage	811.5	675.0	675.2	681.8	4,800	15,000	55,200	6	11	21
L&D 3 at Red Wing, MN	Pool	796.9	674.8	674.0	676.8	4,800	15,000	55,200	6	11	21
	Tail	796.9				8,800	26,100	81,600	8	14	25

(Sheet 1 of 4)

NOTE: Flows based on a combination of rating curves at the locks and dams on the UMR-IWW and U.S. Geological Survey (USGS) mainstem and tributary gage records.

[1] in feet mean sea level (msl) (datum of 1912).

Table 6 (Continued)											
Mississippi River Gage		River Mile	Elevation			Flow			Weighted Coefficients		
			95%	50%	5%	95%	50%	5%	95% SS Conc.	50% SS Conc.	5% SS Conc.
St Paul District (Concluded)											
Lake City, MN	Gage	772.6	667.2	668.1	674.0	8,800	26,100	81,600	8	14	25
Wabasha, MN (Control Point 4)	Gage	760.5	667.0	667.1	671.3	8,800	26,100	81,600	8	14	25
L&D 4 at Alma, WI	Pool	752.8	666.8	666.5	666.5	8,800	26,100	81,600	8	14	25
	Tail	752.8	660.1	660.9	665.9	9,200	27,400	86,400	8	14	26
Control Point – Pool 5	Gage	748.5	660.0	660.0	663.3	9,200	27,400	86,400	8	14	26
L&D 5 at Fountain City, WI	Pool	738.3	659.9	659.9	659.5	9,200	27,400	86,400	8	14	26
	Tail	738.3	651.0	651.6	656.8	9,900	27,900	82,800	9	15	25
L&D 5a at Winona, MN	Pool	728.5	651.0	650.0	652.8	9,900	27,900	82,800	9	15	25
	Tail	728.5	645.7	646.7	652.3	9,400	28,300	84,700	8	15	26
Winona, MN (Control Point 6)	Gage	725.7	645.5	645.7	651.1	9,400	28,300	84,700	8	15	26
L&D 6 at Trempealeau, WI	Pool	714.3	645.3	644.5	645.4	9,400	28,300	84,700	9	16	27
	Tail	714.3	639.2	640.0	644.4	10,200	29,100	81,600	9	16	27
Dakota, MN	Gage	707.2	639.1	639.4	640.8	10,200	29,100	81,600	10	16	28
L&D 7 at La Crosse, WI	Pool	702.3	639.0	639.0	639.0	10,200	29,100	81,600	10	17	29
	Tail	702.3	631.1	632.4	638.9	10,500	31,400	89,700	10	18	30
Control Point 8	Gage	696.9	631.0	631.4	636.2	10,500	31,400	89,700	10	18	31
Brownsville, MN	Gage	689.0	630.9	630.3	632.1	10,500	31,400	89,700	11	19	33
L&D 8 at Genoa, WI	Pool	679.1	630.9	630.0	630.0	10,500	31,400	89,700	11	20	35
	Tail	679.1	621.0	623.3	629.7	11,700	31,800	98,700	12	20	37
Lansing, IA (Control Point 9)	Gage	662.9	620.0	620.0	623.8	11,700	31,800	98,700	13	22	40
L&D 9 at Lynxville, WI	Pool	647.9	619.8	619.0	622.1	11,700	31,800	98,700	14	24	44
	Tail	647.9	612.5	615.3	623.1	16,000	37,000	115,000	16	26	48
McGregor, IA	Gage	633.6	611.8	613.7	620.5	16,000	37,000	115,000	18	28	52
Clayton, IA	Gage	624.4	611.2	611.8	616.3	16,000	37,000	115,000	17	29	59
L&D 10 at Guttenberg, IA	Pool	615.1	611.0	611.0	613.2	16,000	37,000	115,000	17	30	66
	Tail	615.1				16,000	37,000	115,000	17	30	66
Rock Island District											
Mississippi River at Cassville, WI	Gage	606.7	603.2	605.0	610.2	16,000	37,000	115,000	16	31	74
Mississippi River at Waupeton, IA	Gage	600.0	603.0	604.1	606.8	16,000	37,000	115,000	16	32	81
Mississippi River at Specht's Ferry	Gage	592.2	602.6	603.3	604.7	16,000	37,000	115,000	15	33	89
L&D 11 at Dubuque,IA	Pool	583.0	602.4	603.1	603.5	16,000	37,000	115,000	15	34	100
	Tail	583.0	592.3	594.1	601.0	16,000	37,000	115,000	15	34	100
											(Sheet 2 of 4)

Table 6 (Continued)											
Mississippi River Gage		**River Mile**	**Elevation**			**Flow**			**Weighted Coefficients**		
			95%	**50%**	**5%**	**95%**	**50%**	**5%**	**95% SS Conc.**	**50% SS Conc.**	**5% SS Conc.**
Rock Island District (Concluded)											
Mississippi River at Dubuque, IA	Gage	579.9	592.2	594.0	600.8	16,000	37,000	115,000	15	34	104
L&D 12 at Bellevue, IA	Pool	556.7	591.4	592.0	594.5	16,000	37,000	116,000	14	34	107
	Tail	556.7	583.6	586.2	593.1	16,000	37,000	116,000	14	34	107
Mississippi River at Sabula, IA	Gage	535.0	583.0	583.8	586.5	16,000	37,000	116,000	14	34	109
L&D 13 at Fulton, IL	Pool	522.4	582.3	583.2	583.5	17,000	38,000	116,000	15	34	110
	Tail	522.4	572.7	575.0	582.3	17,000	38,000	116,000	15	34	110
Mississippi River at Camanche, IA	Gage	511.9	572.0	573.8	578.2	17,300	38,100	116,000	15	34	111
Mississippi River at Princeton, IA	Gage	502.0	571.9	572.9	575.2	17,300	38,100	116,000	15	34	112
L&D 14 at Leclaire, IA	Pool	493.3	571.1	572.2	572.4	18,000	41,000	118,000	15	37	115
	Tail	493.3	561.2	562.2	566.0	18,000	41,000	118,000	15	37	115
L&D 15 at Rock Island, IL	Pool	482.9	560.6	561.1	561.3	18,000	41,000	118,000	15	37	116
	Tail	482.9	545.8	548.7	555.4	18,000	41,000	118,000	15	37	116
Rock River											
Mississippi River nr Fairport, IA	Gage	463.5	544.8	545.7	549.3	19,000	46,000	135,000	16	42	137
L&D 16 nr Illinois City, IL	Pool	457.2	544.0	545.4	547.7	19,000	46,000	135,000	16	42	137
	Tail	457.2	536.5	539.2	547.2	19,000	46,000	135,000	16	42	137
Mississippi River at Muscatine, IA	Gage	453.3	536.4	538.3	545.8	19,000	46,000	135,000	16	42	138
Mississippi River at Blanchard Island	Gage	450.2	536.2	537.6	544.4	19,000	46,000	135,000	16	42	138
L&D 17 nr New Boston, IL	Pool	437.1	535.4	536.0	541.4	19,000	47,000	136,000	15	43	141
	Tail	437.1	528.9	532.4	540.5	19,000	47,000	136,000	15	43	141
Iowa River											
Mississippi River at Keithsburg, IL	Gage	427.7	528.4	530.7	536.5	20,000	52,000	161,000	16	48	172
L&D 18 nr Gladstone, IL	Pool	410.5	527.5	528.0	529.7	20,000	52,000	161,000	16	48	176
	Tail	410.5	519.1	521.9	528.7	20,000	52,000	161,000	16	48	176
Mississippi River at Burlington, IA	Gage	401.0	518.8	520.7	526.7	20,000	52,000	161,000	16	48	178
Skunk River											
Mississippi River at Fort Madison, IA	Gage	383.9	518.3	518.9	521.5	20,900	55,000	172,000	15	49	194
L&D 19 at Keokuk, IA	Pool	364.2	518.0	518.6	518.9	20,900	55,000	172,000	14	47	198
	Tail	364.2	480.1	483.0	492.3	20,900	55,100	172,000	14	47	198
											(Sheet 3 of 4)

Table 6 (Concluded)											
Mississippi River Gage		River Mile	Elevation			Flow			Weighted Coefficients		
			95%	50%	5%	95%	50%	5%	95% SS Conc.	50% SS Conc.	5% SS Conc.
Des Moines River											
Mississippi River at Warsaw, IL	Gage	359.9	479.4	481.9	490.8	22,000	58,000	195,000	15	50	231
Mississippi River nr Gregory, MO	Gage	352.9	478.9	480.6	488.0	22,000	58,000	195,000	15	50	231
L&D 20 nr Canton, MO	Pool	343.2	477.4	479.2	583.7	22,000	60,000	195,000	15	53	230
	Tail	343.2	470.5	473.8	482.7	22,000	60,000	195,000	15	53	230
Mississippi River at LaGrange, MO	Gage	335.7	470.2	472.0	479.1	22,000	60,000	195,000	15	53	230
Mississippi River at Quincy, IL	Gage	327.9	469.6	470.2	475.9	22,000	60,000	195,000	15	53	229
L&D 21 at Quincy, IL	Pool	324.9	469.7	470.2	475.7	22,000	61,000	197,000	15	55	232
	Tail	324.9	460.2	463.8	474.0	22,000	61,000	197,000	15	55	232
Mississippi River at Hannibal, MO	Gage	309.0	459.3	460.4	467.4	22,000	61,000	197,000	16	55	231
L&D 22 nr Saverton, MO	Pool	301.2	459.1	459.5	463.5	23,000	64,000	200,000	17	59	235
	Tail	301.2	449.7	452.6	462.1	23,000	64,000	200,000	17	59	235
St. Louis District											
RM 284.05		284.1				19,500	78,000	216,000	14	75	256
RM 237.0		237.0				20,000	80,000	220,000	16	79	257
RM 220.4		220.4				22,000	82,000	222,000	18	82	258
RM 201.4		201.4				35,000	95,000	250,000	43	117	306
RM 195.0		195.0				35,000	95,000	250,000	43	118	312
RM 179.6		179.6				63,800	159,000	462,000	80	204	610
RM 109.9		109.9				66,200	166,000	482,000	86	244	819
RM 1.4		1.4				66,800	170,000	486,000	87	245	784

(Sheet 4 of 4)

The 5, 50, and 95 percent exceedance flows on the Mississippi River were determined using a combination of discharge ratings at the locks and dams on the UMR-IWW and USGS rating curves, and the associated exceedance water surface elevation (see Tables 6 and 7).

Suspended Sediment Concentrations

The Upper Mississippi River Corps of Engineers Districts and the USGS have collected daily suspended sediment concentrations at selected stations along the UMR and IWW. Table 8 summarizes the available data. All of the stations listed sample the main channel. A regression analysis (using a log-log transformation) was performed relating the suspended sediment concentration to stream flow for each station. Estimates of ambient total suspended sediment

Table 7
Water Surface Elevations, Flows, and Sediment Concentrations on Illinois River

Illinois River Gage		River Mile	Elevation[1]			Flow			Weighted Coefficients		
			95%*	50%	5%	95%	50%	5%	95% SS Conc.	50% SS Conc.	5% SS Conc.
Lake Michigan											
O'Brien Lock & Dam	Tail	326.5	577.4	577.6	578.4						
Lockport Lock	Pool	291.1	574.3	575.7	576.2						
	Tail	291.1	538.5	539.0	539.8	3,200	5,800	6,650	37	43	44
Des Plaines River		290.0				3,250	6,100	8,550	37	43	47
Brandon Road Lock & Dam	Pool	285.9	538.4	538.7	539.1	3,250	6,100	8,550	37	43	47
	Tail	285.9	504.7	505.2	506.2	3,250	6,100	8,550	37	43	47
Hickory Creek		285.9				3,300	6,150	8,900			
Du Page River		276.9				3,350	6,300	9,800			
Kankakee River		273.0				4,050	9,000	23,100			
Dresden Island Lock & Dam	Pool	271.5	504.5	504.7	505.2	4,050	9,000	23,100	39	47	58
	Tail	271.5	483.7	485.3	492.4	4,050	9,000	23,100	39	47	58
Mazon River		365.5				4,100	9,100	24,600	39	47	59
Illinois River nr Morris, IL	Gage	263.1	483.5	484.4	489.5	4,100	9,100	24,600	39	47	59
Marseilles Lock & Dam	Pool	247.0	482.8	483.2	483.7	4,100	9,100	24,600	39	47	59
Illinois River at Marseilles, IL (rapids)	Gage	246.5	464.2	465.6	469.7	4,100	9,100	24,600	39	47	59
Marseilles Lock Lower	Tail	244.3	458.8	459.5	462.6	4,100	9,100	24,600	39	47	59
Fox River		239.7				4,400	10,200	31,000			
Illinois River at Ottawa, IL	Gage	239.7	458.6	459.3	460.3	4,400	10,200	31,000	40	48	62
Starved Rock Lock & Dam	Pool	231.1	458.4	458.8	459.4	4,400	10,200	31,000	40	48	62
	Tail	231.1	440.9	443.2	452.0	4,400	10,200	31,000	40	48	62
Vermilion River		226.4				4,450	10,600	36,000			
Illinois River nr LaSalle, IL	Gage	224.7	440.8	443.0	451.8	4,450	10,600	36,000	40	49	64
Illinois River at Spring Valley, IL	Gage	218.4	440.7	442.6	450.9	4,450	10,600	36,000	40	49	64
Illinois River at Hennipen	Gage	207.5	440.5	441.6	448.7	4,450	10,600	36,000	40	49	64
Illinois River nr Henry, IL	Gage	196.0	440.4	441.4	449.2	4,450	10,600	36,000	40	49	64
Illinois River at Chillicothe	Gage	180.4	440.1	440.8	446.9	4,450	10,600	36,000	46	55	73
Illinois River at Peoria, IL	Gage	164.6	439.7	440.5	447.2	4,450	10,600	36,000	52	63	82
Peoria Lock & Dam	Pool	157.9	438.9	440.2	446.2	4,450	10,600	36,000	55	66	87
	Tail	157.9	431.1	435.7	446.1	4,450	10,600	36,000	55	66	87
Illinois River at Pekin, IL	Gage	152.9	430.9	434.8	445.2	4,450	10,600	36,000	57	69	90
Mackinaw River		147.7				4,500	10,900	39,800			
Illinois River nr Kingston Mines, IL	Gage	145.4	430.8	435.2	445.6	4,500	10,900	39,800	61	74	98

(Continued)

NOTE: All flows based on USGS mainstem and tributary gage records.
[1] in feet msl (datum of 1929)

Table 7 (Concluded)											
Illinois River Gage		**River Mile**	**Elevation[1]**			**Flow**			**Weighted Coefficients**		
			95%*	**50%**	**5%**	**95%**	**50%**	**5%**	**95% SS Conc.**	**50% SS Conc.**	**5% SS Conc.**
Illinois River nr Copperas Creek, IL	Gage	136.8	430.6	434.8	444.6	4,500	10,900	39,800	65	79	105
Illinois River at Liverpool, IL	Gage	128.0	430.4	433.6	442.2	4,500	10,900	39,800	70	85	112
Illinois River nr Havana, IL	Gage	119.6	430.0	433.4	442.9	4,500	10,900	39,800	75	91	120
Spoon River		119.5				4,800	12,000	44,000			
Illinois River at Browning, IL	Gage	97.3	429.5	431.1	440.0	4,800	12,000	44,000	92	111	146
Sangamon River		89.0				5,300	14,200	54,500			
Illinois River at Beardstown, IL	Gage	88.6	429.1	430.0	439.7	5,300	14,200	54,500	100	124	164
La Moine River		83.3				5,600	15,300	58,600			
New LaGrange Lock & Dam	Pool	80.2	427.9	429.3	437.5	5,600	15,300	58,600	109	134	178
	Tail	80.2	420.3	425.4	437.5	5,600	15,300	58,600	109	134	178
Illinois River nr Meredosia, IL	Gage	71.3	420.1	424.9	437.5	5,600	15,300	58,600	117	144	191
Illinois River nr Valley City, IL	Gage	61.4	419.8	423.9	435.9	5,600	15,300	58,600	127	156	206
St. Louis District											
Illinois River		61.4 to 0				6,050	17,200	62,800	129	160	209

Table 8
Locations of Stations Providing Daily Suspended Sediment Concentrations

District	Gage Name	River Mile	Pool	Years of record
St Paul	Mississippi River at Winona, MN	725.7	6	14
	Mississippi River at McGregor, IA	633.4	10	20
Rock Island	Mississippi River at Dubuque, IA	579.9	12	26
	Mississippi River at Burlington, IA	401.0	19	26
	Mississippi River at Keokuk, IA	364.2	20	27
St Louis	Mississippi River at Grafton, IL	214.6	26	4
	Mississippi River at Alton, IL	202.7	Open river	10
	Mississippi River at Chester, IL	109.9		15
	Mississippi River at Thebes, IL	43.7		15
Rock Island	Illinois River at Henry	196.0	Peoria	4
St Louis	Illinois River at Valley City	61.3	Alton	9

were made for each river section by inverse distance weighting the estimates derived from the suspended sediment rating curves for the next upstream and downstream station. This analysis was not meant to imply a perfect relationship between flow and suspended sediment concentrations but rather was used to estimate a representative concentration that could be used as a backdrop for the towboat resuspension and light extinction calculations. Tables 6 and 7 summarize the ambient total suspended sediment concentrations for the low, medium, and high flows at various river miles throughout the study reach. The values shown include wash load because this information was used to address issues such as light extinction for plants as well as sedimentation of backwaters having a single inlet and no outlet where trap efficiencies are expected to be large.

4 Numerical and Analytical Modeling of Ambient Velocity

Hydrodynamic Modeling in Trend Pools

Trend pools on the UMR-IWW were pools 4, 8, 13, 26, and Lagrange. In the trend pools of the UMR-IWW, hydrodynamic modeling was conducted to determine the ambient velocity at each 10-m-wide cell at each cross-section for low, medium, and high flows.

The numerical model used for this effort was RMA2 (RMA - River Management Associates). RMA2 is a numerical model that solves the two-dimensional, vertically averaged Reynolds form of the Navier-Stokes equations for free surface flow. The RMA2 model is documented in Donnell et al. (2003). The model computes the water surface elevations and flow velocities at nodal points of a finite element mesh representing the river. The Surface-Water Modeling System (SMS) was used to develop the finite element mesh and to display model results.

The RMA2 model is capable of modeling secondary flow conditions such as outdraft and eddies; however, the model's ability to represent three-dimensional flow conditions such as that occurring through the submerged ports of a guard wall or in the immediate vicinity of the dam gates (when the dam is in operation) is limited.

For each of the trend pools, finite element meshes were constructed that described the bathymetry (bottom surface geometry) and adjacent topography of the sections of river being modeled. Hydrographic survey data in the form of XYZ coordinates were input into SMS as the basis for construction of the finite element meshes.

Model boundary conditions were entered as an incoming (upstream) flow rate and a downstream water surface elevation (at the dam). Also specified are roughness (Manning's n) and turbulent exchange parameters for each element of the model. Although Pool 13 is the only model study described herein, the other trend pools were modeled in a similar manner.

The ambient velocities determined in the hydrodynamic models are shown in the NAVEFF input files discussed subsequently.

Pool 13 Hydrodynamic Modeling

The Pool 13 numerical model investigated flow conditions between RM 522.5 (Lock & Dam 13) and RM 556.7 (Lock & Dam 12) using the RMA2 model. Three models were built for the upper (RM 549.0 to 556.7), middle (RM 535.2 to 549.0), and lower (RM 522.5 to 535.2) portions of Pool 13. Combined, the three models consisted of 39,570 elements and 115,668 nodes.

Bathymetric information, used to create the model grid, was obtained from the Rock Island District and was based on 1997 soundings supplemented with backwater and secondary channel soundings obtained from the UMESC (formerly the Environmental Management Technical Center). Topographic information was obtained from 1:24000 USGS Quad Maps.

Calibration of the numerical models was accomplished through comparison with prototype measurements of velocities and water surface profiles. Computed water surface slopes were compared to historical water surface slopes (for known flow rates) between the Lock & Dam 13 pool gage and the Lock & Dam 12 tailwater gage. Additional comparisons were made to historical records collected at the Sabula stream gage (RM 535.0). Prototype measurements of velocities and flow splits at islands were taken at a flow of 40,000 cfs, approximately equal to the medium flow value.

Four different material types were used in the model: open channel, submerged aquatic vegetation, emergent and terrestrial grasses, and wooded terrestrial. Land use/land cover information (developed using 1989 aerial photography by the UMESC) was used to delineate wooded areas and the extent of aquatic plant beds. The final selected Manning's n values for the selected material types were: 0.025 for the open channel, 0.035 for submerged aquatic plants, 0.040 for emergent and terrestrial grasses, and 0.100 for wooded terrestrial areas. Turbulent exchange parameters (eddy viscosities) were automatically computed and assigned by the hydraulic model using a Peclet number of 20. The Peclet number defines the relationship between element properties, velocity, and eddy viscosity and is one method of quantifying the effects of turbulence in a numerical model.

The RMA2 calculations in the trend pools should have captured the effects of submerged dikes on the velocity distribution input to the NAVEFF model.

Nontrend Pools Analytical Modeling

In the nontrend pools of the UMR-IWW, a technique was needed for determining ambient velocities where hydrodynamic models were not run. The "Alpha" method (U.S. Army Corps of Engineers 1994) was used to determine velocities across the cross-section. The Alpha method ratios the conveyance in each 10-m-wide cell to the total conveyance to determine the portion of the total discharge in each cell. The conveyance in a cell of the cross-section, $Conv_i$, is defined as

$$Conv_i = \left(C_i\, dep^{1/2}\right) A_i = C_i\, dep^{3/2}\, B_i \tag{1}$$

where C_i = Chezy coefficient, defined as

$$C_i = 32.6 \log_{10} \frac{12.2\, dep}{k_s} \tag{2}$$

dep = local depth at the midpoint of the cell

A_i = area of the cell

B_i = width of the cell

k_s = equivalent sand grain roughness = $3D_{50}$.

The discharge in a cell, Q_i, is

$$Q_i = Q_{total} \frac{Conv_i}{Conv_{total}} \tag{3}$$

where

Q_{total} = total discharge in the cross-section

$Conv_{total}$ = sum of all the $Conv_i$

Since the depth-averaged velocity in the cell is $V_i = Q_i/A_i$, substitution of Equations 1 and 3 results in

$$V_i = \frac{Q_{total}\, C_i\, dep^{1/2}}{Conv_{total}} \tag{4}$$

The ability of the Alpha method to reproduce velocities computed by the two-dimensional RMA2 model was evaluated using 3 cross-sections in Pool 13. Results are shown in Figures 6-8 for Section 1 (RM 547.4), a relatively straight reach, Section 2 (RM 541.8), just upstream of a 90-deg bend, and Section 3 (RM 537.8), which is downstream of a bend in a long expansion. The three cross-sections are shown in Figure 9. For each cross-section, the Alpha method was used to compute a channel velocity at the midpoint node of each element of the numerical model's finite element mesh. Two k_s values were used and had almost no impact on the simplified method. The RMA2 model used in this comparison assigned eddy viscosities using the Peclet control with a value of 20. The depth values used in the Alpha method calculation also correspond to the midpoint node. All comparisons were made at the medium flow of 37,000 cfs (50 percent). In each of the three cross-sections, the Alpha method yielded values of

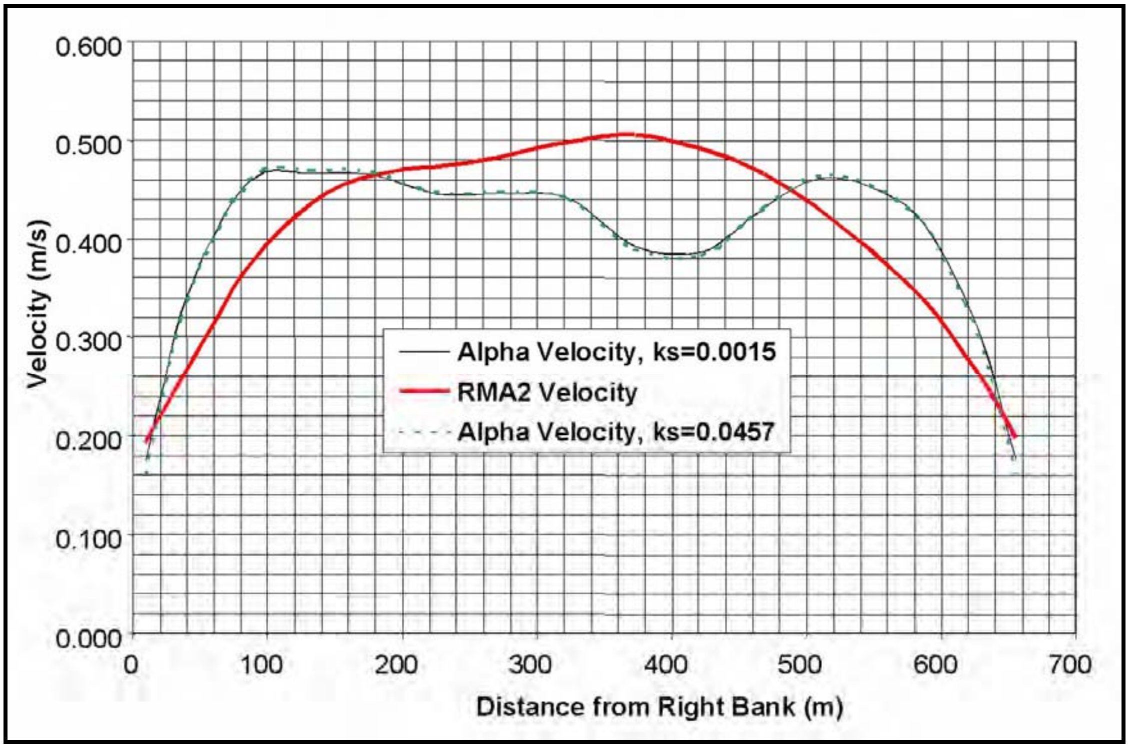

Figure 6. Comparison of velocity estimates, Pool 13 - Section 1, medium flow – 50 percent annual duration

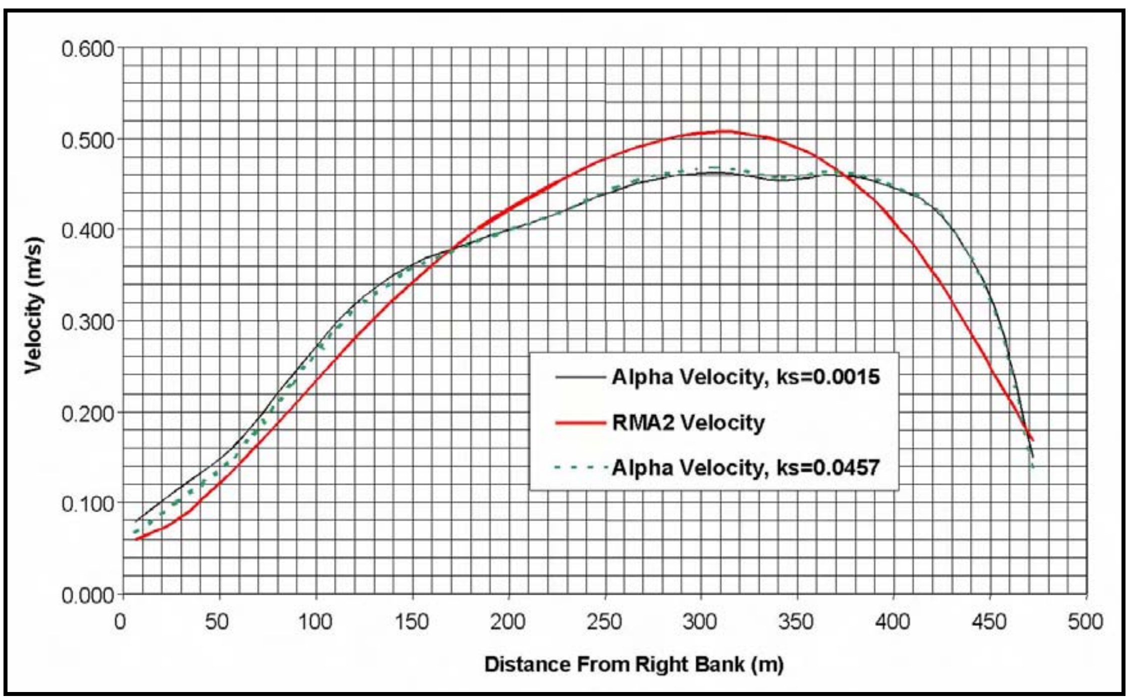

Figure 7. Comparison of velocity estimates, Pool 13 - Section 2, medium flow – 50 percent annual duration

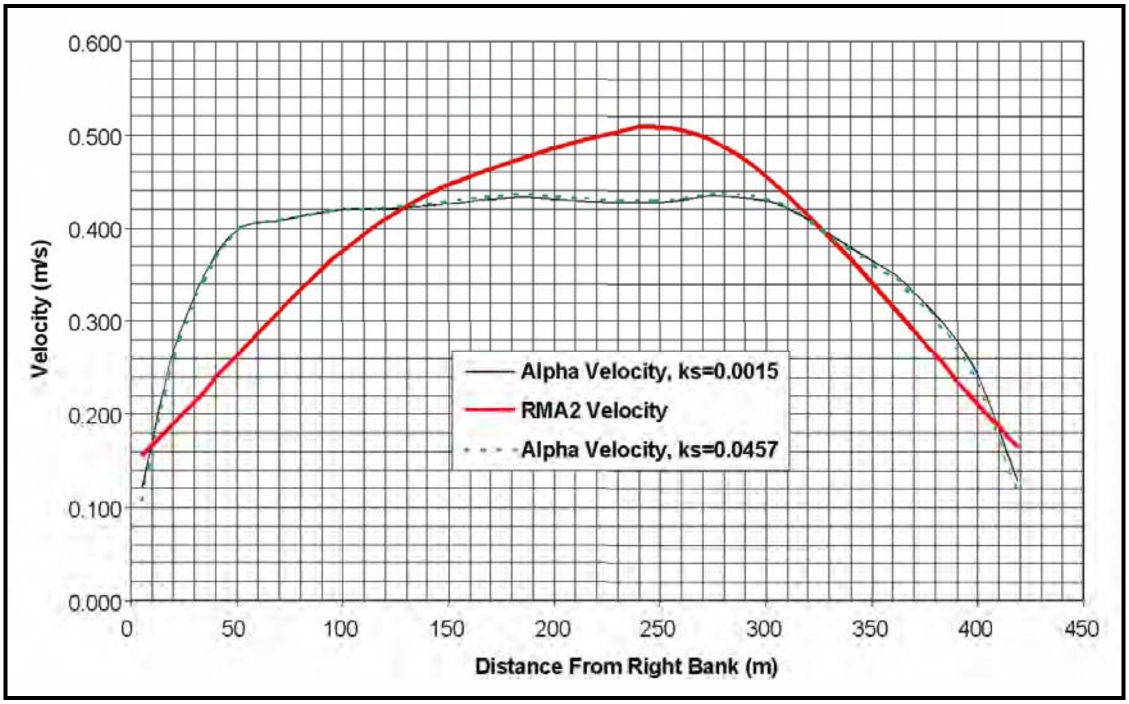

Figure 8. Comparison of velocity estimates, Pool 13 - Section 3, medium flow – 50 percent annual duration

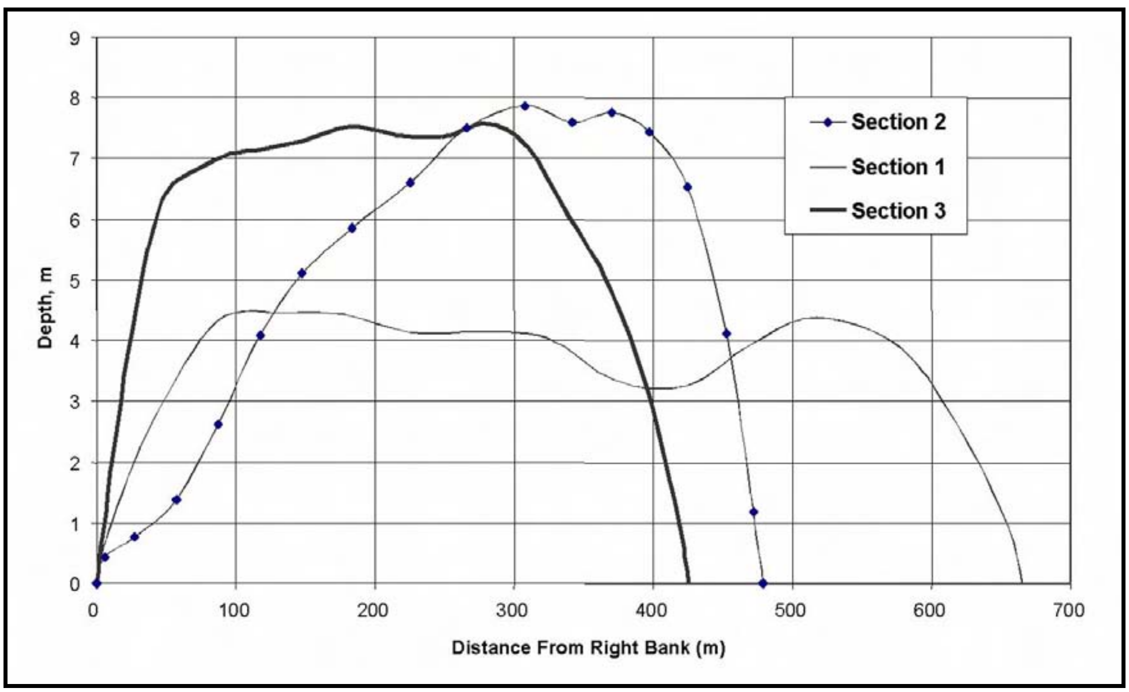

Figure 9. Comparison of cross-sections, Pool 13 - Sections 1-3, medium flow – 50 percent annual duration

similar magnitude and distribution to those of the numerical model. The minor differences observed between the two methods would not significantly affect the results of the NAVEFF and subsequent calculations. While RMA2 velocities were in an input file to NAVEFF for trend pools, the Alpha method was programmed into the NAVEFF model for nontrend pools. The Alpha method, being one-dimensional and based on the 10-m bathymetry in the NAVEFF model, likely did not capture the effects of submerged wing dams in the river. Somewhat mitigating the lack of effects of the wing dams in the nontrend pool Alpha velocities is the fact that many of the dikes in the lock and dam reach have limited exposed portions of the dike.

5 Traffic Variables

General

Physical effects produced by commercial vessels are related to the configuration characteristics of the tow. To evaluate physical effects, the following information is needed regarding vessel characteristics.

a. Size of barge train: length, width

b. Draft

c. Direction of travel: up or down bound

d. Vessel speed (relative to water)

e. Type propulsion system: Kort nozzle or open wheel

f. Applied power

g. Lateral location of vessel in channel or sailing line

Economists for the navigation study evaluated 1996 traffic data from the Lock Performance Monitoring System (LPMS). All data related to size, draft, direction of travel, and speed were analyzed, and categories were developed to combine these characteristics.

Size

From the 1996 traffic data, economics generated three classes of vessels as follows:

Small = less than or equal to 4 barges
Medium = 5 to 11 barges
Big = 12 or more barges

The configuration assigned to each class by the Modeling Integration Simulation Team (MIST), and therefore setting the dimensions of the vessel, was

S	1×3	10.7 m × 178.4 m
M	2×4	21.3 m × 237.8 m
B	3×5	32.0 m × 297.3 m

A potential fourth category could be a Lightvessel, or towboat operating without barges. For purposes of computing navigation effects, it could be represented as a vessel 10.7 m wide by 45.7 m long by 2.74 m draft. None of these vessels were included in the most recent traffic data file and are excluded from these computations. This option is programmed into NAVEFF but has not been used.

Draft

The draft is broken into three classes as follows:

Loaded	2.74 m
Mixed	2.13 m
Empty	0.6 m

Speed

Vessel speeds were broken into three categories (slow-medium-fast) based on transit times from the LPMS data base. The average speed over the length of the pool (pool length/transit times) includes the effects of ambient currents on travel time and any delays along the pool, making it difficult to use the speeds from the LPMS data base to determine physical effects in the system model. Based on discussion with pilots, general knowledge of MIST members, and analysis of Bhowmik data presented in Maynord (1999b), the following speeds relative to water were assigned:

Upper Mississippi River

Slow	5 mph
Medium	6.5 mph
Fast	8 mph

Illinois Waterway

Slow	3 mph
Medium	5 mph
Fast	7 mph

Propulsion

Towboats have either open wheel or Kort nozzle propulsion systems. Kort nozzle towboats have a streamlined cylinder around the propellers to improve performance at certain speeds and are typically found on the larger horsepower towboats. Open wheel towboats have no cylinder around the propellers and are typically found on lower powered towboats.

Sailing Lines

Three sailing lines, left, middle, and right, were established to define tow locations for calculating the physical forces from navigation. The left and right sailing lines were assigned a probability of occurrence of 5 percent with the middle sailing line occurring 90 percent of the time. The left and right sailing lines were initially selected to reflect a 300-ft-wide navigation channel. Several resource agencies noted that tows can be found outside a 300-ft channel width. The left and right sailing lines were changed to reflect left and right limits of navigation based on available depth at low flow and reach alignment rather than a fixed navigation width of 300 ft.

The five different tow parameters results in (2 directions) × (2 propulsions types, Kort or open) × (3 tow sizes) × (3 drafts) × (3 speeds) = 108 tow types. The fleet configuration represented by the 108 different tow types did not change from one traffic scenario to another. The three flows (5 percent, 50 percent, and 95 percent) along with the three sailing lines (left, middle, and right) results in a total number of input combinations of 972.

6 NAVEFF Model

Description of Algorithms

NAVEFF is a one-dimensional model plus empirical relations for estimating physical forces across a cross-section caused by shallow-draft navigation. The algorithms for return velocity and drawdown in NAVEFF are described in Maynord (1996) and Maynord (1999a) except for several modifications that are presented herein. The algorithms for propeller jet velocity and other near vessel forces are described in Maynord (2000b). The algorithm for wave height is described in Knight (1999). The algorithm for scour is presented herein. The source code for NAVEFF used on UMR-IWW is presented in Appendices A and B.

Wide Section Modification

The conservation of energy and mass equations on which NAVEFF is based results in the existence of a limiting speed, which is the speed which cannot be exceeded by a self-propelled displacement vessel in a relatively small or shallow channel because the resistance becomes extremely large. The equations use the average channel depth (area/top width) to define the depth. In wide sections having a deep center section where navigation occurs with one or both areas on the sides being very wide, shallow, overbank areas, the average channel depth often becomes small (sometimes less than the draft of the vessel), and the vessel reaches the computed limiting speed. This limiting speed, based on the total width having a shallow average depth, is much less than actual speeds of tows routinely operating in the center navigation channel. A method was needed to address this special case because the model would stop running when the limiting speed was equaled or exceeded. The problem was not present when the ratio of the cross-sectional average depth/maximum depth was greater than or equal to 0.666, which was the case for all of the field data collected by the Illinois State Water Survey. No field data were taken in sections with average depth/maximum depth less than 0.666. The HIVEL2D model (Stockstill and Berger 2001) was run with several hypothetical sections having a deep center section flanked by shallow overbanks of varying width. Several modifications to the average depth used in NAVEFF were tried and compared to the return velocity and drawdown output from the HIVEL2D model. When average depth/maximum depth was less than 0.666, the following modification to the average depth, h, was found to provide fair agreement with the HIVEL2D results in

(5) $$h_{\text{mod}} = h\left(3 - 3\frac{h}{MaxDepth}\right)$$

While this equation solved the majority of the shallow channel problems (which were few in number to begin with), several cases were found where the model still computed a depth that led to the limiting speed being exceeded and the model would stop. To eliminate this required another modification. Tows do not operate at greater than about 80-90 percent of limiting speed because doing so requires a large amount of power and is uneconomical. Since speeds were selected that are known to be used on the river, the problem still lay in how the average depth was calculated for a few unusual cross-section shapes. To ensure that realistic estimates of actual speed/limiting speed were used in determining return velocity and drawdown, first the limiting speed was computed using equations in Maynord (1996) along with the modification in Equation 5. Next, if the actual speed exceeded 95 percent of the computed limiting speed, a $Vtemp = 0.95V(\text{limit})$ was determined. Then the NAVEFF equations were used to determine the average return velocity V_r for tow speed $Vtemp$. Third, the ratio (V_r at $Vtemp$)/$Vtemp$ was computed. This ratio was then multiplied by the actual tow speed to obtain V_r saved in the output. This modification was used in very few cases but prevented problems with the model stopping in the middle of a lengthy run. No modification was required for drawdown because return velocity is used to calculate drawdown. Drawdown calculations were made as described in Maynord (1996) for all cases.

Secondary Wave Routine

The maximum secondary wave height, H_{wave}, equation from Knight (1999) is

$$H_{wave} = \alpha\,(X_{wave})^{-1/3}\left(\frac{V_w}{\sqrt{g}}\right)^{2.67} \qquad (6)$$

where

X_{wave} = distance from the edge of the tow to the cell of interest and must be greater than 14 m

V_w = tow speed relative to water

α = coefficient that depends on the cross-sectional area of the tow or AB = beam*draft

For AB less than or equal to 30 m^2, $\alpha = 0.5$. For AB greater than 30 m^2 and less than or equal to 65 m^2, $\alpha = 0.6$. For AB greater than 65 m^2, $\alpha = 0.7$. If H_{wave}/dep is greater than 0.6, H_{wave} is output as a negative value. For X_{wave} less than 14 m, a value of -9.0 is output. The value of H_{wave} is still used for computations of impacts; the negative value just indicates that the computations may not be completely valid for this region.

Maximum Scour Routine

The scour routine was developed by Garcia et al. (1998) and is based on Garcia and Parker (1991) sediment entrainment equation. The scour routine uses one routine for scour (VRSCOUR) away from the boat where return velocity is the dominant mechanism producing scour. Another routine for scour (PROPSCOU) is used near and beneath the tow.

VRSCOUR

VRSCOUR is based on a dimensionless time-history of return velocity shown in the NAVEFF source code in Appendix B and developed in Maynord and Martin (1997). The dimensionless time-history of return velocity is converted into a time-history of return velocity using the maximum return velocity from NAVEFF. The time-history of velocity is changed into a time-history of bed shear stress using the equation from Blaauw et al. (1984):

$$\tau = 1/2\ \rho\ cfc \left(Va_{Cell} + \sqrt{\frac{cfr}{cfc}}\ V_r \right)^2 \tag{7}$$

where

τ = bed shear stress

ρ = water density

Va_{Cell} = depth-averaged ambient velocity from RMA-2 numerical model or the Alpha method

The friction coefficient, cfr, for return velocity, V_r, is defined as

$$cfr = \left[2.87 + 1.58 \log_{10} \left(\frac{x}{k} \right) \right]^{-2.5} \tag{8}$$

where

x = distance from initiation of boundary layer development and conservatively set to 1 m

$k = 3\ D_{50}$

D_{50} is the value from the midpoint data set presented previously. The friction coefficient for ambient flows is

$$cfc = \frac{0.06}{\left[\log_{10}\left(\frac{12\,dep}{k}\right)\right]^2} \tag{9}$$

where *dep* = local depth at center of cell.

Use of the time-history of bed shear stress generated from return velocity to determine scour will be presented subsequently.

PROPSCOU

The first step in the propeller scour routine is to determine the amount of propeller thrust required to propel the tow at the given speed. The power versus speed relations given in Maynord (2000a) were used with roughness allowance (increase of friction resistance above hydraulically smooth boundary) Δ_{cf} = 0.00075, pressure coefficient C_p = 0.20, kinematic viscosity of water ν = 0.00000112 m^2/sec, and a semi-integrated tow. The applied power from the equations in Maynord (2000a) is multiplied by 1.2 to provide the installed power of the towboat. The installed horsepower (IHP) of the towboat is used only to estimate the propeller diameter based on unpublished data from tows on the Ohio River, which resulted in the following equation for Kort nozzle propellers

$$D_p = 0.16\ IHP^{0.33} \tag{10}$$

where

D_p = propeller diameter, m

IHP = installed power, hp

For open wheel propellers

$$D_p = 0.133\ IHP^{0.35} \tag{11}$$

D_p is limited to a maximum of 2.8 m and a minimum of 1.8 m. The distance between propeller centerlines is set equal to 2.19D_p, and all towboats are assumed to be twin-screw towboats.

PROPSCOU is based on a dimensionless time-history of shear shown in the NAVEFF source code in Appendix B that was developed in Maynord (2000b). The dimensionless shear is based on values measured in a physical model and uses one distribution for the shear under the bow of the barges and another under the propeller jet. Determination of the peak shear used to convert the dimensionless shear distribution into a time-history of shear is described in Maynord (2000b). The model values of shear were measured on a smooth boundary and converted to shear on a rough surface using the plot from Maynord (1998), which is described by the equation

$$\frac{\tau(rough)}{\tau(smooth)} = 7.87\, D_{50}^{\;0.18} \qquad (12)$$

where D_{50} is measured in meters and is from the midpoint data set described previously.

Scour calculations

After the time-history of shear is determined in either VRSCOUR or PROPSCOU, the scour computations are the same. A time step of 0.1 sec is used to determine the time-history of scour. From Garcia et al. (1998), Engelund and Fredsoe (1976) equation is used to estimate the dimensionless bedload transport per unit width, q^*, at each time step and given as

$$q^* = 18.74 \left(\tau^* - \tau_c^*\right) \left[\left(\tau^*\right)^{0.5} - 0.7 \left(\tau_c^*\right)^{0.5}\right] \qquad (13)$$

where

τ^* = dimensionless shear stress

τ_c^* = 0.05 = dimensionless critical Shields stress.

The bedload transport per unit width q_b is

$$q_b = q^* \sqrt{g\ (S_g - 1)\ D_{50}}\ D_{50} \qquad (14)$$

where

g = gravity

S_g = specific gravity of sediment

The dimensionless shear stress is

$$\tau^* = \frac{\tau}{\rho g\left(S_g - 1\right) D_{50}} \qquad (15)$$

Garcia and Parker use a shape factor to convert the concentration at the bed C_b to a depth-averaged concentration, C, according to

$$C_b = r_0\, C \qquad (16)$$

The shape factor r_0 is defined as

$$r_0 = 1 + 31.5\left(\frac{U*}{v_s}\right)^{-1.46} \quad (17)$$

where

$U*$ = shear velocity = $(\tau/\rho)^{0.5}$

v_s = fall velocity of sediment

For some of the larger values of shear stress computed in NAVEFF, the shape factor according to Equation 9 became much larger than any of the values used by Garcia and Parker (1991) in the development of their equation. Therefore, the maximum value of r_0 from the Garcia and Parker data of 87.7 was used as an upper limit for r_0. The suspended sediment concentration equation is solved numerically as

$$C_{new} = C_{old}\left[1 - \frac{\Delta t\ v_s\ r_{0(old)}}{dep}\right] + \frac{\Delta t\ v_s\ E_{s(old)}}{dep} \quad (18)$$

where

C_{new} = concentration at present time step

C_{old} = concentration at previous time step (equal 0 at first time step)

Δt = time step = 0.1 sec

E_s = sediment entrainment coefficient defined as

$$E_s = \frac{A_{Z_u^5}}{\left(1 + \frac{A}{0.3} Z_u^5\right)} \quad (19)$$

where $A = 1.3(10)^{-7}$ and the similarity variable Z_u is

$$Z_u = \frac{U*}{v_s} R_{ep}^{0.6} \quad (20)$$

where the particle Reynolds number is defined as

$$R_{ep} = \frac{(\sqrt{g\ \ S_g\ -\ 1)\ D_{50}}\ D_{50}}{\nu} \quad (21)$$

where ν = kinematic viscosity of water. The final step is the Exner equation defined by Garcia et al. (1998) as

$$\eta = \frac{-1}{1-\lambda_p}\left(\frac{q_b}{V_g} + dep\ C_{new}\right) \quad (22)$$

where

η = scour depth

λ_p = porosity = 0.3

V_g = tow speed relative to ground.

The scour computations were conducted for the entire time-history of shear and the maximum scour depth during the passage of the tow was output from NAVEFF.

Input and Output Files

Pool numbers used in file names are defined as follows: Pools 2-5 are 02-05. Pool 5A is 95. Pools 6-25 are 06-25. Pool 96 is the Melvin Price pool above the confluence of the IWW, and Pool 26 is Melvin Price below IWW from RM 203-217.5. Lagrange on the IWW is Pool 31. Some of the information that follows is similar to that given in the GIS coverages, but the following paragraphs document file format and order of variables for input and output.

Input files

Input files are listed below.

P*_elev.dat. The * is the 2-character pool number. This file contains the river mile, cell ID, northing and easting coordinates of the cell center, bottom elevation of the cell center, ambient velocity at low, medium, and high flow, bed sediment D_{50}, bed sediment fall velocity, sediment ID#1 (3 for noncohesive, 2 for cohesive), sediment ID#2 (1 for cohesive-soft, 2 for cohesive-medium) for each cell. In some cells, sediment data was not available, and a value of 9999.0 was entered for all sediment-related fields. The file begins with the 1st cell on the left (looking downstream) of the most downstream cross-section in the particular pool and continues with cells across that cross-section until reaching the last cell on the right. The left and right cells represent the limits of the bathymetric data and are often farther away from the channel centerline than the left bank and right bank that will be defined in the P*_chan.dat file. The next upstream cross-section is presented, also going from left to right until reaching the last and most upstream cross-section in the pool. UMR trend pools have cross-sections every 0.5 mile, whereas LaGrange trend pool on the IWW and all nontrend pools on both the UMR and IWW have cross-sections every mile. All cells are 10 m wide. The file format is shown in Table 9.

Table 9 **Cell Information About a Cell's Midpoint at Each River Mile (ASCII File Format, Comma Delimited)**				
Cell Information Input File (ex. P*_ELEV.DAT)				
Variable	**Description**	**Type**	**Format**	**Example**
RIVER_MI	River mile	Numeric	5.1	523.5
CELL_ID	Cell ID	Character	10	305L5235
XCOORD	Midpoint X-coordinate	Numeric	12.1	713255.2
YCOORD	Midpoint Y-coordinate	Numeric	12.1	4681465
MSL_M	Mean sea level elevation at flat pool (m)	Numeric	8.3	179.821
AMBVEL_L	Ambient current velocity at low stage (m/s)	Numeric	8.3	0.141
AMBVEL_M	Ambient current velocity at medium stage (m/s)	Numeric	8.3	0.291
AMBVEL_H	Ambient current velocity at high stage (m/s)	Numeric	8.3	0.346
D50_GSZ_MM	D50 particle grain size (mm)	Numeric	8.3	0.081
D50_VEL_CMS	D50 particle fall velocity (cm/s)	Numeric	8.3	0.531
COH_SED	Cohesive sediment	Numeric	6	2
COH_CLASS	Cohesive class for Group 2	Numeric	6	2

P*_lr.trf. This file contains which tows will be run in NAVEFF. The file format is given in Table 10.

Table 10 **Traffic Configuration (ASCII File Format, Comma Delimited)**				
Traffic Input File (ex. P*_LR.TRF)				
Variable	**Description**	**Type**	**Format**	**Example**
RIVER_MI	River mile	Numeric	5.1	523.5
DIR	Upbound/downbound	Character	1	U
SPEED	Fast/medium/slow	Character	1	F
SIZE	Big/medium/slow	Character	1	M
DRAFT	Load/mixed/empty	Character	1	E
TURBINE	Open wheel/Kort nozzle	Character	1	O
STAGE	High/medium/low	Character	1	L
SL_POS	Left/middle/right	Character	1	R

Pool*.dat (or called P*_lmh.dat). This file contains the river mile and water surface elevations at low, medium, and high discharges for that river mile. The file begins at the most downstream cross-section of a pool and proceeds upstream to the last cross-section in a pool. The file format is given in Table 11.

Table 11
Water Stages At Each River Mile (ASCII File Format, Comma Delimited)

Water Stages at Each River Mile (ex. P*_LMH.DAT)				
Variable	**Description**	**Type**	**Format**	**Example**
RIVER_MI	River mile	Numeric	5.1	523.5
LSTG_MSL_M	Low stage value in msl (m)	Numeric	8.2	177.49
MSTG_MSL_M	Medium stage value in msl (m)	Numeric	8.2	177.76
HSTG_MSL_M	High stage value in msl (m)	Numeric	8.2	177.88

P*_sail.dat. This file defines the left, middle, and right sailing line position, which does not vary with stage. The file format is shown in Table 12.

Table 12
Sail Line Position for All Three Stages at Each River Mile (ASCII File Format, Columnar)

Sail Line Position (P*_SAIL.DAT)				
Variable	**Description**	**Type**	**Format**	**Example**
RIVER_MI	River mile	Numeric	5.1	523.5
LSTG_LSL	Cell ID location of left sailing line at low stage	Character	10	305L5235
LSTG_MSL	Cell ID location of middle sailing line at low stage	Character	10	55L5235
LSTG_RSL	Cell ID location of right sailing line at low stage	Character	10	205R5235
MSTG_LSL	Cell ID location of left sailing line at medium stage	Character	10	305L5235
MSTG_MSL	Cell ID location of middle sailing line at medium stage	Character	10	55L5235
MSTG_RSL	Cell ID location of right sailing line at medium stage	Character	10	205R5235
HSTG_LSL	Cell ID location of left sailing line at high stage	Character	10	305L5235
HSTG_MSL	Cell ID location of middle sailing line at high stage	Character	10	55L5235
HSTG_RSL	Cell ID location of right sailing line at high stage	Character	10	205R5235

P*_parm.dat. This file contains tow characteristics. The file format is shown in Table 13.

Table 13
Tow Characteristics for UMRS (ASCII File Format, Text)

Boat Characteristics (P*_PARM.DAT)			
Position 1	**Position 2**	**Position 9**	**Remark**
#	Speed		
S	2.24		Slow speed (M/S)
M	2.91		Medium speed (M/S)
F	3.58		Fast speed (M/S)
(Blank Row)			
			(Continued)

Table 13 (Concluded)			
Boat Characteristics (P*_PARM.DAT)			
Position 1	**Position 2**	**Position 9**	**Remark**
#	Size		
L	10.67	(1 Blank)45.72	Light size (M)
S	10.67	178.31	Small size (M)
M	21.34	237.74	Medium size (M)
B	32.00	297.18	Big size (M)
(Blank Row)			
#	Draft		
L	2.74		Loaded (M)
M	2.13		Mixed (M)
E	0.61		Empty (M)

P*_chan.dat. This file contains location of the left and right bank for low, medium, and high flows. The file format is shown in Table 14.

Table 14 Bank Positions for All Stages at Each River Mile (ASCII File Format, Columnar)				
Bank Positions (P*_CHAN.DAT)				
Variable	**Description**	**Type**	**Format**	**Example**
RIVER_MI	River mile	Numeric	5.1	523.5
LSTG_LBK	Cell ID location of left bank line at low stage	Character	10	405L5235
LSTG_RBK	Cell ID location of right bank line at low stage	Character	10	305L5235
MSTG_LBK	Cell ID location of left bank line at medium stage	Character	10	505L5235
MSTG_RBK	Cell ID location of right bank line at medium stage	Character	10	605L5235
HSTG_LBK	Cell ID location of left bank line at high stage	Character	10	905L5235
HSTG_RBK	Cell ID location of right bank line at high stage	Character	10	805L5235

Output file

The NAVEFF output file is P*_#$.out and is created for each of the nine combinations of three sailing lines and three stages. The # is either H, M, or L for high, medium, or low stage, and the $ is L, M, or R for left, middle, or right sailing line. The output file starts at the downstream cross-section of the pool and provides output for the first of the 108 tow combinations for every cell beginning with the left bank and terminating at the right bank as defined in the P*_chan.dat file. Output for every cell in the cross-section is provided for each of the 108 tow combinations before going to the next upstream cross-section. File format is shown in Table 15.

Table 15
NAVEFF Output Variables Computed for Every Cell Midpoint, for Low Stage and Right Sailing Line, at Each River Mile (ASCII File Format, Comma Delimited)

NAVEFF Output Variables				
Variable	**Description**	**Type**	**Format**	**Example**
RIVER_MI	River mile	Numeric	5.1	523.5
DIR	Upbound/downbound	Character	1	U
SPEED	Fast/medium/slow	Character	1	F
SIZE	Big/medium/small	Character	1	B
DRAFT	Load/mixed/empty	Character	1	L
TURBINE	Open wheel/Kort nozzle	Character	1	O
STAGE	High/medium/low	Character	1	H
SL_POS	Left/middle/right	Character	1	L
TRAFFIC	Variables 2 thru 6 concatenated	Character	5	UFBLO
STG_SL	Variables 7 and 8 concatenated	Character	2	HL
CELL_ID	Cell ID	Character	10	305L5235
DEPTH	Depth (M)	Numeric	6.2	3.55
VEL_CHANGE	Maximum velocity change (M/S)	Numeric	7.3	0.205
DRAWDOWN	Drawdown (M)	Numeric	7.3	0.107
SL_DIST	Distance from sailing line (M)	Numeric	7.1	20.8
SEC_WH	Secondary wave height (M), Flag = -9.000	Numeric	7.3	0.107
MX_SCOUR	Maximum scour (M), Flag = 9999.000	Numeric	9.4	-0.1816
MX_SHEAR	Maximum shear stress (PA), Flag = 9999.000	Numeric	9.4	176.2432
AMB_FLUX	Ambient flux (particle/particle by vol.) Flag = 9999.0000	Numeric	12.7	0.0001112
MX_AFLUX	Maximum ambient flux (particle/particle by vol.) Flag = 9999.0000	Numeric	12.7	0.2848123
AMB_SHEAR	Ambient shear stress (PA), Flag = 9999.000	Numeric	9.4	176.2432

On each line of output in the NAVEFF output file, the following is provided:

(1) River mile.
(2) Up (U) or downbound (D).
(3) Speed slow (S), medium (M), or fast (F).
(4) Tow size small (S), medium (M), or big (B).
(5) Draft empty (E), mixed (M), or loaded (L).
(6) Kort (K) or open (O) wheel propellers.
(7) Stage low (L), medium (M), or high (H).
(8) Sailing line location left (L), middle (M), or right (R).
(9) Five-character tow descriptor combining items 2-6 such as UFBLO for upbound, fast, big tow, loaded, open wheel.
(10) Two-character stage/sailing line descriptor combining items 7-8 such as LM for low stage, middle sailing line.
(11) Cell ID, such as 75L5230, which is the 10-m-wide cell whose center is 75 m left (looking downstream) of a reference line that is generally (but not always) close to the middle sailing line. The cell is located at RM 523.0.
(12) Depth at middle of cell in meters.

(13) Computed maximum velocity change from ambient conditions, in meters per second. One tow width away from the center of the tow out to the bankline, the maximum velocity change is the maximum return velocity as determined in Maynord (1996). From one tow width on the left side of the tow to one tow width on the right side of the tow, the maximum return velocity is interpolated between the two points. Under the tow the maximum velocity change will be the maximum of (a) the maximum return velocity, or (b) the velocity change at the bow of the tow, or (c) the maximum velocity from the propeller jet. Between the edge of the tow and the point one tow width away from the tow centerline, the program determines maximum velocity change by interpolating between the maximum return velocity at one tow width away from the center of the tow and the maximum velocity under the edge of the tow. Equations are presented in Maynord (2000b). For wide sections having a deep center section such as in areas just upstream of the navigation dam, the routine for return velocity was modified and will be described subsequently.

(14) Maximum drawdown, in meters. One tow width away from the center of the tow out to the bankline, the maximum drawdown is calculated in NAVEFF according to Maynord (1996). From one tow width on the left side of the tow to one tow width on the right side of the tow, the maximum drawdown is interpolated between these two points.

(15) Distance of cell from centerline of tow, in meters.

(16) Maximum secondary wave height, in meters. Because the wave equations are not meaningful at the tow, -9.0 is output if the center of the cell is less than 14 m from the edge of the barge. If the secondary wave height/cell depth was greater than 0.6, the secondary wave height was output as a negative value.

(17) Maximum scour during passage of tow, in meters. The equations used in the scour routine will be presented subsequently. If sediment data was not available, a 9999.0 was output in this field and in fields 18-21.

(18) Maximum bed shear stress, pascals. Equations are presented in Maynord (2000b).

(19) Ambient sediment concentration in parts/part calculated using the Garcia and Parker (1991) equation and the ambient bed shear stress. (This does not include wash load, which is one of the reasons the values are less than measured total concentration).

(20) Maximum sediment concentration in parts/part using Garcia and Parker (1991) and the maximum shear stress.

(21) Ambient shear stress, in pascals. Based on mean velocity logarithmic equations with $K_s = 3\ D_{50}$.

7 NAVSED Model

The NAVSED model uses output from the NAVEFF model and computes a time-history of sediment concentration based on the effects of waves, shear at the bow of the barges, propeller jet effects, return velocity, and ambient conditions. The concentration given is the combined concentration of both fines and sand. The NAVSED model is documented in Copeland et al. (2001). Two-dimensional numerical sediment modeling conducted in Copeland's study for several of the trend pools was used to develop a set of curves to define the distribution and time-history of sediment concentration used in NAVSED.

Revisions to Wave Resuspension Algorithm

Revisions were made to the wave resuspension coefficients in the NAVSED model to better reproduce observed field data in cohesive sediments in 1.5-m depths or less. Additionally, a modification was necessary in extremely shallow cells.

Cohesive sediments on the UMR system are classified as soft, medium, or hard. Copeland et al. (2001) discusses the determination of these classifications. Only a small portion of cells in the UMR system data are classified as cohesive and most are in the shallow near shore zone where wave activity can resuspend sediments. For example, of the cells having sediment data in pool 13, only 8 percent are classified as cohesive. It should be noted that none of the cohesive sediments on the UMR system are classified as hard.

The majority of the field data in Bhowmik et al. (1998) show no significant resuspension at 1.5 m depth or greater in the near shore zone, and vessel effects measurements have been taken in 0.5 m water depth or greater. The original NAVSED program and all versions discussed herein limit depth used in the wave resuspension calculation to a minimum of 1.2**Hmax*, which is required for the wave model to be applicable. *Hmax* is the maximum wave height from the vessel which is the value shown in the NAVEFF output files. The wave resuspension algorithm in NAVSED contains an option to include currents and waves together in calculating resuspension. The algorithm is extremely sensitive to currents of any significant magnitude. For that reason, the NAVSED wave resuspension algorithm is run with currents set to zero because of this sensitivity to current. Current effects are addressed in NAVSED in the return velocity portion of the resuspension model.

The NAVSED model uses the erosion rate constants a_r and b_r used in Equation 7 from Parchure et al. (2001):

$$s = s_{\max} e^{-a_r \tau_s^{b_r}} \tag{23}$$

The values of a_r and b_r were originally set to 8.0 and 0.5, respectively, for all cohesive sediment types. In a report by the developer of the wave/sediment model used in the NAVSED model, Lee and Mehta (1994) report the values of a_r and b_r shown in Table 16 for seven different sediment types. None of the seven sediment types can be correlated to the soft and medium UMR system sediments, but the a_r and b_r are presented to show the range of a_r and the relatively constant b_r.

Table 16
Values of a_r and b_r from Lee and Mehta (1994)

Group	a_r	b_r
1	1.345	0.368
2	2.892	0.372
3	3.905	0.356
4	4.938	0.355
5	6.594	0.382
6	9.011	0.386
7	10.582	0.252

The approach taken herein is to adopt the average value of b_r from Lee and Mehta (1994) from Table 16, which is 0.35, and use field data to determine the appropriate value of a_r for soft and medium sediments. The field data are from Bhowmik et al. (1998) and the sampling techniques are described therein. The data are from the Apple River site on the Mississippi River (RM 546.4, Pool 13) and Kampsville trip #1 on the Illinois Waterway (RM 35.2, Alton Pool). Pertinent details and data from each site are presented in the following paragraphs.

Apple River

At Apple River, the two sediment sampling meters in water depths of 0.5 and 1.0 m showed increases in concentration during tow passage for most tows. The sediment meters in 1.7 m and 3.1 m of water depth showed increases during tow passage for only two of the tows. These results show that wave activity is the dominant sediment resuspension mechanism in the near shore zone because return velocities were small and propeller resuspension too far from the bank for the relatively large channel at Apple River. Both sediment sampling meters were 0.15 m above the bed. The primary concern with the Apple River data is with the sediment type. Bed sediment sizes in Bhowmik et al. show the site to be predominately sand. The UMR-IWW classifies the site as having sand in the main channel but medium cohesive sediment in the shallow near shore zone. Computations for this comparison with field data were based on cohesive medium sediment in the near shore zone because the observed values in Table 17 are much larger than expected for the stated wave heights if the bed material was sand. Different values of a_r were tried with the Apple River data. Table 17 shows the data for the selected tows that were used to determine an a_r = 6.5 for medium cohesive sediments.

Table 17
Resuspension Data from the Apple River Site on the Mississippi River, Medium Sediments

Tow	Measured *Hmax*, m	Water Depth, m (distance meter above bed, m)	Measured Peak Concentration Change from Ambient, mg/L	Computed Peak Conc Change, Recommended a_r= 6.5 and b_r = 0.35 for Medium Sediments
Rusty Flowers	0.122	0.5 (0.15)	60	99
		1.0 (0.15)	20[1]	0
Tom Talbert	0.29	0.5 (0.15)	545	1474
		1.0 (0.15)	200	154
Walter Brunson	0.122	0.5 (0.15)	65	99
		1.0 (0.15)	25[1]	0

[1] Small changes in concentration have a high degree of uncertainty.

While sediment data were collected, the following tows were not chosen for this comparison (the reason they were not selected is also indicated):

- *Merlin Banta*, very little change in concentration.
- *Herman Potter* and *Julia Swain* passed just before *Herman Potter*.
- *Dell Butcher*, very little change in concentration.
- *Mary Gail#1*, *T.S. Kunsman*, and *D Ray Miller*, all passed within a period of 36 min, which made it impossible to determine the effect from a single tow.
- *Mary Gail#2* and *Mississippi Belle II* passed 12 min earlier.
- *Jack D. Wofford* and *Trojan*, passed the site within 10 min of each other.

Kampsville trip #1

At Kampsville, the sediment meters were in 1.0, 1.6, 2.6, and 4.0 m of water depth. Almost every tow produced an increase in concentration at the two meters in 1.0 m of water depth. About 50 percent of the tows showed an increase in concentration at the two meters in 1.6 m of depth. Few of the tows showed increases at depths of 2.6 m and 4.0 m. One complicating factor during trip #1 was that the water depth rose 0.47 m during the field experiments. Depths at the sediment meters were adjusted to reflect the changing stage for computations. Another factor was the sediment type. The IWW has much finer sediments than the Mississippi River as evidenced by far more locations in the UMR-IWW data base on the IWW having cohesive soft as compared to the Mississippi River. The Bhowmik et al. (1998) bed samples were cohesive medium based on the grain sizes but were not taken in the shallowest zone where the two meters in the shallowest depth were located. The concentration changes at the Kampsville site were larger than on the Apple River site for the same wave height and depth. In addition, the suspended sediment grain-size distribution during passage of a tow event, although coarser than ambient conditions, reflected a sediment closer to a cohesive soft sediment. For these reasons, the Kampsville site was classified as cohesive soft. A final complicating factor at Kampsville was that the return velocities measured at this site were large compared to the Mississippi River and were almost certainly contributing to the observed concentrations. For this reason, comparisons were limited to the tows having the largest waves with the expectation that wave resuspension would be the dominant mechanism, at least in the shallow near shore zone. By using these data, which had a contribution from return velocity, results will be conservative for areas where return velocity is small. Field data for soft sediments subject only to wave activity were not available. Comparisons were only made for the meter in 1.0 m of water depth because the changes at 1.6 m of water depth were small. Several values of a_r were tested with the wave heights and depths in Table 18. Table 18 shows the data for the tows having wave heights greater than 0.15 m and the computed concentration using a_r = 7.0 for soft sediments.

Table 18
Resuspension Data from Kampsville Trip #1 Site on IWW, Soft Sediments

Tow	Measured *Hmax*, m	Water Depth[1], m (distance meter above bed, m)	Measured Peak Concentration Change from Ambient, mg/L	Computed Peak Conc Change, mg/L, Recommended a_r = 7.0 and b_r = 0.35 for Soft Sediments
Luke Burton[2]	0.244	0.98 (0.15)	290	798
		0.98 (0.46)	165	798
Mr Lawrence	0.168	1.02 (0.15)	290	248
		1.02 (0.46)	135	248
Nicole Brent	0.229	1.23 (0.15)	260	277
		1.23 (0.46)	145	277
Frank Peavey	0.153	1.23 (0.15)	40	41
		1.23 (0.46)	40	41

[1] Depth changes because of changing stage during field experiments.
[2] Although the *Sugarland* closely followed the *Luke Burton*, *Sugarland* is being ignored because it had a much lesser wave height (0.092 m).

Computed concentrations from the original NAVSED model for typical wave height and depths are shown in Table 19. The 0.5-m depth in Table 19 was selected because it is the minimum depth for which sediment concentration measurements have been made for vessel effects. The 1.0-m depth is typical for sediment measurement sites for vessel effects.

Table 19 **Computed Peak Concentrations for Typical Wave Height and Depths**					
			Concentration, mg/L		
Sediment Type	***Hmax*, m**	**Depth, m**	**NAVSED Original, a_r= 8.0, b_r = 0.5, All Sediment Types**	**NAVSED Lab, a_r= 8.0, b_r= 0.2 for Soft, a_r= 9.0, b_r= 0.15 for Medium**	**NAVSED Recommended, a_r= 7.0, b_r= 0.35 for Soft, a_r= 6.5, b_r= 0.35 for Medium**
Soft	0.15	0.5	3566	283	1856
		1.0	343	27	179
Medium		0.5	299	8	232
		1.0	<5	<5	<5

While the 299- and 343-mg/L values for the original a_r and b_r seem reasonable based on observed sediment measurements in Tables 17 and 18, calculated values of 3,566 mg/L are well above measured values under any condition. Consideration was given to using laboratory values of a_r and b_r determined for UMR-IWW sediments, which were a_r = 8.0 and 9.0 for soft and medium sediments, respectively, and b_r = 0.2 and 0.15 for soft and medium sediments, respectively. These values were based on lab tests at the U.S. Army Engineer Research and Development Center (ERDC) of the actual UMR-IWW soft and medium sediments. Computed concentrations using these a_r and b_r are shown in Table 19 for the typical wave height and depths and are generally lower than observed field data. Concentrations for the typical depths and wave heights are shown in the last column of Table 19 for the recommended a_r = 7.0 and b_r = 0.35 for soft sediments and a_r = 6.5 and b_r = 0.35 for medium sediments. Plots of peak sediment concentrations versus maximum wave height versus depth for the NAVSED model with the recommended a_r and b_r are shown in Figures 10 and 11 for soft and medium sediments, respectively.

In addition to adjustments in the coefficients, a modification was necessary in shallow depth cells. When the cell depth is small, extremely large concentration time-histories can result. Some cells on the UMR-IWW have depths as low as 0.08 m, and the wave and sediment algorithm with the recommended a_r and b_r for soft sediment gives concentrations of 16,800 mg/L for a 0.06-m maximum wave. This is simply a result of using the algorithm for values outside the intended range for which it was developed. According to Nana Parchure (Coastal and Hydraulics Laboratory, ERDC, personal communication), concentrations of greater than 1,000 mg/L should not be expected for the non-breaking waves being addressed. To address shallow depths for which field data are not available (<0.5 m), concentrations from the wave algorithm will be limited to 3,000 mg/L for soft sediments and 1,500 mg/L for medium sediments to address the need for wave resuspension values outside the applicable range of the algorithm. These relatively large limits provide a crude application of these nonbreaking wave algorithms to a breaking wave environment.

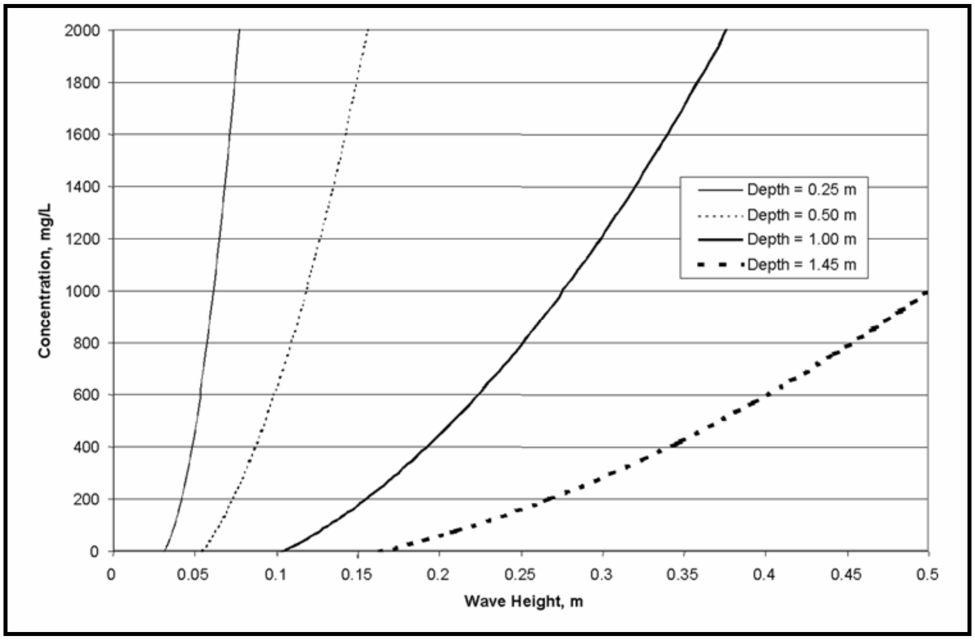

Figure 10. Peak computed sediment concentration, soft sediment

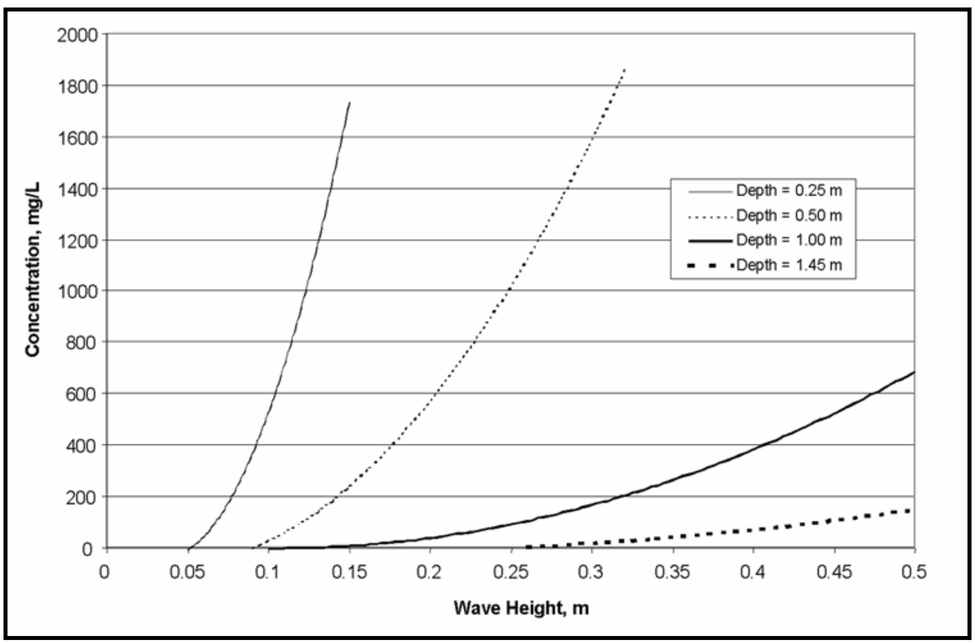

Figure 11. Peak computed sediment concentration, medium sediment

Revisions for Backwater/Secondary Channel Sediment Loading Calculations

In analyzing the amount of sediment entering backwater and secondary channels, the sediment concentration time-history at a representative shoreline cell was selected to describe the sediment input to the inlet. The sensitivity of the wave resuspension algorithm to depth impacted the calculated concentration at the inlet when using the actual inlet depth. Inlets with a midpoint depth at the representative cell of 1.7 m would have no resuspended sediments and thus no sediment entering the inlet, whereas an inlet with a midpoint depth of 1.0 m at the representative cell would have sediment resuspension and sediment entering the inlet. In reality, both cells would have some portion of the shoreline cell where the depth was low enough for sediment resuspension and both cells would contribute some sediment to the inlet. In computing the sediment concentration at the representative shoreline cell for backwaters and secondary channels, the following rules were used:

a. For inlets having representative cell depth less than or equal to 0.5 m, the actual depth was used in the calculations, and no modifications were made to the NAVSED calculations for the sediment concentration.

b. For inlets having a representative cell depth greater than 0.5 m, a fixed depth of 0.5 m was used to compute the sediment concentration. The next step was to ratio the concentration based on 0.5-m depth using the actual cell depth according to

$$C_{BW} = C_{0.5\ m\ \ depth} \frac{0.25}{\left(depth_{actual}\right)^2} \tag{24}$$

where C_{BW} = sediment concentration used in backwater and secondary channel loading calculations.

8 Rollup of Models

The enormous amount of output from NAVEFF and NAVSED had to be reduced to a usable size and presented in a risk-based format to use in both the sediment and ecological modeling. For example, Pool 13 had 68 cross-sections with up to 400 cells per cross-section. One of the nine NAVEFF files for the nine combinations of stage and sailing line had over 143,000 lines of output. This section describes how the data were reduced to a statistical/risk-based format.

Rollboat Program

Rollboat (Bartell, unpublished) outputs the distribution of the 108 tow types for the three stages and sailing lines according to their probability of occurrence. The probability of occurrence is based on the LPMS data and varies by pool and month. Input to Rollboat is a specified number of tow events (sample size to be only large enough to prevent significant effects from too small of a sample; does not have anything to do with traffic levels), a specified month, and a specified pool. Rollboat outputs each event such as UFBMK MR, which stands for upbound, fast, big tow size, medium draft, Kort nozzle, at medium stage, and on the right sailing line according to the probability of occurrence of that tow in that month and that pool. (The description of the NAVEFF output file P*_#$.out describes the different letters describing a tow). For example, if UFBMK MR represents 3 percent of all tows and the sample size is 5,000 tows, UFBMK MR should show up about 150 times in the output file. Output files from Rollboat are named P13_04_5000.smp and were developed for each navigable month of the year. The 04 stands for the month April, and the 5000 stands for the sample size. For example, Pool 13 had nine P13_*_5000.SMP files for months 03-11 because months 12-02 are not navigable.

Histogram Program

A histogram program was developed to determine the distribution of physical forces and sediment parameters using the tow events prescribed in the *.SMP files. Whether it was the NAVEFF output or the NAVSED output, all nine output files (nine combinations of three stages and three sailing lines) had to be opened to gather the appropriate physical force or sediment parameter and store the selected sample in a temporary file for analysis. For the output of the physical forces from the NAVEFF program and the sediment output from NAVSED, histograms were developed for sample sizes of 500, 1,000, 2,000, 5,000, and 10,000 tow events using the Rollboat program. The histograms were compared for the various sample sizes and it was found that a sample size from Rollboat of 5,000 tow events was required to produce a distribution that did not vary significantly from histograms developed using larger sample sizes. Even with this relatively large sample size, some variation was found in the sample, which led to the use of the same rollboat file for a given pool and month for all analysis. Had there been a new rollboat file generated every time a new traffic scenario was developed, there would have been a small amount of variation in the navigation effects attributable to differences from sample to sample.

The challenge in developing the histogram program was that the distribution had a large percentage of near zero values with a small percentage of relatively large values, particularly for the sediment parameter to be described subsequently. Describing the distribution required a large number of classes. The first step in the histogram was to determine the average and maximum value of the parameter of interest. Next a parameter "ratio" was defined as 10(max value)/(average value) that was used to define the class width. Ratio was not allowed to exceed 1,000 or be less than 25. For relatively uniform distributions, ratio was small. For extremely nonuniform distributions like the UMR system sediment parameters, ratio often was large, number of classes was large, and class width was small. Class width was defined as (average value)/ratio. The number of values were counted in each class, and a cumulative percentage or probability was determined based on the total number of values of 5,000. From this cumulative probability, values of the specified parameter were determined at probabilities of 0.1 - 0.9 in increments of 0.1. *These probabilities are the values for nonexceedance by a single tow.* The program outputs nonexceedance probability, but most of the histograms in this study are presented as probability of exceedance. The output for each parameter of interest contained the minimum value of the 5,000 entries, the nine values of the parameter for probabilities of 0.1 - 0.9, and the maximum value of the 5,000 entries for a total of eleven values. Output from the histogram program was checked against the output from a spreadsheet sort program and found to be in agreement. The histogram routine is a subroutine in NAVFPROB, NAVSEDPR, and BWMASSPROB.

Rollup Program NAVFPROB

NAVFPROB develops a histogram of the physical forces output from NAVEFF. The histogram routine is a subroutine in NAVFPROB. Input files to NAVFPROB were *.SMP files from rollboat and all nine NAVEFF output files. Results from NAVEFF were rolled up into the following format: (1) cellid, (2) 11 values of maximum velocity change, m/sec, (3) 11 values of maximum drawdown, m, (4) 11 values of maximum secondary wave height, m, (5) 11 values of maximum scour, m, and (6) 11 values of maximum bed shear stress, pascals. NAVFPROB outputs a file containing all cells in a single cross-section for a single month with filenames such as P13_523.0_05.NFP. This file was for Pool 13, the cross-section at RM 523.0, and the month of May.

Rollup Program SPAWNROL

The ecological models needed various outputs from the NAVFPROB rollup and other information not in the *.NFP files. For the fish spawning study, ambient velocity, depth, and bed material D_{50} were needed to determine the initial habitat conditions. Values of maximum velocity change and maximum substrate scour were obtained from the *.NFP files to determine the modifiers to the habitat conditions. The ambient velocity, depth, and D_{50} were taken from P*_elev.dat and Pool*.dat. The ambient velocity and depths at the three different stages were combined into a representative value for the month determined for depth as

$$Dep_{rep} = \frac{Dep_{low\,Q}(\%\,low\,Q) + Dep_{medium\,Q}(\%\,medium\,Q) + Dep_{high\,Q}(\%\,high\,Q)}{100} \tag{25}$$

The representative ambient velocity was determined in the same manner. Different values of percent low, medium, and high flow were used for the Mississippi River above the Missouri River, for the Mississippi River below the Missouri River, and for the Illinois Waterway as shown in Tables 3-5. In some cases, the high flow would have a cell that was not present at medium and/or low flow because of the change in water level. In these cases, a 9998.0 was output for both the representative ambient velocity and depth. In cases where there was no sediment data, a 9999.0 was output for both D_{50} and the maximum scour depth. The output file from SPAWNROL contained all cells in a pool for one specified probability. Each line of the file contains results for one cell, specifically (1) river mile, (2) cellid, (3) D_{50}, mm, (4) 12 monthly values of representative ambient velocity, m/sec, (5) 12 monthly values of representative depth, m, (6) 12 monthly values of maximum velocity change for the specified probability, m/sec, and (7) 12 monthly values of maximum scour for the specified probability, m. In many pools, navigation ceases in winter months, and a value of zero is entered for maximum velocity change and scour for months with no navigation. This zero is apparent in the entries for maximum velocity change but not so apparent for scour because many entries have zero scour for the number of digits that are output. A typical output filename is P13_spwn_p5.dat for pool 13, spawning data, and probability of 0.5 of non-exceedance by a single tow.

Rollup Program NAVSEDPR

The NAVSED model outputs a time-history of sediment concentration as a result of tow passage. One output file is created by NAVSED for each of nine combinations of three stages and three sailing lines. Required input to NAVSEDPR is the month of interest and the representative sediment concentration (based on measured values, shown in Tables 6 and 7 and percent of flows shown in Tables 3-5). The representative ambient sediment concentration is calculated as

$$Conc_{rep} = \frac{Conc_{lowQ}(\%\,low\,Q) + Conc_{mediumQ}(\%\,medium\,Q) + Conc_{highQ}(\%\,high\,Q)}{100} \tag{26}$$

For example, from Table 6, Pool 8, the low, medium, and high concentrations are 11, 19, and 33 mg/L, respectively. From Table 3 in June, the percent of low, medium, and high flow is 7.8, 57.3, and 34.8, respectively. The representative concentration for June in Pool 8 becomes [(11)(7.8) + (19)(57.3) + (33)(34.8)]/ 100 = 23.2 mg/L. NAVSEDPR uses the 5,000 tows specified in the *.SMP files from Rollboat for input. NAVSEDPR extracts the time-history of the sediment concentration from the appropriate NAVSED output file and computes the area under the time-history of the sediment concentration curve that is above the computed ambient concentration. This area is called the "SI" for sediment index and has units of sec(mg/L). NAVSEDPR also extracts the maximum concentration from the time-history of the sediment concentration. At this point a histogram is run on the SI and on the maximum concentration for the 5,000 values of each variable. Output from NAVSEDPR is one file per month and per cross-section. Each line of the output file describes one cell and presents (1) cellid, (2) 11 values of SI for probability of nonexceedance, sec(mg/L), (3) 11 values of maximum concentration for probability of nonexceedance, mg/L, and (4) representative ambient sediment concentration, mg/L. A typical output file is P13_523.0_05.NSP. The maximum sediment concentration is the combination of computed ambient and computed boat-induced resuspension. The computed ambient concentration in the nine NAVEFF output files is always less than the measured ambient shown in Tables 6 and 7 because the measured values contain wash load, which is a significant portion of the total measured concentration.

Rollup Program PLANTUM

The ecological model dealing with plants needed NAVSEDPR output in a format different from that in the *.NSP files. PLANTUM requires input from files P*_elev.dat and Pool*.dat to determine the representative depth for the month of interest. The representative concentration from Equation 26 is also input to PLANTUM as well as the *.NSP files from NAVSEDPR. The program outputs all cells in a pool for a specified month. Each line represents one cell and gives (1) cellid, (2) 11 values of SI for probability of nonexceedance, sec(mg/L), (3) 11 values of maximum concentration for probability of nonexceedance, mg/L, (4) representative ambient sediment concentration, mg/L, and (5) representative depth for specified month. A typical output file is P13_05.NSP for Pool 13 and month 05 (May). The omission of the river mile means the file is for the whole pool and differentiates the PLANTUM files from the NAVSEDPR files.

9 Larval Fish Entrainment

One element of the UMR-IWW study is evaluation of the mortality of larval fish as they are entrained in the propeller jet of towboats. Larval fish mortality depends on the amount of water entrained in the propeller jets, where the water originates in the channel, percent of larval fish that suffer mortality upon passage through the propeller jets, density of larval fish in the zone affected by the propeller jets, and mixing of the waterway between tows. These issues and results from the mortality studies are provided in Bartell et al. (2003).

In support of the larval fish studies by Bartell, the applied power and the resulting discharge through the propellers had to be calculated for mortality estimates. The applied power was based on Maynord (2000a) using $C_p = 0.15$, a local depth of 4.6 m, semi-integrated tow, average return velocity of 0.3 m/sec, and drawdown of 0.08 m. For small tows (10.7 m wide by 175.3 m long), the applied power for a fully loaded tow (2.74-m draft) having Kort nozzle propellers was determined as

$$HP_a = 151.3 + 40.0(V_{WMPH}) + 5.83(V_{WMPH})^2 + 1.38(V_{WMPH})^3 \tag{27}$$

where

Hp_a = applied power, hp

V_{WMPH} = tow speed relative to water, mph

For medium tows (21.3 m wide by 237.8 m long), the applied power for a fully loaded tow (2.74-m draft) having Kort nozzle propellers was determined as

$$HP_a = 327.8 + 64.8(V_{WMPH}) + 18.1(V_{WMPH})^2 + 1.80(V_{WMPH})^3 \tag{28}$$

For big tows (32.0 m wide by 297.3 m long) the applied power for a fully loaded tow (2.74-m draft) having Kort nozzle propellers was determined as

$$HP_a = 512.4 + 93.1(V_{WMPH}) + 33.6(V_{WMPH})^2 + 2.21(V_{WMPH})^3 \tag{29}$$

The above three equations are valid for V_{WMPH} from 2.5 to 8 mph. For open wheel tows, the applied power is 1.2 times HP_a from a Kort nozzle. For tows having drafts less than fully loaded, multiply HP_a by 0.87 for mixed tows having a 2.13-m draft and by 0.5 for empty tows having a 0.61-m draft. The simplified equations (27-29) and the adjustments for draft and type of propeller were used to prevent having to run the power model for each tow scenario. HP_a is used in the propeller discharge equations in Maynord (1999b) with a wake fraction of 0.85, and a propeller diameter of 2.0, 2.7, and 2.9 m for small, medium, and big tows, respectively. The representative velocity for mortality estimates is set equal to the average of the velocity at the plane of the propeller and the velocity increase caused by the propeller.

10 Summary and Conclusions

The UMR-IWW system model was used to evaluate the physical effects of commercial navigation traffic. The system model provided input to a range of ecological models to evaluate the impacts of increases in vessel traffic on fish, mussels, and other macroinvertebrates, and aquatic macrophytes. The system model also provides input to the evaluation of sedimentation of secondary channels and backwaters. Numerous other UMR-IWW reports present and utilize results from the system model. The purpose of this report is to document some of the assumptions and techniques used in the physical effects portion of the system model and is not intended to be a summary of the UMR-IWW study.

The system model begins with delineation of the planform and bathymetry of the UMR-IWW using a GIS framework. The UMR-IWW is described by cross-sections at 0.5-to 1.0-mile intervals, and each cross-section is divided into 10-m-wide cells. Each cell has known attributes concerning depth, ambient velocity, substrate characteristics, and location.

Low, medium, and high discharges, velocities, and water surface elevations are determined to address a range of ambient conditions. Next, traffic characteristics are defined such as size, speed, direction, type of propulsion, and sailing line location. These various combinations along with different ambient conditions define 972 different combinations that are used at each cross-section.

The bathymetry, ambient conditions, and traffic characteristics are input to the NAVEFF model to define tow-induced physical forces at each section. These forces are maximum velocity change, maximum drawdown, maximum wave height, maximum bed scour, and maximum shear stress on the river bed. Results from the system model were compared to the return velocity and drawdown field data not used in development of the model and were found to be in agreement with model results.

Output from NAVEFF is also used as input to NAVSED to determine the time-history of sediment concentration as a result of tow passage. NAVSED is also run on all 972 combinations. NAVSED provides input to the ecological models and the sedimentation of secondary channels and backwaters.

The output from 972 combinations provides a large amount of information that is summarized by describing the various outputs as probability distributions to use in a risk-based procedure.

In addition, this report presents modifications to the NAVSED program to address resuspension from wave effects. Equations are presented to document techniques used for the applied power for larval fish entrainment calculations.

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Appendix A Documentation of Procedures for Assigning Sedimentation Values (D_{50}, Bottom Typing, and Fall Velocities) to Midpoints

A computer program (listing provided at the end of this appendix) was developed to extrapolate sediment point data (collected by field teams) to the main navigation channel and channel border areas. The program was written in Arc Macro Language (AML) and was designed to be executed within the ArcInfo geographical information system (GIS) software package. The procedures in this program extrapolate sediment data (collected at 3-mile intervals for pool 8 and 5-mile intervals for the remaining pools) to midpoints that are located at 0.5-mile intervals for the trend pools and 1-mile intervals for the remaining pools. The sediment samples were collected at specific locations across the river channel. Figure A1 shows the sample locations and gives a brief description of each sample location. The sediment variables referred to in this appendix are listed in Table A1.

Program Description

First, it was necessary to break up the 10-m cells by river mile. To accomplish this, the AML program intersects the 10-m-wide cell polygons with a GIS coverage of thiessen polygons. Thiessen polygons are polygons whose boundaries define the area closest to the point (in this case a river mile marker) relative to all other points. They are mathematically defined by the perpendicular bisectors of the line between all points. This produces a GIS coverage of 10-m-wide zones divided by river mile. Figure A2 illustrates the zone polygons for a portion of pool 7. These zones are 10 m wide and extend from the top of the pool to the bottom. Figure A3 shows the thiessen polygons for the same portion of pool 7 as Figure A2.

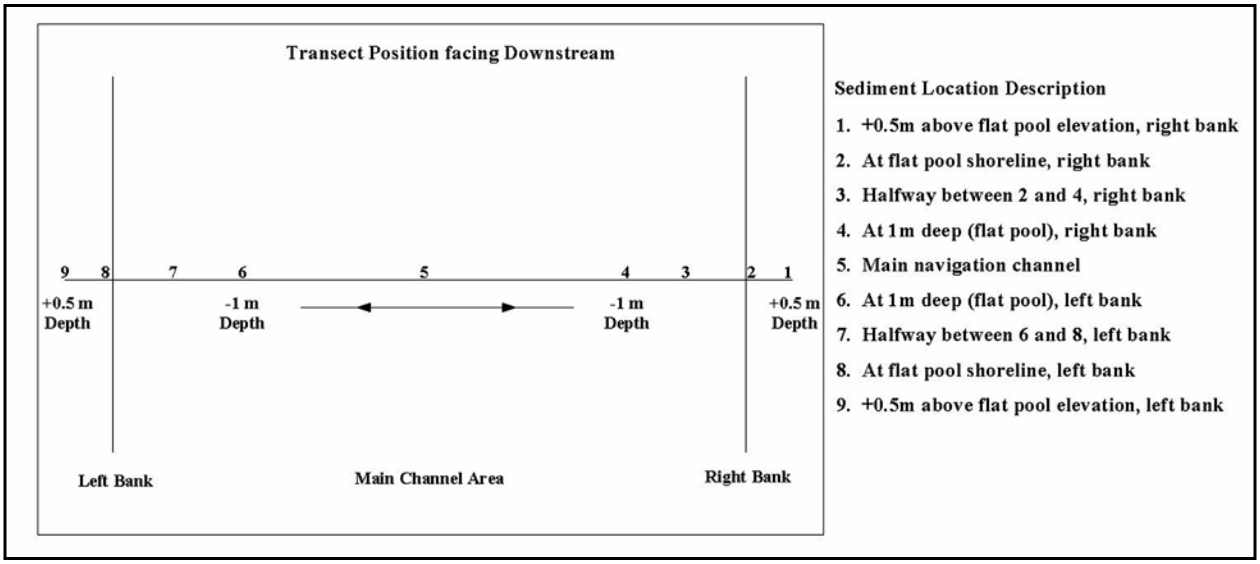

Figure A1. River channel sediment sample locations

Table A1
Sediment Variable Descriptions

Variable	Description
Sample_loc	The location of the sample (positions 2-8) used to assign sediment attributes to the cells
Coh_sed	1 = Cohesive (No samples met this criteria) 2 = Silt Mixture (Group 2 cohesive) 3 = Sand Mixture (Noncohesive)
loss_oi_perc	Loss in ignition percentage
wet_blkd_g/ml	Wet bulk density
162um	Percent of sample less than 62 μ in size
d16_gsz_mm	Diameter of grain size in millimeters
d50_gsz_mm	Diameter of grain size in millimeters
d84_gsz_mm	Diameter of grain size in millimeters
coh_class	Bottom classification of silt mixtures (Group 2 cohesive) 1 = Soft 2 = Medium 3 = Hard
d50_vel_cms	Fall velocity. Calculated for each unique D_{50} grain size by Coastal and Hydraulics Laboratory using the DOS program SAM. Values were provided to the Environmental Laboratory in screen dump format and retyped into a word processor, saved as ASCII files, and imported into an INFO database table. Values in centimeters per second.

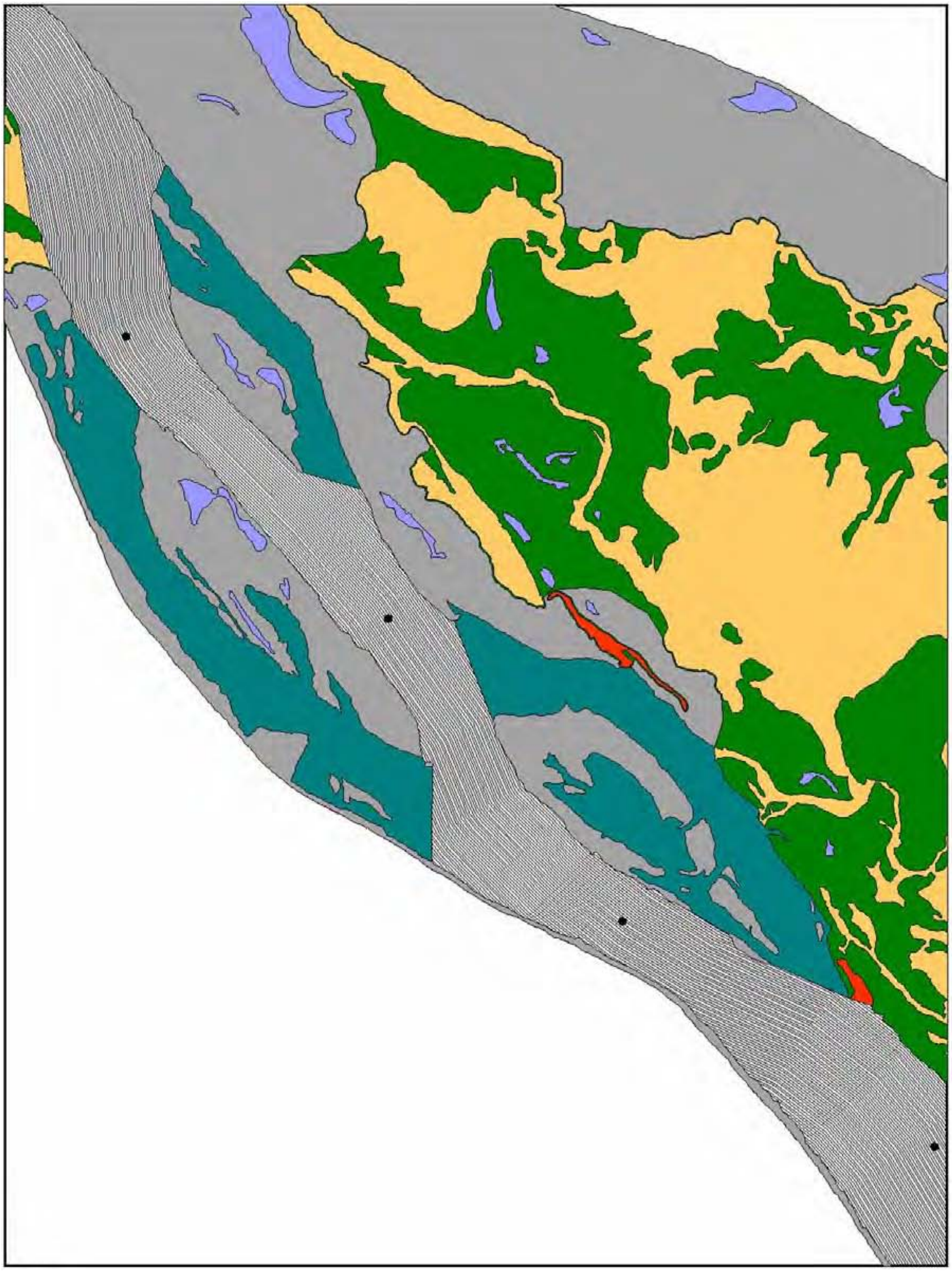

Figure A2. Zone polygons for a portion of Pool 7

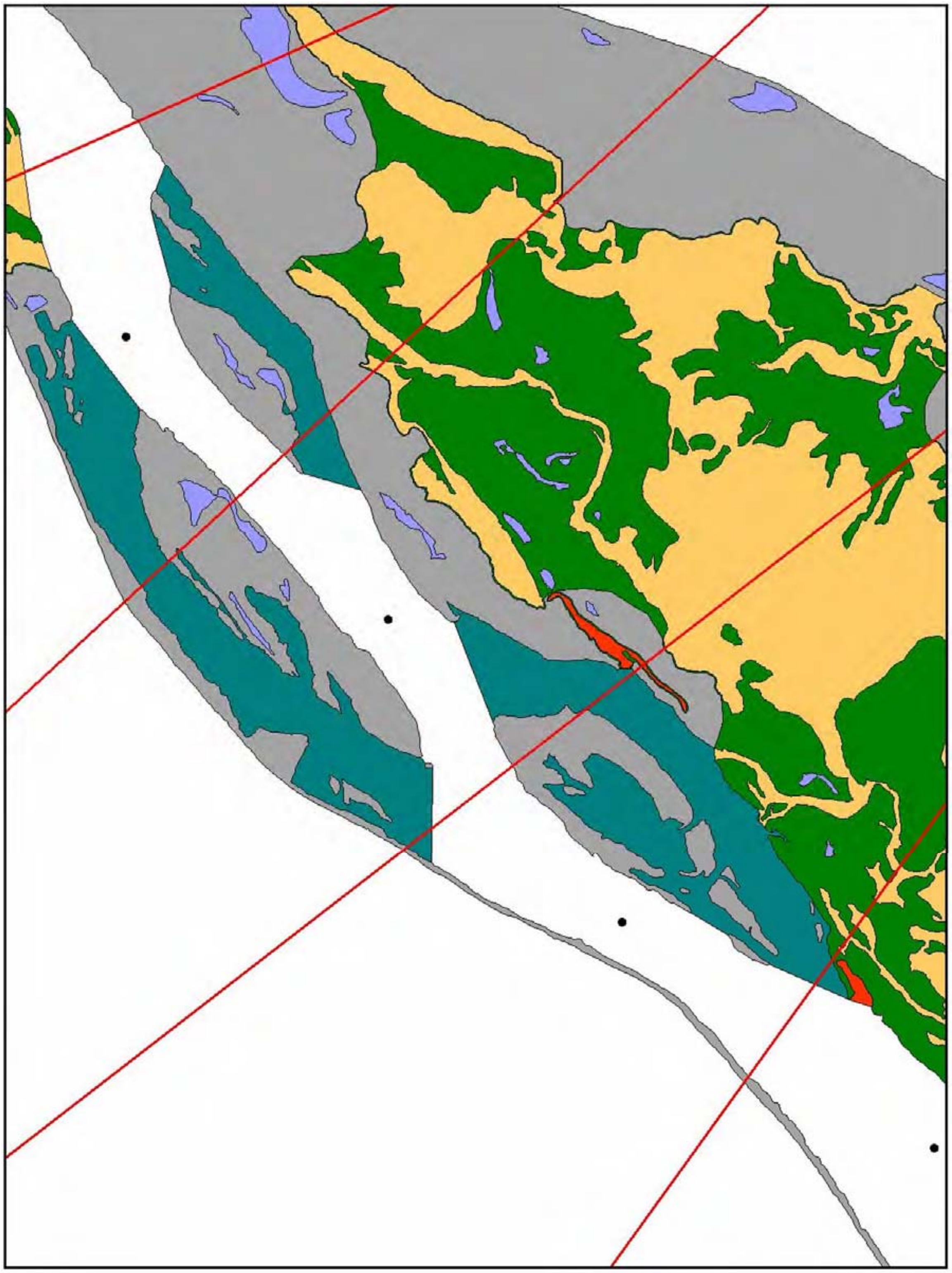

Figure A3. Thiessen polygons generated around river mile markers

Next, the AML steps through each river mile in the pool and assigns the appropriate sediment characteristics to the 10-m-wide zones (cells). Cells are selected according to the following criteria for assigning main channel sediment characteristics:

a. In the current river mile and up and downstream 2.5 miles.
b. Which are greater than 1.0 m in depth.
c. Which are in the main navigation channel or the main border channel.

The AML assigns the selected cells the sediment attributes of sediment sample location 5.

The AML then clears the selected set of cells and then selects all the cells closest to the left bank which meet the following requirements:

a. In the current river mile and up and downstream 2.5 miles (for pool 8 the distance is 1.5 miles since sediments samples were collected every 3 miles).
b. Which are less than or equal to 1.0 m in depth.
c. Which are in the main navigation channel or the main border channel.
d. Those polygons on the left bank.
e. Those polygons which are not on the inside of bends.
f. The AML also selects the sediment samples with a sample location attribute of 6, 7, or 8 and then determines which sample has the maximum LT62UM (less than 62 μ) value (Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Thomas Pokrefke, personal communication). The AML then assigns the attributes from this sediment sample to the cell.
g. The program then selects areas that meet the above criteria and which also are located on the inside of bends.
h. Instead of assigning these areas the values of the sample size with the max LT62UM value, the D_{50} of sample 5 (center main channel sample) is multiplied by 0.05 and assigned to these areas (Pokrefke, personal communication).

The AML conducts the same procedure for the right bank and then proceeds to the next river mile.

Note: In some instances, there were no samples available along the banks to assign to the cells. In those cases, a flag value of 9999 was assigned instead.

After completing all the river miles in the pool, the AML program copies an INFO (database) table of D_{50} values and associated fall velocities (Table A2) and enters the ArcEdit program. The LOOKUP command is used to assign fall velocities to the cells. Fall velocities of 9999 are calculated for all cells with a D_{50} value of 9999.

Table A2
Fall Velocities Lookup Table

Record	D50_GSZ_MM	D50_VEL_CMS	Record	D50_GSZ_MM	D50_VEL_CMS
1	0.01200	0.013	42	0.08500	0.578
2	0.01300	0.015	43	0.09500	0.705
3	0.01400	0.017	44	0.09900	0.758
4	0.01600	0.023	45	0.10000	0.800
5	0.01700	0.026	46	0.10400	0.825
6	0.01800	0.029	47	0.10600	0.852
7	0.01900	0.032	48	0.10700	0.866
8	0.02000	0.037	49	0.10900	0.894
9	0.02100	0.039	50	0.11100	0.922
10	0.02200	0.043	51	0.11200	0.936
11	0.02300	0.047	52	0.11300	0.950
12	0.02400	0.051	53	0.11400	0.964
13	0.02600	0.059	54	0.11500	0.978
14	0.02700	0.064	55	0.11600	0.992
15	0.02800	0.069	56	0.11700	1.007
16	0.02900	0.074	57	0.11800	1.021
17	0.03000	0.080	58	0.11900	1.035
18	0.03100	0.084	59	0.12100	1.064
19	0.03200	0.089	60	0.12200	1.078
20	0.03300	0.095	61	0.12400	1.107
21	0.03400	0.101	62	0.12600	1.136
22	0.03600	0.113	63	0.12700	1.151
23	0.03700	0.119	64	0.12800	1.165
24	0.03800	0.125	65	0.13000	1.195
25	0.03900	0.132	66	0.13200	1.224
26	0.04100	0.145	67	0.13300	1.238
27	0.04300	0.159	68	0.13600	1.283
28	0.04400	0.167	69	0.13800	1.312
29	0.04500	0.174	70	0.14000	1.341
30	0.04600	0.182	71	0.14100	1.356
31	0.04700	0.189	72	0.14200	1.371
32	0.04800	0.197	73	0.14400	1.401
33	0.05000	0.220	74	0.14500	1.415
34	0.05200	0.230	75	0.14600	1.430
35	0.05300	0.239	76	0.15000	1.500
36	0.05500	0.256	77	0.15100	1.504
37	0.05800	0.283	78	0.15300	1.534
38	0.05900	0.293	79	0.16000	1.637
39	0.06000	0.300	80	0.16100	1.652
40	0.06400	0.342	81	0.16200	1.666
41	0.08000	0.530	82	0.16400	1.696

(Sheet 1 of 3)

Table A2 (Continued)

Record	D50_GSZ_MM	D50_VEL_CMS	Record	D50_GSZ_MM	D50_VEL_CMS
83	0.16600	1.725	126	0.28300	3.289
84	0.16900	1.769	127	0.28400	3.301
85	0.17000	1.784	128	0.28500	3.312
86	0.17100	1.799	129	0.28700	3.333
87	0.17600	1.872	130	0.29100	3.381
88	0.17700	1.886	131	0.29200	3.396
89	0.17800	1.901	132	0.29600	3.454
90	0.18500	2.002	133	0.29800	3.484
91	0.18700	2.031	134	0.29900	3.498
92	0.19100	2.088	135	0.30000	4.000
93	0.19200	2.102	136	0.30100	3.527
94	0.19400	2.130	137	0.30500	3.586
95	0.19600	2.159	138	0.30700	3.615
96	0.19700	2.173	139	0.31200	3.688
97	0.19800	2.187	140	0.31300	3.703
98	0.20200	2.243	141	0.31900	3.791
99	0.20500	2.285	142	0.32000	3.805
100	0.20600	2.299	143	0.32500	3.878
101	0.20700	2.313	144	0.32800	3.922
102	0.20800	2.327	145	0.33000	3.951
103	0.21200	2.382	146	0.33400	4.010
104	0.21500	2.423	147	0.33500	4.025
105	0.22300	2.532	148	0.33800	4.068
106	0.23100	2.639	149	0.34000	4.098
107	0.23200	2.652	150	0.34300	4.141
108	0.23700	2.718	151	0.34600	4.185
109	0.24000	2.757	152	0.34900	4.229
110	0.24700	2.848	153	0.35000	4.244
111	0.24900	2.873	154	0.35100	4.258
112	0.25200	2.911	155	0.36000	4.390
113	0.25300	2.924	156	0.37000	4.535
114	0.25400	2.937	157	0.38000	4.681
115	0.25500	2.949	158	0.40000	4.972
116	0.26000	3.012	159	0.41200	5.146
117	0.26200	3.037	160	0.41700	5.218
118	0.26500	3.074	161	0.45600	5.780
119	0.27000	3.135	162	0.50000	6.500
120	0.27300	3.172	163	0.55900	7.242
121	0.27400	3.181	164	0.60000	7.739
122	0.27600	3.205	165	0.64700	8.275
123	0.27900	3.241	166	0.70000	8.786
124	0.28000	3.253	167	0.80000	10.045
125	0.28200	3.277	168	0.83000	10.274

(Sheet 2 of 3)

Table A2 (Concluded)					
Record	**D50_GSZ_MM**	**D50_VEL_CMS**	**Record**	**D50_GSZ_MM**	**D50_VEL_CMS**
165	0.64700	8.275	192	10.56200	45.050
166	0.70000	8.786	193	12.91700	49.820
167	0.80000	10.045	194	13.07900	50.131
168	0.83000	10.274	195	14.94200	53.583
169	0.90000	10.954	196	15.63200	54.806
170	1.00000	12.135	197	16.21900	55.826
171	1.27800	14.335	198	16.71300	56.670
172	1.27900	14.343	199	16.83800	56.881
173	2.00000	19.519	200	18.29100	59.285
174	2.56300	21.612	201	19.75100	61.605
175	2.68000	21.881	202	20.78400	63.196
176	3.00000	23.367	203	21.11100	63.691
177	3.75300	26.570	204	21.31500	63.998
178	4.00000	27.427	205	21.78600	64.701
179	4.40500	28.922	206	25.51800	70.024
180	4.55000	29.476	207	26.02800	70.720
181	5.11700	31.341	208	26.11900	70.844
182	7.08000	36.889	209	26.27200	71.051
183	8.11600	39.491	210	27.24800	72.359
184	8.16300	39.605	211	29.00300	74.652
185	8.61600	40.689	212	29.56300	75.370
186	8.70100	40.889	213	33.58900	80.338
187	8.90600	41.368	214	38.20400	85.679
188	9.59500	42.941	215	38.58400	86.105
189	9.59600	42.941	216	40.49100	88.207
190	9.68700	43.144	217	40.94300	88.698
191	10.11100	44.078	218	61.48200	108.692
					(Sheet 3 of 3)

Next, the AML enters the TABLES program and determines which cohesive sediment category to associate with each cell. This is based on grain-size characteristics and the position in the channel. Specific decision rules were as follows:

Group 2 cohesives (silt mixtures):

LT62UM <= 0 and LT62UM < 9999 (eliminates flags)
LT62UM >= 70 or D16_GSZ_MM <= 0.004
HYD_CODE = 1 or 3 (Either in the navigation channel or main channel border)

A value of 2 is assigned as the COH_SED attribute for samples which met the above critera.

Noncohesives (sand mixtures):

> COH_SED not equal to 2 and LT62UM >= 0 and LT62UM < 9999 and HYD_CODE = 1 or 3

A value of 3 is assigned to the COH_SED attribute.

Next, the program assigns bottom type classifications to the Group 2 cohesive polygons using the decision rules shown in Table A3.

Table A3
Cohesive Classification Decision Rules

Cohesive Classification (COH_CLASS)	Criteria (Must meet all conditions of any one of the three criteria)
1 (soft)	COH_SED = 2 LOSS_OI_PERC < 5 WET_BLKD_G/ML < 1.5
	COH_SED = 2 LOSS_OI_PERC >= 5 and LOSS_OI_PERC <= 10 WET_BLKD_G/ML < 1.4
	COH_SED = 2 LOSS_OI_PERC > 10 WET_BLKD_G/ML < 1.3
2 (medium)	COH_SED = 2 LOSS_OI_PERC < 5 WET_BLKD_G/ML >= 1.5 and WET_BLKD_G/ML <= 2.2
	COH_SED = 2 LOSS_OI_PERC >= 5 and LOSS_OI_PERC <= 10 WET_BLKD_G/ML >= 1.4 and WET_BLKD_G/ML <= 2.1
	COH_SED = 2 LOSS_OI_PERC > 10 WET_BLKD_G/ML>=1.3 and WET_BLKD_G/ML <=2.0
3 (hard)	COH_SED = 2 LOSS_OI_PERC < 5 WET_BLKD_G/ML > 2.2
	COH_SED = 2 LOSS_OI_PERC >= 5 and LOSS_OI_PERC <= 10 WET_BLKD_G/ML > 2.1
	COH_SED = 2 LOC_OI_PERC > 10 WET_BLKD_G/ML > 2.0

Program Listing - ASSIGNSED.AML

Language: ArcInfo GIS Macro Language (AML)

Version of ArcInfo: 7.1.2

Operating System: Solaris 2.5.1

Program Author: Mark R. Graves, U.S. Army Engineer Research and Development Center, Environmental Laboratory

Purpose: Assign sediment characteristics to cells using decision rules developed by the ERDC Coastal and Hydraulics Laboratory

```
/*************************************************************************
/*
/*    AML to assign sedimentation values to zone polygons.
/*
/*
/* M. Graves
/* April 1998
/*
/* NOTES:  Run from arc prompt
/*
/**************************************************************************

/*
/* COMMAND TO RUN:  &r assignsed {pool_number}
/*
/*
/* REQUIREMENTS:    Three Arc/Info coverages:
/*                      1) p13_impzns     (Raw zones -- not divided
/*                                                  by river mile)
/*                      2) p13_midpnts   (Midpoint Coverage)
/*                      3) hydcls13s        (Hydraulic Classification)
/*                                                 -with side channels
added

/***********************************************************************
/*
/*                       ZONE PREPARATION
/*
/*
/***********************************************************************

&args pool_number

/*
/* Get necessary coverages from the archive directory
/*
```

```
&type copying necessary coverages.....

&sv  cover := P%pool_number%_sedzns
&sv  longdir := /dta8/hydraulics/aquatic_areas/umrs_pool

copy %longdir%%pool_number%/p%pool_number%_impzns p%pool_number%_impzns
copy %longdir%%pool_number%/p%pool_number%_midpnt p%pool_number%_midpnt
copy %longdir%%pool_number%/hydcls%pool_number%s hydcls%pool_number%s

/*
/*
/*  Find out if rm_theis cover exists in work directory
/*    -if it does not copy it over
/*
/*  RMTHEIS   is a coverage produced by running the THEISSEN
/*            command on the river mile markers for the whole
/*            river
/*
/*            ITEMS:
/*
/*            ITEM NAME           WIDTH OUTPUT  TYPE N.DEC
/*
/*            RMILE                  4     6     F      1
/*
 &if ^ [exists rm_theis -cover] &then
   &do
     copy /dta8/hydraulics/aquatic_areas/graves/sedmap/rm_theis rm_theis
   &end

&type Processing Pool Number %pool_number%
/*
/*  Intersect the raw zone polygons (not broken up by river
/*  mile) with the RM_THEIS coverage to produce a coverage of
/*  zones broken up by river mile
/*
intersect p%pool_number%_impzns rm_theis p%pool_number%_rmzn poly 0.001
JOIN
/*
/*  Next we need to find out which midpoint relates to each zone
/*
identity P%pool_number%_MIDPNT P%pool_number%_RMZN P%pool_number%_RMZN_i ~
  point 0.001 join
/*
/*  Joinitem now appends the midpoint attributes to the divided zones
/*
joinitem P%pool_number%_RMZN.pat P%pool_number%_RMZN_i.pat ~
  P%pool_number%_RMZN.pat P%pool_number%_RMZN-ID RM_theis#
/*
/*  Cleanup
/*
/*
kill rm_theis all
kill P%pool_number%_RMZN_i all
/**********************************************************************
/*
/*                  PROCESSING THE SEDIMENT INFORMATION
/*
/*
/**********************************************************************
/*
/*  Intersect the hydraulic classification coverage with the
/*   divided zones created above.  This tells us which
/*   portions of the zones belong to the Nav Channel and
/*   the main channel border
/*
intersect hydcls%pool_number%s p%pool_number%_rmzn hyd_zones%pool_number%

&sv cover := HYD_ZONES%pool_number%

&type Processing pool number: %pool_number%
/*
/*  Copy over the master sediment (Point samples) coverage
/*
&if ^ [exists miss_sed -cover] &then
   &do
```

```
    copy /dta8/hydraulics/aquatic_areas/graves/sedmap/miss_sed miss_sed
   &end
   &else
   &do
    kill miss_sed all
    copy /dta8/hydraulics/aquatic_areas/graves/sedmap/miss_sed miss_sed
   &end
/*
/*  Go into tables to see what the minimum and the maximum river
/*   miles are in the pool we are working on
/*
tables
select miss_sed.pat
reselect pool_name cn [quote %pool_number%]

statistics # temp.stt
min rmile
max rmile
end

select temp.stt
&sv frommile = [calc [show record 1 ITEM MIN-RMILE] - 5]
&sv tomile = [calc [show record 1 ITEM MAX-RMILE] + 5]
&type Need to process from river mile %frommile% to %tomile%

erase temp.stt
y


quit
/*
/*  Begin the real work
/*
arcplot

&do mile = %frommile% &to %tomile% &by 5

  &type Processing river mile %mile%
  /*
  /* Process polygons greater than 1m in depth
  /*
  /* Get proper river mile polygons
  reselect %cover% polys rmile >= [calc %mile% - 2.5] and ~
    rmile <= [calc %mile% + 2.5]
  /*
  /* Get polygons greater than 1m in depth
  /*
  reselect %cover% polys fpd_m > 1.0
  /*
  /* Now get only the ones in nav channel and border channel
  /*
  reselect %cover% polys hyd_code in {1,3}
  /*
  /* Process sample in center of channel
  /*
  reselect miss_sed points rmile = %mile%
  reselect miss_sed points sample_loc = 5

  statistics miss_sed points
  max lt62um
  min loss_oi_perc
  min WET_BLKD_G/ML
  min d16
  min d50
  min d84
  min sample_loc
  end

  &type setting values for variables

  &sv stat62 = [show statistic 1 1]
  &sv statloss = [show statistic 2 1]
  &sv statbulk = [show statistic 3 1]
  &sv stat16 = [show statistic 4 1]
  &sv stat50 = [show statistic 5 1]
```

```
&sv stat84 = [show statistic 6 1]
&sv statloc = [show statistic 7 1]
&type calculating values
&sv midd50 = %stat50%
calculate %cover% polys lt62um = %stat62%
calculate %cover% polys loss_oi_perc = %statloss%
calculate %cover% polys WET_BLKD_G/ML = %statbulk%
calculate %cover% polys d16_gsz_mm = %stat16%
calculate %cover% polys d50_gsz_mm = %stat50%
calculate %cover% polys d84_gsz_mm = %stat84%
calculate %cover% polys sample_loc = %statloc%

clearselect %cover% polys
clearselect miss_sed points
/*
/* Now do the ones in shallow water ( <=1.0m in depth )
/*  --THOSE NOT ON INSIDE BENDS
/*
&type Shallow Water..... (RIGHT BANK)

reselect %cover% polys rmile >= [calc %mile% - 2.5] and ~
  rmile <= [calc %mile% + 2.5]
reselect %cover% polys fpd_m <= 1.0
reselect %cover% polys hyd_code in {1,3}
reselect %cover% polys cell_id cn 'R'
reselect %cover% polys hyd_reach nc 'INSIDE'

reselect miss_sed points rmile = %mile%
reselect miss_sed points bank = 'R'
reselect miss_sed points sample_loc in {2,3,4}
/*
/* Need to check the number of selected samples at this point, because
/* there could be NO samples that meet the criteria - OUCH!
/*
&sv numsel = [extract 1 [unquote [show select miss_sed point]]]
&if %numsel% = 0 &then
  &do
     calc %cover% polys lt62um = 9999
     calc %cover% polys loss_oi_perc = 9999
     calc %cover% polys WET_BLKD_G/ML = 9999
     calc %cover% polys d16_gsz_mm = 9999
     calc %cover% polys d50_gsz_mm = 9999
     calc %cover% polys d84_gsz_mm = 9999
     calc %cover% polys sample_loc = 9999
  &end
  &else
  &do
     /*
     /* Calculate statistics for the select set of sed samples
     /* Specifically, find the one with the maximum lt62um value
     /*
     statistics miss_sed points
     max lt62um
     end
     /*
     /* Get the value from the statistics file
     /*
     &sv record = [show statistic 1 1]
     /*
     /* Now that we know which sed record has the highest lt62um
     /* Get all the attributes for that record and assign them to
     /* the polygons
     /*
     reselect miss_sed points lt62um = %record%
     statistics miss_sed points
     max lt62um
     min loss_oi_perc
     min WET_BLKD_G/ML
     min d16
     min d50
     min d84
     min sample_loc
     end
     &sv stat62 = [show statistic 1 1]
     &sv statloss = [show statistic 2 1]
```

```
      &sv statbulk = [show statistic 3 1]
      &sv stat16 = [show statistic 4 1]
      &sv stat50 = [show statistic 5 1]
      &sv stat84 = [show statistic 6 1]
      &sv statloc = [show statistic 7 1]
      calculate %cover% polys lt62um = %stat62%
      calculate %cover% polys loss_oi_perc = %statloss%
      calculate %cover% polys WET_BLKD_G/ML = %statbulk%
      calculate %cover% polys d16_gsz_mm = %stat16%
      calculate %cover% polys d50_gsz_mm = %stat50%
      calculate %cover% polys d84_gsz_mm = %stat84%
      calculate %cover% polys sample_loc = %statloc%
  &end
clearselect miss_sed points
clearselect %cover% polys
/*
/* Now do the left bank areas on the inside of bends
/*
&type Shallow Water..... (RIGHT BANK) (INSIDE BEND)

reselect %cover% polys rmile >= [calc %mile% - 2.5] and ~
  rmile <= [calc %mile% + 2.5]
reselect %cover% polys fpd_m <= 1.0
reselect %cover% polys hyd_code in {1,3}
reselect %cover% polys cell_id cn 'R'
reselect %cover% polys hyd_reach cn 'INSIDE'

&sv calcd50 = [calc %midd50% * 0.5]
calculate %cover% polys lt62um = 9999
calculate %cover% polys loss_oi_perc = 9999
calculate %cover% polys WET_BLKD_G/ML = 9999
calculate %cover% polys d16_gsz_mm = 9999
calculate %cover% polys d50_gsz_mm = %calcd50%
calculate %cover% polys d84_gsz_mm = 9999
calculate %cover% polys sample_loc = 9999

clearselect miss_sed points
clearselect %cover% polys
/*
/* Let's do the left bank now
/*
&type Shallow Water..... (LEFT BANK)
reselect %cover% polys rmile >= [calc %mile% - 2.5] and ~
  rmile <= [calc %mile% + 2.5]
reselect %cover% polys fpd_m <= 1.0
reselect %cover% polys hyd_code in {1,3}
reselect %cover% polys cell_id cn 'L'
reselect %cover% polys hyd_reach nc 'INSIDE'

reselect miss_sed points rmile = %mile%
reselect miss_sed points bank = 'L'
reselect miss_sed points sample_loc in {6,7,8}
/*
/* Need to check the number of selected samples at this point, because
/* there could be NO samples that meet the criteria - OUCH!
/*
&sv numsel = [extract 1 [unquote [show select miss_sed point]]]
&if %numsel% = 0 &then
  &do
      calc %cover% polys lt62um = 9999
      calc %cover% polys loss_oi_perc = 9999
      calc %cover% polys WET_BLKD_G/ML = 9999
      calc %cover% polys d16_gsz_mm = 9999
      calc %cover% polys d50_gsz_mm = 9999
      calc %cover% polys d84_gsz_mm = 9999
      calc %cover% polys sample_loc = 9999
  &end
  &else
  &do
      /*
      /* Calculate statistics for the select set of sed samples
      /* Specifically, find the one with the maximum lt62um value
      /*
      statistics miss_sed points
      max lt62um
```

```
      end

      /* Get the value from the statistics file
      &sv record = [show statistic 1 1]
      /*
      /* Now that we know which sed record has the highest lt62um
      /* Get all the attributes for that record and assign them to
      /* the polygons
      /*
      reselect miss_sed points lt62um = %record%
      statistics miss_sed points
      max lt62um
      min loss_oi_perc
      min WET_BLKD_G/ML
      min d16
      min d50
      min d84
      min sample_loc
      end
      &sv stat62 = [show statistic 1 1]
      &sv statloss = [show statistic 2 1]
      &sv statbulk = [show statistic 3 1]
      &sv stat16 = [show statistic 4 1]
      &sv stat50 = [show statistic 5 1]
      &sv stat84 = [show statistic 6 1]
      &sv statloc = [show statistic 7 1]
      calculate %cover% polys lt62um = %stat62%
      calculate %cover% polys loss_oi_perc = %statloss%
      calculate %cover% polys WET_BLKD_G/ML = %statbulk%
      calculate %cover% polys d16_gsz_mm = %stat16%
      calculate %cover% polys d50_gsz_mm = %stat50%
      calculate %cover% polys d84_gsz_mm = %stat84%
      calculate %cover% polys sample_loc = %statloc%
   &end
  clearselect %cover% polys
  clearselect miss_sed points
  /*
  /* Now do the left bank areas on the inside of bends
  /*
  &type Shallow Water..... (LEFT BANK) (INSIDE BEND)

  reselect %cover% polys rmile >= [calc %mile% - 2.5] and ~
    rmile <= [calc %mile% + 2.5]
  reselect %cover% polys fpd_m <= 1.0
  reselect %cover% polys hyd_code in {1,3}
  reselect %cover% polys cell_id cn 'L'
  reselect %cover% polys hyd_reach cn 'INSIDE'

  &sv calcd50 = [calc %midd50% * 0.5]
  calculate %cover% polys lt62um = 9999
  calculate %cover% polys loss_oi_perc = 9999
  calculate %cover% polys WET_BLKD_G/ML = 9999
  calculate %cover% polys d16_gsz_mm = 9999
  calculate %cover% polys d50_gsz_mm = %calcd50%
  calculate %cover% polys d84_gsz_mm = 9999
  calculate %cover% polys sample_loc = 9999

  clearselect miss_sed points
  clearselect %cover% polys
&end

clearselect %cover% polys
reselect %cover% polys d50_gsz_mm <= 0
calc %cover% polys lt62um = 9999
calc %cover% polys loss_oi_perc = 9999
calc %cover% polys WET_BLKD_G/ML = 9999
calc %cover% polys d16_gsz_mm = 9999
calc %cover% polys d50_gsz_mm = 9999
calc %cover% polys d84_gsz_mm = 9999
calc %cover% polys sample_loc = 9999

quit
kill miss_sed all

&type Entering tables to compute classification values
```

```
tables

select %cover%.pat
asel
calc coh_sed = 9999
       resel lt62um >= 0 and lt62um < 9999     /* Eliminate negative flags
       resel lt62um ge 70 or d16_gsz_mm le 0.004001
       resel hyd_code in {1,3}
calc coh_sed = 2      /* GROUP 2 COHESIVE (Silt Mixture)
asel
reselect coh_sed ne 2 and lt62um >= 0 and lt62um < 9999 and hyd_code in
{1,3}
calc coh_sed = 3      /* NON-COHESIVE (Sand Mixture)
asel
resel coh_sed = 2
resel loss_oi_perc < 5
resel wet_blkd_g/ml < 1.5
calc coh_class = 1    /* SOFT
asel
resel coh_sed = 2
resel loss_oi_perc < 5
resel wet_blkd_g/ml >= 1.5 and wet_blkd_g/ml <= 2.2
calc coh_class = 2    /* MEDIUM
asel
resel coh_sed = 2
resel loss_oi_perc < 5
resel wet_blkd_g/ml > 2.2
calc coh_class = 3    /* HARD
asel
resel coh_sed = 2
resel loss_oi_perc >= 5 and loss_oi_perc <= 10
resel wet_blkd_g/ml < 1.4
calc coh_class = 1    /* SOFT
asel
       resel coh_sed = 2
       resel loss_oi_perc >= 5 and loss_oi_perc <= 10
       resel wet_blkd_g/ml >= 1.4 and wet_blkd_g/ml <= 2.1
calc coh_class = 2    /* MEDIUM
asel
resel coh_sed = 2
resel loss_oi_perc >= 5 and loss_oi_perc <= 10
resel wet_blkd_g/ml > 2.1
calc coh_class = 3    /* HARD
asel
resel coh_sed = 2
resel loss_oi_perc > 10
resel wet_blkd_g/ml < 1.3
calc coh_class = 1    /* SOFT

asel
resel coh_sed = 2
       resel loss_oi_perc > 10
       resel wet_blkd_g/ml >= 1.3 and wet_blkd_g/ml <= 2.0
calc coh_class = 2    /* MEDIUM
asel
resel coh_sed = 2
       resel loss_oi_perc > 10
       resel wet_blkd_g/ml > 2.0
calc coh_class = 3    /* HARD
quit

/* Add Fall_velocities

&if ^ [exists fall_vel -INFO] &then copyinfo
/dta8/hydraulics/aquatic_areas/graves/sedmap/info!arc!fall_vel

arcedit
ec %cover%
ef labels
sel all
resel hyd_code in {1,3} and d50_gsz_mm >= 0
lookup d50_vel_cms d50_vel_cms fall_vel d50_gsz_mm
save
quit
```

```
tables
sel fall_vel
erase fall_vel
y
sel %cover%.pat
resel D50_GSZ_MM = 9999
calc D50_VEL_CMS = 9999
quit
/*
/* Cleanup
/*

kill p%pool_number%_impzns all
kill p%pool_number%_midpnt all
kill hydcls%pool_number%s all
```

Appendix B
Source Code for NAVEFF Model

```
C     Last change:  SRJ  17 Jul 98    4:25 pm
C     ==================================================================
C     ==                                                              ==
C        DESIGNED & CODED BY :  Eddie Melton
C        MODIFICATIONS       :  12/01/97 Completed ARC/INFO File
C                                        Transfer Code
C     ==                                                              ==
C     ==================================================================

C     ==================================================================
C     ==                   Variable Declarations                      ==
C     ==                                                              ==

      REAL                AmbFlux(100000)
      DOUBLE PRECISION    AveVel
      CHARACTER*10        BankPos(500,4,3)
      CHARACTER*15        BankPosName
      CHARACTER*10        BinLabel(100000)
      INTEGER             BinWidth
      CHARACTER*15        CrossSectionName
      INTEGER             CurTransect
      INTEGER             Direction
      CHARACTER*1         DirLoc
      REAL                Distance(80000)
      REAL                Draft(4)
      CHARACTER*1         DraftLoc
      INTEGER             DraftLocId
      REAL                DrawDown(100000)
      REAL                D50
      REAL                D50Size(100000)
      REAL                D50Vel(100000)

      DOUBLE PRECISION    Easting(100000)
      CHARACTER*4         ErrorCode
      INTEGER             ErrorCount
      REAL                LastRiverMile
      DOUBLE PRECISION    LeftArea
      INTEGER             LeftBankPnt
      INTEGER             LeftNear
      DOUBLE PRECISION    LeftWidth
      REAL                LocDistance
      DOUBLE PRECISION    MaxDepth
      REAL                MaxFlux(100000)
      INTEGER             MaxNumTransects
      INTEGER             MaxNumBins
      INTEGER             MaxRecords
      DOUBLE PRECISION    MaxScour(100000)
      DOUBLE PRECISION    NBNum
      DOUBLE PRECISION    NBIncVal
      DOUBLE PRECISION    MSL(100000)
```

```
DOUBLE PRECISION  Northing(100000)
INTEGER           NumTransects
CHARACTER*15      ParameterName
CHARACTER*1       PoolLevel
CHARACTER*3       PoolName
REAL              VelChange(100000)
DOUBLE PRECISION  RightArea
INTEGER           RightBankPnt
INTEGER           RightNear
DOUBLE PRECISION  RightWidth
REAL              RiverMile
REAL              ShearStress(100000)
REAL              ShearAmb(100000)
CHARACTER*1       SizeLoc
INTEGER           SizeLocID
DOUBLE PRECISION  Tabs(4,100000)
CHARACTER*1       TowLoc
INTEGER           TowLocId
INTEGER           TowLocPnt
CHARACTER*10      TowPos(500,4,4)
CHARACTER*15      TowPosName
REAL              TowSize(5,3)
CHARACTER*6       TrafficFile
INTEGER           Transect(500,4)
REAL              Velocity(4)
CHARACTER*1       VelLoc
INTEGER           VelLocId
DOUBLE PRECISION  WaterDepth(100000)
REAL              WaterLevel(500,4)
CHARACTER*15      WaterLevelName
INTEGER           CohSed
INTEGER           CohClass


DOUBLE PRECISION  ALEFT
DOUBLE PRECISION  ALF
DOUBLE PRECISION  ALFL
DOUBLE PRECISION  ALFR
DOUBLE PRECISION  AM
DOUBLE PRECISION  ARIGHT
DOUBLE PRECISION  ATOTAL
DOUBLE PRECISION  B
DOUBLE PRECISION  BE
DOUBLE PRECISION  BLB
DOUBLE PRECISION  BLEFT
DOUBLE PRECISION  BRB
DOUBLE PRECISION  BRIGHT
DOUBLE PRECISION  BSIDE
DOUBLE PRECISION  BTOTAL
DOUBLE PRECISION  C
DOUBLE PRECISION  CF
DOUBLE PRECISION  D
DOUBLE PRECISION  DE
DOUBLE PRECISION  DEPTOW
DOUBLE PRECISION  DISP
DOUBLE PRECISION  FPV
DOUBLE PRECISION  FV
DOUBLE PRECISION  GRAV
DOUBLE PRECISION  H
DOUBLE PRECISION  L
DOUBLE PRECISION  N
DOUBLE PRECISION  NSIDEL
DOUBLE PRECISION  NSIDER
DOUBLE PRECISION  RL
DOUBLE PRECISION  RTEM
DOUBLE PRECISION  SCHIJF
DOUBLE PRECISION  U1
DOUBLE PRECISION  V
DOUBLE PRECISION  VAM
DOUBLE PRECISION  VDISP
DOUBLE PRECISION  VFACTL
DOUBLE PRECISION  VFACTR
REAL              VG
DOUBLE PRECISION  VL
DOUBLE PRECISION  VLIMRAT
```

```
DOUBLE PRECISION  VLN
DOUBLE PRECISION  VLO
REAL              VNU
DOUBLE PRECISION  VW
DOUBLE PRECISION  VRAL
DOUBLE PRECISION  VRAR
DOUBLE PRECISION  VRLM
DOUBLE PRECISION  VRM
DOUBLE PRECISION  VRRM
real              Y
DOUBLE PRECISION  yy
DOUBLE PRECISION  Z
DOUBLE PRECISION  ZALF
DOUBLE PRECISION  ZALFL
DOUBLE PRECISION  ZALFR
DOUBLE PRECISION  ZC
DOUBLE PRECISION  ZSL
DOUBLE PRECISION  ZSM
DOUBLE PRECISION  ZSML
DOUBLE PRECISION  ZSMR
DOUBLE PRECISION  ZSR
DOUBLE PRECISION  ZT

CHARACTER*1       KOLoc
INTEGER           KOLocId

DOUBLE PRECISION  A
DOUBLE PRECISION  BB
DOUBLE PRECISION  CDECAY
DOUBLE PRECISION  CEXP
DOUBLE PRECISION  CFFACTOR
DOUBLE PRECISION  CFLOW
DOUBLE PRECISION  CFUNC
DOUBLE PRECISION  cj
DOUBLE PRECISION  CJTEMP
DOUBLE PRECISION  coef
DOUBLE PRECISION  cp
DOUBLE PRECISION  CPARA
DOUBLE PRECISION  CPZ1
DOUBLE PRECISION  CPZ2
DOUBLE PRECISION  D0
DOUBLE PRECISION  delcf
REAL              DEP
DOUBLE PRECISION  DEPTMP
REAL              DP
DOUBLE PRECISION  E
DOUBLE PRECISION  FPX
DOUBLE PRECISION  FRES
DOUBLE PRECISION  FUNC
DOUBLE PRECISION  FX
DOUBLE PRECISION  HP
DOUBLE PRECISION  HPN
DOUBLE PRECISION  HPO
DOUBLE PRECISION  K11
DOUBLE PRECISION  KKK
DOUBLE PRECISION  LBARGES
DOUBLE PRECISION  nu
INTEGER           NUMX
INTEGER           NUMY
DOUBLE PRECISION  P1DECAY
DOUBLE PRECISION  P2DECAY
REAL              PSPACE
DOUBLE PRECISION  PUSH
DOUBLE PRECISION  PUSH1
DOUBLE PRECISION  PUSH2
DOUBLE PRECISION  PUSH3
DOUBLE PRECISION  RHO
DOUBLE PRECISION  RR
DOUBLE PRECISION  s
DOUBLE PRECISION  SETBACK
REAL              TBL
DOUBLE PRECISION  temp1
REAL              THRUST
DOUBLE PRECISION  THRUSTP
DOUBLE PRECISION  TIHP
```

```
      DOUBLE PRECISION  U2
      DOUBLE PRECISION  V0
      DOUBLE PRECISION  V1
      DOUBLE PRECISION  V2
      REAL              VA
      DOUBLE PRECISION  VBDMAX
      DOUBLE PRECISION  VDIRECT
      DOUBLE PRECISION  VELLOCc
      DOUBLE PRECISION  VLM(5)
      DOUBLE PRECISION  VMAXTEST
      DOUBLE PRECISION  VMPH
      DOUBLE PRECISION  VR
      DOUBLE PRECISION  VRES
      DOUBLE PRECISION  VTEST
      DOUBLE PRECISION  vtotal
      DOUBLE PRECISION  VWAKEgx
      DOUBLE PRECISION  vwakamax
      DOUBLE PRECISION  VXMAX
      DOUBLE PRECISION  VXRL
      DOUBLE PRECISION  VXRPROP
      DOUBLE PRECISION  VXRR
      DOUBLE PRECISION  X
      DOUBLE PRECISION  XBEGIN
      DOUBLE PRECISION  XCALC
      DOUBLE PRECISION  XPROP
      DOUBLE PRECISION  XSPACE
      DOUBLE PRECISION  YL
      DOUBLE PRECISION  YR
      DOUBLE PRECISION  YSPACE
      DOUBLE PRECISION  ZZB

      DOUBLE PRECISION  AB
      DOUBLE PRECISION  alpha
      DOUBLE PRECISION  SecWaveHgt(100000)

      DOUBLE PRECISION HSave1
      DOUBLE PRECISION HSave2

      CHARACTER AKO*5

C     ==                                                              ==
C     ==                   Variable Declarations                      ==
C     ==================================================================

C     ==================================================================
C     ==                   Define Default Values                      ==
C     ==                                                              ==

      DATA MaxNumTransects / 100 /
      DATA MaxNumBins / 800 /

      MaxRecords = MaxNumTransects * MaxNumBins
      NumTransects = MaxNumTransects
      ErrorCount = 0

C     ==                                                              ==
C     ==                   Define Default Values                      ==
C     ==================================================================

C     ==================================================================
C     ==               Open Traffic and Output Files                  ==
C     ==                                                              ==

      WRITE(*,*) 'Enter Traffic File Name: '
      READ(*,*) TrafficFile
      PoolName = TrafficFile(1:3)

      OPEN(1, FILE=TrafficFile//'.trf', STATUS='old')
      OPEN(8, FILE=TrafficFile//'.err', STATUS='new')
      OPEN(9, FILE=TrafficFile//'.out', STATUS='new')

C     ==                                                              ==
C     ==               Open Traffic and Output Files                  ==
C     ==================================================================
```

```
C     ==================================================================
C     ==                 Read Traffic File Header                     ==
C     ==                                                              ==

      WRITE(8,*) 'ErrCode,Trans,Dir,Speed,Size,Draft,K/O,Stage,Sail,Traf
     *fic,Stg_Sl,TotArea,LftArea,TotWth,LftWth,TowWth,TowLen,Tow Draft,V
     *,Vamb,MaxDepth,HBefore,Hafter,RetVel,DrwDwn'

C     ==                                                              ==
C     ==                 Read Traffic File Header                     ==
C     ==================================================================

C     ==================================================================
C     ==           Get Water Levels for Current River Mile            ==
C     ==                                                              ==

      WaterLevelName = PoolName//'_lmh.dat'
      OPEN(2, FILE=WaterLevelName, STATUS='old')
      DO i = 1, NumTransects
        READ(2, *, END=200) RiverMile, WaterLevel(i,1),
     *                      WaterLevel(i,2), WaterLevel(i,3)
        Transect(i,1) = INT(RiverMile * 10.0)
      END DO
 200  CONTINUE
      NumTransects = i - 1
      CLOSE(2)

C     ==                                                              ==
C     ==           Get Water Levels for Current River Mile            ==
C     ==================================================================

C     ==================================================================
C     ==          Get Tow Positions for Current River Mile            ==
C     ==                                                              ==

      TowPosName = PoolName//'_sail.dat'
      OPEN(3, FILE=TowPosName, STATUS='old')
      DO i = 1, NumTransects
        READ(3, 350, END=300) RiverMile,
     *                        TowPos(i,1,1),TowPos(i,1,2),TowPos(i,1,3),
     *                        TowPos(i,2,1),TowPos(i,2,2),TowPos(i,2,3),
     *                        TowPos(i,3,1),TowPos(i,3,2),TowPos(i,3,3)
      END DO
 300  CONTINUE
      CLOSE(3)
 350  FORMAT(f5.1, a10, a10, a10, a10, a10, a10, a10, a10, a10)

C     ==                                                              ==
C     ==          Get Tow Positions for Current River Mile            ==
C     ==================================================================

C     ==================================================================
C     ==          Get Bank Positions for Current River Mile           ==
C     ==                                                              ==

      BankPosName = PoolName//'_chan.dat'
      OPEN(4, FILE=BankPosName, STATUS='old')
      DO i = 1, NumTransects
        READ(4, 450, END=400) RiverMile,
     *                        BankPos(i,1,1), BankPos(i,1,2),
     *                        BankPos(i,2,1), BankPos(i,2,2),
     *                        BankPos(i,3,1), BankPos(i,3,2)
      END DO
 400  CONTINUE
      CLOSE(4)
 450  FORMAT(f5.1, a10, a10, a10, a10, a10, a10)

C     ==                                                              ==
C     ==          Get Bank Positions for Current River Mile           ==
C     ==================================================================

C     ==================================================================
C     ==                                                              ==
C     ==                                                              ==
```

```
      ParameterName = PoolName//'_parm.dat'
      OPEN(5, FILE=ParameterName, STATUS='old')
      READ(5, *)
      DO i = 1, 3
        READ(5, 550) Velocity(i)
      END DO
      READ(5, *)
      READ(5, *)
      DO i = 1, 4
        READ(5, 551) TowSize(i,1), TowSize(i,2)
      END DO
      READ(5, *)
      READ(5, *)
      DO i = 1, 3
        READ(5, 552) Draft(i)
      END DO
      CLOSE(5)
c      WRITE(*,*) 'Velocity(1) ',Velocity(1)
c      WRITE(*,*) 'Velocity(2) ',Velocity(2)
c      WRITE(*,*) 'Velocity(3) ',Velocity(3)
c      WRITE(*,*) 'TowSize(1,x)',TowSize(1,1),TowSize(1,2)
c      WRITE(*,*) 'TowSize(2,x)',TowSize(2,1),TowSize(2,2)
c      WRITE(*,*) 'TowSize(3,x)',TowSize(3,1),TowSize(3,2)
c      WRITE(*,*) 'TowSize(4,x)',TowSize(4,1),TowSize(4,2)
c      WRITE(*,*) 'Draft(1)    ',Draft(1)
c      WRITE(*,*) 'Draft(2)    ',Draft(2)
c      WRITE(*,*) 'Draft(3)    ',Draft(3)
 550  FORMAT(2x, f4.2)
 551  FORMAT(2x, f5.2, x, f6.2)
 552  FORMAT(2x, f4.2)

C     ==                                                              ==
C     ==                                                              ==
C     ==================================================================

C     ==================================================================
C     ==                   Read CrossSection Data                     ==
C     ==                                                              ==

      CrossSectionName = PoolName//'_elev.dat'
      OPEN(6, FILE=CrossSectionName, STATUS='old')
      j = 0
      LastRiverMile = 0.0
      DO i = 1, MaxRecords
c       WRITE(*,*) i
        READ(6, 650, END=600) RiverMile, BinLabel(i),
     *                        Easting(i), Northing(i),
     *                        MSL(i), Tabs(1,i), Tabs(2,i), Tabs(3,i),
     *                        D50Size(i), D50Vel(i), CohSed, CohClass
        IF (D50Size(i) .LT. 999.0) THEN
          D50Size(i) = D50Size(i) / 1000.0
          D50Vel(i) = D50Vel(i) / 100.0
        END IF
        IF(ABS(RiverMile - LastRiverMile) .LT. 0.01) THEN
          Transect(j,3) = i
        ELSE
          j = j + 1
          Transect(j,2) = i
          LastRiverMile = RiverMile
        END IF
      END DO
 600  CONTINUE
      MaxRecords = i - 1
      CLOSE(6)
 650  FORMAT(f5.1,a10,f12.1,f12.1,f8.1,f8.1,f8.1,f8.1,f8.3,f8.3,i6,i6)

C     ==                                                              ==
C     ==                   Read CrossSection Data                     ==
C     ==================================================================
c     GOTO 149
C     ==================================================================
C     ==        Read Traffic File and Loop Through Algorithms         ==
C     ==                                                              ==

      DO icount = 1,99999
```

```
       ErrorCode = 'None'
       READ(1,151,END=149) RiverMile, DirLoc, VelLoc, SizeLoc,
     *                     DraftLoc, KOLoc, PoolLevel, TowLoc
 151   FORMAT(f5.1,x,a1,x,a1,x,a1,x,a1,x,a1,x,a1,x,a1)

C     ==                                                                ==
C     ==        Read Traffic File and Loop Through Algorithms           ==
C     ====================================================================

C     ====================================================================
C     ==            Reformat and Change Units of Variables              ==
C     ==                                                                ==

       IF((DirLoc .EQ. 'U') .OR. (DirLoc .EQ. 'u')) Direction = -1
       IF((DirLoc .EQ. 'D') .OR. (DirLoc .EQ. 'd')) Direction = 1
       IF((VelLoc .EQ. 'S') .OR. (VelLoc .EQ. 's')) VelLocId = 1
       IF((VelLoc .EQ. 'M') .OR. (VelLoc .EQ. 'm')) VelLocId = 2
       IF((VelLoc .EQ. 'F') .OR. (VelLoc .EQ. 'f')) VelLocId = 3
       IF((SizeLoc .EQ. 'L') .OR. (SizeLoc .EQ. 'l')) SizeLocId = 1
       IF((SizeLoc .EQ. 'S') .OR. (SizeLoc .EQ. 's')) SizeLocId = 2
       IF((SizeLoc .EQ. 'M') .OR. (SizeLoc .EQ. 'm')) SizeLocId = 3
       IF((SizeLoc .EQ. 'B') .OR. (SizeLoc .EQ. 'b')) SizeLocId = 4
       IF((DraftLoc .EQ. 'L') .OR. (DraftLoc .EQ. 'l')) DraftLocId = 1
       IF((DraftLoc .EQ. 'M') .OR. (DraftLoc .EQ. 'm')) DraftLocId = 2
       IF((DraftLoc .EQ. 'E') .OR. (DraftLoc .EQ. 'e')) DraftLocId = 3
       IF((KOLoc .EQ. 'K') .OR. (KOLoc .EQ. 'k')) KOLocId = 1
       IF((KOLoc .EQ. 'O') .OR. (KOLoc .EQ. 'o')) KOLocId = 2
       IF((PoolLevel .EQ. 'L') .OR. (PoolLevel .EQ. 'l')) LevelId = 1
       IF((PoolLevel .EQ. 'M') .OR. (PoolLevel .EQ. 'm')) LevelId = 2
       IF((PoolLevel .EQ. 'H') .OR. (PoolLevel .EQ. 'h')) LevelId = 3
       IF((TowLoc .EQ. 'L') .OR. (TowLoc .EQ. 'l')) TowLocId = 1
       IF((TowLoc .EQ. 'M') .OR. (TowLoc .EQ. 'm')) TowLocId = 2
       IF((TowLoc .EQ. 'R') .OR. (TowLoc .EQ. 'r')) TowLocId = 3

C     ==                                                                ==
C     ==            Reformat and Change Units of Variables              ==
C     ====================================================================

       DO i = 1,NumTransects
         IF(INT(RiverMile * 10.0) .EQ. Transect(i,1)) GOTO 100
       END DO
       GOTO 859
 100   CONTINUE
       CurTransect = i
      WRITE(*,*) 'Transect',RiverMile,'(',icount,')','[',ErrorCount,']'

       TowLocPnt = 0
       LeftBankPnt = 0
       RightBankPnt = 0
       DO i = Transect(CurTransect,2), Transect(CurTransect,3)
         WaterDepth(i) = WaterLevel(CurTransect,LevelId) - MSL(i)
         IF(WaterDepth(i) .LT. 0.0) WaterDepth(i) = 0.0
c        *** Find Tow Location ***
         IF(TowPos(CurTransect,LevelId,TowLocId) .EQ. BinLabel(i))
     *      TowLocPnt = i
         IF(BankPos(CurTransect,LevelId,1) .EQ. BinLabel(i))
     *      LeftBankPnt = i
         IF(BankPos(CurTransect,LevelId,2) .EQ. BinLabel(i))
     *      RightBankPnt = i
       END DO

c       DO i = LeftBankPnt, RightBankPnt
c         IF(WaterDepth(i) .EQ. 0.0) WRITE(8,*) BinLabel(i),',',LevelId
c       END DO

       IF(TowLocPnt .EQ. 0) GOTO 860
       IF(LeftBankPnt .EQ. 0) GOTO 861
       IF(RightBankPnt .EQ. 0) GOTO 862

c      *** Calculate Areas ***
       LeftArea = 0.0
       RightArea = 0.0
       DO i = TowLocPnt, LeftBankPnt, -1
         LeftArea = LeftArea + (WaterDepth(i) * 10.0)
       END DO
```

```
        DO i = TowLocPnt, RightBankPnt
          RightArea = RightArea + (WaterDepth(i) * 10.0)
        END DO
c       *** Adjust Areas for the Tow Location ***
        LeftArea = LeftArea - (WaterDepth(TowLocPnt) * 10.0 / 2.0)
        RightArea = RightArea - (WaterDepth(TowLocPnt) * 10.0 / 2.0)

        AveVel = 0.0
        MaxDepth = 0.0
        DO i = LeftBankPnt, RightBankPnt
          AveVel = AveVel + (Tabs(LevelId,i) * (WaterDepth(i) * 10.0))
          IF(WaterDepth(i) .GT. MaxDepth) MaxDepth = WaterDepth(i)
          Distance(i) = ABS(SQRT(((Easting(TowLocPnt)-Easting(i))**2.0)
     *                + ((Northing(TowLocPnt)-Northing(i))**2.0)))
        END DO
        AveVel = AveVel / (LeftArea + RightArea)

      LeftWidth = SQRT(
     *            ((Easting(TowLocPnt)-Easting(LeftBankPnt)) ** 2.0) +
     *            ((Northing(TowLocPnt)-Northing(LeftBankPnt)) ** 2.0))
      RightWidth = SQRT(
     *            ((Easting(TowLocPnt)-Easting(RightBankPnt)) ** 2.0) +
     *            ((Northing(TowLocPnt)-Northing(RightBankPnt)) ** 2.0))

      BinWidth = INT(TowSize(SizeLocId,1) / 10.0)
      LeftNear = TowLocPnt - BinWidth
      RightNear = TowLocPnt + BinWidth

c      GOTO 99
C     ==================================================================
C     ==        Start of SCHIJF Method from Visual Basic Code         ==
C     ==                                                              ==

      BTOTAL = LeftWidth + RightWidth
      BLEFT = LeftWidth
      ATOTAL = LeftArea + RightArea
      ALEFT = LeftArea

      D = Draft(DraftLocId)
      B = TowSize(SizeLocId,1)
      L = TowSize(SizeLocId,2)
      DEPTOW = WaterDepth(TowLocPnt)

      IF(DEPTOW .LT. 3.0) GOTO 854

      VAM = AveVel
      VW = Velocity(VelLocId)
      VG = VW + VAM * Direction
      V = ABS(VG - (Direction * 1.2 * VAM))
      GRAV = 9.805

c     *** SET WATER VISCOSITY = 0.0000011 M**2/SEC FOR TEMP = 17 DEG C
      VNU = 0.0000011

c     *** COMPUTE GEOMETRIC FACTORS
      AM = B * D
      BRIGHT = BTOTAL - BLEFT
      ARIGHT = ATOTAL - ALEFT
      NSIDEL = 2.0 * ALEFT / AM
      NSIDER = 2.0 * ARIGHT / AM
      BLB = BLEFT / BTOTAL
      BRB = BRIGHT / BTOTAL
      H = ATOTAL / BTOTAL
      HSave1 = H
      N = ATOTAL / AM
      IF((H / MaxDepth) .GT. 0.666) GOTO 21
      H = H * (3.0 - (3.0 * H / MaxDepth))
 21   CONTINUE
      HSave2 = H

c     SOLVE HOCHSTEIN EQUATION FOR U1 FOR DISPLACEMENT CALCULATION
      U1 = ABS(V) * ((N / (N-1)) ** 1.25-1)

c     *** COMPUTE DISPLACEMENT THICKNESS
 50   continue
```

```
      VDISP = ABS(V) + U1
      RL = VDISP * L / VNU
      DISP = 0.292 * L / (0.43429 * LOG(ABS(RL))) ** 2.58
      DE = D + DISP
      BE = B + 2.0 * DISP
      N = ATOTAL / BE / DE

c     *** SOLVE SCHIJF EQUATION FOR LIMIT SPEED USING NEWTON RAPHSON
      LoopCnt = 1
      VLO = ABS(V)
 54   continue
      RTEM = VLO ** 2.0 / GRAV / H
      FV = 1.0 - 1.0 / N + 0.5 * RTEM - 1.5 * RTEM ** (1.0 / 3.0)
      FPV = VLO / GRAV / H - (VLO ** (-1.0 / 3.0)) /
     *      (GRAV * H) ** (1.0 / 3.0)
      VLN = VLO - FV / FPV
      IF (ABS((VLO - VLN) / VLO) .LT. 0.0001) GOTO 55
      LoopCnt = LoopCnt + 1
      VLO = VLN
      IF(LoopCnt .GE. 100) GOTO 853
      GOTO 54
 55   continue
      VL = VLN
C     THIS ROUTINE FINDS U1 FOR V > .95*VL
      IF (V .LT. 0.95*VL) GOTO 57
      VTEMP = .95 * VL


      Z = .01
 56   SCHIJF = (1 + N * Z / H) / (N - 1 - N * Z / H)
      ZT = (VTEMP ** 2 / 2 / GRAV) * ((SCHIJF ** 2) + 2 * SCHIJF)
      U1 = ABS(VTEMP) * SCHIJF
      IF (ABS((ZT- Z) / ZT) .LT. 0.00001) GOTO 45
      Z = ZT
      GOTO 56
 45   VRRAT = U1 / VTEMP
      U1 = V * VRRAT
      GOTO 52


c     *** SOLVE SCHIJF EQUATION FOR RETURN VELOCITY
 57   LoopCnt = 1
      Z = 0.01
 51   SCHIJF = (1.0 + N * Z / H) / (N - 1.0 - N * Z / H)
      ZT = (V ** 2.0 / 2.0 / GRAV) * ((SCHIJF ** 2.0) + 2.0 * SCHIJF)
      U1 = ABS(V) * SCHIJF
      IF (ABS((ZT - Z) / ZT) .LT. 0.00001) GOTO 52
      LoopCnt = LoopCnt + 1
      Z = ZT
      IF(LoopCnt .GE. 100) GOTO 852
      GOTO 51

 52   CONTINUE
      VLIMRAT = ABS(V) / VL

c     *** APPLY CORRECTION FACTOR
 61   continue
      CF = 1.78 - 1.07 * VLIMRAT
      IF (CF .LT. 1.0) CF = 1.0

      U1 = CF * U1
      ZT = (ABS(V) + U1) ** 2.0 / 2.0 / GRAV - V ** 2.0 / 2.0 / GRAV

c     *** COMPUTE a(ALF) AND AVERAGE Vr FOR EACH SIDE OF TOW
      VFACTL = 1.65 - 1.3 * BLB
      IF (BLB .GT. 0.5) VFACTL = 1.35 - 0.7 * BLB
      VFACTR = 1.65 - 1.3 * BRB
      IF (BRB .GT. 0.5) VFACTR = 1.35 - 0.7 * BRB
      VRAL = U1 * VFACTL
      VRAR = U1 * VFACTR
      ZSL = ZT * VFACTL
      ZSR = ZT * VFACTR
      ALFL = 0.75 * NSIDEL ** 0.18
      ALFR = 0.75 * NSIDER ** 0.18
      IF (ALFL .LT. 1.0) ALFL = 1.0
```

```
      IF (ALFR .LT. 1.0) ALFR = 1.0
      ZALFL = ALFL ** 0.5
      ZALFR = ALFR ** 0.5
      VRLM = ALFL * VRAL
      VRRM = ALFR * VRAR
      ZSML = ZALFL * ZSL
      ZSMR = ZALFR * ZSR
      IF ((ARIGHT .GT. ALEFT) .AND. (VRRM .GT. VRLM)) VRRM = VRLM
      IF ((ALEFT .GT. ARIGHT) .AND. (VRLM .GT. VRRM)) VRLM = VRRM

c     *** Print input parameters
c      WRITE(9,881) ATOTAL, ALEFT
c      WRITE(9,882) BTOTAL, BLEFT
c      WRITE(9,883) B, D
c      WRITE(9,884) L
c      WRITE(9,885) VG
c      WRITE(9,886) VAM

c     *** COMPUTE RETURN VELOCITY AND DRAWDOWN DISTRIBUTION
      ALF = ALFL
      VRM = VRLM
      ZALF = ZALFL
      ZSM = ZSML
      BSIDE = BLEFT
      C = 3.0 * LOG(1.0 / ALF)
      ZC = 3.0 * LOG(1.0 / ZALF)
      DO i = LeftBankPnt, LeftNear
        y = Distance(i) * (-1.0)
        yy = ABS(Y)
        VelChange(i) = VRM * EXP(C * (yy - B) / (BSIDE - B))
        DrawDown(i) = ZSM * EXP(ZC * (yy - B) / (BSIDE - B))
      END DO

      ALF = ALFR
      VRM = VRRM
      ZALF = ZALFR
      ZSM = ZSMR
      BSIDE = BRIGHT
      C = 3.0 * LOG(1.0 / ALF)
      ZC = 3.0 * LOG(1.0 / ZALF)
      DO i = RightNear, RightBankPnt
        y = Distance(i)
        yy = ABS(Y)
        VelChange(i) = VRM * EXP(C * (yy - B) / (BSIDE - B))
        DrawDown(i) = ZSM * EXP(ZC * (yy - B) / (BSIDE - B))
      END DO

C     ==                                                             ==
C     ==        Start of SCHIJF Method from Visual Basic Code         ==
C     =================================================================

C     =================================================================
C     ==                    Secondary Wave Height                    ==
C     ==                                                             ==

        DO i = LeftBankPnt, RightBankPnt
        SecWaveHgt(i) = 0.0
        LocDistance = TowSize(SizeLocId,1) / 2.0 + 14.0
        IF(Distance(i) .GT. LocDistance) THEN
          AB = TowSize(SizeLocId,1) * Draft(DraftLocId)
          IF(AB .LE. 30.0) THEN
            alpha = 0.5
          ELSE
            IF(AB .LE. 65.0) THEN
              alpha = 0.6
            ELSE
              alpha = 0.7
            END IF
          END IF
          SecWaveHgt(i) = alpha * ((Distance(i) - (TowSize(SizeLocId,1)
     *                    / 2.0)) ** (-1.0/3.0)) * ((Velocity(VelLocId)
     *                    / SQRT(GRAV)) ** 2.67)
          IF((SecWaveHgt(i) / WaterDepth(i)) .GT. 0.6) THEN
            SecWaveHgt(i) = SecWaveHgt(i) * (-1.0)
          END IF
```

```
        ELSE
          SecWaveHgt(i) = -9.0
        END IF
      END DO

C     ==                                                                ==
C     ==                    Secondary Wave Height                       ==
C     ==================================================================

C     ==================================================================
C     ==   Start of Propellor Jet Velocities from Visual Basic Code   ==
C     ==                                                                ==

      VAM = AveVel
      VW = Velocity(VelLocId)
      VG = VW * Direction + VAM
      B = TowSize(SizeLocId,1)
      D = Draft(DraftLocId)
      LBARGES = TowSize(SizeLocId,2)
      VDIRECT = Direction

c     THE FOLLOWING 2 VALUES ARE TYPICAL OF UMRS TOWS AND WOULD BE VERY
c     DIFFICULT TO DETERMINE THEIR ACTUAL VALUES FOR ALL TOWBOATS
      TBL = 52.0      ! TOWBOAT LENGTH
      SETBACK = 5.0   ! DISTANCE FROM PROP TO TOWBOAT STERN(16.4 FT OR 5 M)
      VA = VAM    ! enter ambient AVG CHANNEL velocity
      DEP = WaterDepth(TowLocPnt)
      VR = U1  ! AVERAGE RETURN VELOCITY FROM NAVEFF
      z = ZT    ! AVERAGE DRAWDOWN FROM NAVEFF

c     *** VEL PREDICTION AT 0.46 m ABOVE CHANNEL BOTTOM TO AGREE WITH
MEASUREMENTS
      VELLOCc = 0.46
c      BC = DEP - D  ! BOTTOM CLEARANCE USED IN WAKE FLOW COMPUTATIONS
      grav = 9.805
      RHO = 999.8

c     *** Compute thrust using PROGRAM "power.BAS" relations
c     *** program assumes a semi-integrated tow (FRES = 1.0)
      FRES = 1.0
      nu = 0.00000112   ! ABOUT 16 DEG C
      delcf = 0.00075
      cp = 0.20

c     *** computations
      vtotal = VW + VR
      s = 2.0 * D * LBARGES + LBARGES * B ! HULL AREA EXPOSED TO WATER

c     *** COMPUTE SKIN FRICTION COEFFICIENT FOR DEEP WATER
      CF = (0.075 * (((LOG10(ABS(vtotal * LBARGES / nu))) -
     *      2.0) ** (-2.0))) + delcf

c     *** INCREASE HULL SHEAR FOR LOW UKC
      CFFACTOR = 1.55 - 0.105 * DEP / D
      IF(CFFACTOR .LT. 1.0) CFFACTOR = 1.0
      CFLOW = CF * CFFACTOR

c     *** COMPUTE RESISTANCE USING VAN DE KAA (1978)
      PUSH1 = CFLOW * 0.5 * RHO * vtotal ** 2.0 * s
      PUSH2 = RHO * grav * B * D * z
      PUSH3 = cp * 0.5 * RHO * VW ** 2.0 * B * D
      PUSH = PUSH1 + PUSH2 + PUSH3

c     *** ADJUST RESISTANCE FOR TOW INTEGRATION (ASSUMED TO BE SEMI-
INTEGRATED)
      THRUST = FRES * PUSH
c     PRINT "TOTAL THRUST (NEWTONS) = ", THRUST

c     *** TOUTANT POWER USING NEWTON-RAPHSON
      IF(KOLocId .EQ. 1) THEN
        A = 31.82
        BB = 5.4
      ELSE
        A = 23.57
        BB = 2.3
```

```
      END IF

      VMPH = ABS(VA - VG) * 3.28 * 60.0 / 88.0
      THRUSTP = THRUST / 4.4482
      V1 = THRUSTP / A
      V2 = (BB / A) * VMPH ** 2.0
      HPO = 500.0
      KKK = 0.0
 15   FX = HPO ** 0.974 - V1 - V2 * HPO ** 0.5
      FPX = 0.974 * HPO ** (-0.026) - 0.5 * V2 * HPO ** (-0.5)
      HPN = HPO - FX / FPX
      IF(ABS(HPO - HPN) .LT. 0.1) GOTO 19
      IF(KKK .GT. 50.0) GOTO 80
      HPO = HPN
      KKK = KKK + 1.0
      GOTO 15
 19   CONTINUE

c     *** SET TOTAL INSTALLED HORSEPOWER = 1.2*APPLIED HP
      TIHP = 1.2 * HPN

c     *** COMPUTE PROPELLER DIAMETER USING REGRESSION EQUATIONS
      IF(KOLocId .EQ. 1) DP = ((6.3 * TIHP ** 0.33) / 12.0 / 3.28)
      IF(KOLocId .EQ. 2) DP = ((5.25 * TIHP ** 0.35) / 12.0 / 3.28)
      IF(DP .GT. 2.80) DP = 2.80 ! LIMITS DP TO 9.5 FT
      IF(DP .LT. 1.80) DP = 1.80 ! LIMITS DP TO 6 FT
c     PRINT "PROPELLER DIAMETER (METERS) = ", DP
      PSPACE = 2.19 * DP  ! SETS DIST BETWEEN PROPS BASED ON DP

c     *** SET HP = DEPTH MINUS 1/2 PROP DIAMETER
      HP = DEP - DP / 2.0
      THRUST = THRUST / 2.0 !CONVERTS TO THRUST PER PROPELLER

c     *** X IS MEASURED FROM BOW OF BARGES
      XBEGIN = LBARGES + TBL - 20.0 !BEGIN LOOKING FOR MAX 20M AHEAD OF
STERN
      XSPACE = 1.9
      NUMX = 200

c     *** Y IS MEASURED LATERALLY FROM CENTER OF TOWBOAT
      Y = 3.0  !Y=0 M IS REPRESENTED BY VEL AT Y=3 M BECAUSE PEAK AT 3 M
c     *** CAN BE SUBSTANTIALLY GREATER THAN AT Y=0 AT SHALLOW DEPTHS
      YSPACE = 10.0
      NUMY = 3

c     *** MISCELLANEOUS INPUT

c     ***INPUT APPLICABLE TO BOTH PROPELLER TYPES
      CDECAY = 0.34
      P1DECAY = 0.93
      P2DECAY = 0.24

      IF(KOLocId .EQ. 1) GOTO 70
c     *** THIS SECTION FOR SETTING OPEN WHEEL PARAMETERS
      D0 = 0.71 * DP
      E = 0.43
      CPARA = 0.12 * (DP / HP) ** 0.6666
      CEXP = 0.656
      CFUNC = 0.5
      GOTO 190
 70   CONTINUE
c     *** THIS SECTION FOR SETTING KORT NOZZLE PARAMETERS
      D0 = DP
      E = 0.58
      CPARA = 0.04
      CEXP = 0.85
      CFUNC = 0.25
c     *** END OF KORT VERSUS OPEN
 190  CONTINUE

c     *** end input

c     *** COMPUTE VELOCITY EXITING PROPELLER
      V0 = 1.13 / D0 * (THRUST / RHO) ** 0.5
      U2 = V0
```

```
      IF(U2 .EQ. 0.0) U2 = 0.00001
c      PRINT "VELOCITY EXITING PROPELLER (METERS/SEC) = ", U2

c     *** BEGIN ITERATION LOOP FOR X AND Y
      DO J = 1, NUMY
        IF(J .EQ. 2) Y = 10.0 !THIS RESETS LOCATION TO 10 M INCREMENTS
        X = XBEGIN  !x = 0 at bow of barges
        VTEST = 0.0
        DO i = 1, NUMX

c         *** COMPUTE PEAK VELOCITY CHANGE AT BOW
          VBDMAX = (VA - VG) * 0.79 * (DEP / D) ** (-1.21)
          IF(Y .GT. (B / 2.0)) VBDMAX = 0.0
          IF(ABS(VBDMAX) .GT. VTEST) VTEST = ABS(VBDMAX)

c         *** compute wake velocity
          vwakamax = (-1.0) * (VA - VG) * 0.78 * (D / DEP) ** 1.81
          VWAKEgx = 0.0
          IF((X - LBARGES) .GT. TBL) GOTO 30
          coef = X - LBARGES
          IF(coef .LT. 0.0) coef = 0.0
          IF(Y .GT. (B / 2.0)) coef = 0.0
          VWAKEgx = vwakamax * coef / TBL
          GOTO 39
 30       CONTINUE
          temp1 = (1 + 0.0075 * (TBL / D) - 0.0075 * (X - LBARGES) / D)
          IF(temp1 .LT. 0.0) temp1 = 0.0
          IF(Y .GT. (B / 2.0)) temp1 = 0.0
          VWAKEgx = vwakamax * temp1
c         *** END WAKE VEL
 39       CONTINUE

c         *** BEGIN PROPELLOR JET VELOCITY
          XPROP = X - LBARGES - TBL + SETBACK  !x relative to props
          VXRPROP = 0.0
          IF(XPROP .LT. 0.0) GOTO 69        !GOES TO END OF PROPELLER

c         *** COMPUTE VELOCITY IN ZONE 1 WHICH IS TWO JETS ADDED TOGETHER

c         *** DECAY MAX JET VELOCITY USING SINGLE JET EQUATION
          XCALC = XPROP
          IF(XPROP .LT. (2.03 * DP)) XCALC = 2.03 * DP
          VXMAX = U2 * 1.45 * (XCALC / DP) ** (-0.524)
          IF(VXMAX .GT. U2) VXMAX = U2

c         *** COMPUTE LOCATION OF PARABOLIC JET OFF RUDDER
c         *** CJ IS THE LOCATION OF THE CENTER OF THE JET RELATIVE TO SHAFT
          CJTEMP = CPARA * grav * (XPROP-SETBACK/2.0) ** 2.0 / U2 ** 2.0
     *             / 0.957
          cj = (-1.0) * (0.2126 * (XPROP - SETBACK / 2.0) - CJTEMP)
          ZZB = HP + cj - VELLOCc !ZZB IS CENTER OF JET RELATIVE TO VELLOC
          IF(XPROP .LT. (SETBACK / 2.0)) ZZB = HP - VELLOCc !THIS IS BEFORE
JET DEFLECTED
          IF(XPROP .LT. (SETBACK / 2.0)) GOTO 601  !OFF OF THE RUDDER
          IF(ZZB .GT. (DEP - VELLOCc)) GOTO 500   !THIS DEFINES END OF ZONE
1 WHERE
c                                                  PARABOLIC SHAPE GOES TO
SURFACE
 601      CONTINUE
          YL = Y + PSPACE / 2.0
          YR = Y - PSPACE / 2.0
          RL = SQRT(YL ** 2.0 + (ZZB) ** 2.0)
          RR = SQRT(YR ** 2.0 + (ZZB) ** 2.0)
          CPZ1 = 0.18
          VXRL = VXMAX * EXP((-1.0) * (RL) ** 2.0 / (2.0 *
     *           (CPZ1) ** 2.0 * (XPROP) ** 2.0))
          VXRR = VXMAX * EXP((-1.0) * (RR) ** 2.0 / (2.0 *
     *           (CPZ1) ** 2.0 * (XPROP) ** 2.0))
          VXRPROP = VXRR + VXRL

c         *** THIS LIMITS PROP VEL IN ZONE 1 TO FUEHRER, ROMISCH, ENGELKE
TYPE EQ

          VMAXTEST = E * (DP / HP) * U2
          IF(VXRPROP .GT. VMAXTEST) VXRPROP = VMAXTEST
```

```
          GOTO 69  !THIS SKIPS ZONE 2 CALC BECAUSE STILL IN ZONE 1

c         *** COMPUTE MAX PROP VEL IN ZONE 2
 500      CONTINUE
          VXMAX = U2 * CEXP * 2.7183 ** (-0.0178 * XPROP / DP)

c         *** COMPUTE LATERAL DISTRIBUTION OF MAXIMUM WHICH IS AT SURFACE

          CPZ2 = 0.84 * (XPROP / DP) ** (-0.62)
          VXRPROP = VXMAX * EXP(-Y ** 2.0 / (2.0 * (CPZ2) ** 2.0 *
     *              (XPROP) ** 2.0))

c         *** COMPUTE DECAY FROM SURFACE TO BOTTOM
          K11 = CDECAY * (DP / HP) ** P1DECAY * (XPROP / DP) ** P2DECAY
          IF(K11 .GT. 0.95) K11 = 0.95
          VXRPROP = VXRPROP * K11

c         *** SUM OF VPROP, VWAKE
 69       CONTINUE
          FUNC = 1.0 - CFUNC * ABS((VA - VG) / U2) * (HP / DP) ** 1.5
          IF(FUNC .LT. 0.0) FUNC = 0.0
          VRES = (-1.0) * VDIRECT * VXRPROP * FUNC + VWAKEgx
          IF(ABS(VRES) .GT. VTEST) VTEST = ABS(VRES)

          X = X + XSPACE
        END DO

        VLM(J) = VTEST
        Y = Y + YSPACE
      END DO

c     *** END ITERATION LOOP ON X AND Y

c     *** OUTPUT

c     PRINT "CL DIST, M   MAX VEL CHANGE, M/SEC"
c     FOR K = 1 TO NUMY
c     YY(1) = 0
c     PRINT YY(K), VLM(K)
c     NEXT K
c     PRINT "TOTAL INSTALLED HORSEPOWER (=1.2*APPLIED POWER) = ", TIHP

 80   CONTINUE

C     ==                                                                ==
C     ==   Start of Propellor Jet Velocities from Visual Basic Code     ==
C     ====================================================================

      DO i = LeftBankPnt, (TowLocPnt-1)
        Distance(i) = Distance(i) * (-1.0)
      END DO

      NBNum = RightNear - LeftNear + 2.0
      NBIncVal = (DrawDown(RightNear+1) - DrawDown(LeftNear-1)) / NBNum
      DO i = LeftNear, RightNear
        DrawDown(i) = DrawDown(i-1) + NBIncVal
      END DO

      NBNum = RightNear - LeftNear + 2.0
      NBIncVal = (VelChange(RightNear+1)-VelChange(LeftNear-1)) / NBNum
      DO i = LeftNear, RightNear
        VelChange(i) = VelChange(i-1) + NBIncVal
      END DO

      IF(VLM(1) .GT. VelChange(TowLocPnt))
     *  VelChange(TowLocPnt) = VLM(1)
      IF(VLM(2) .GT. VelChange(TowLocPnt-1))
     *  VelChange(TowLocPnt-1) = VLM(2)
      IF(VLM(2) .GT. VelChange(TowLocPnt+1))
     *  VelChange(TowLocPnt+1) = VLM(2)

c      IF(VelChange(TowLocPnt-1) .LT. VelChange(LeftNear-1))
c     *  VelChange(TowLocPnt-1) = VelChange(LeftNear-1)
```

```
c      IF(VelChange(TowLocPnt+1) .LT. VelChange(RightNear+1))
c     *  VelChange(TowLocPnt+1) = VelChange(RightNear+1)
c      IF(VelChange(TowLocPnt) .LT. VelChange(TowLocPnt-1))
c     *  VelChange(TowLocPnt) = VelChange(TowLocPnt-1)
c      IF(VelChange(TowLocPnt) .LT. VelChange(TowLocPnt+1))
c     *  VelChange(TowLocPnt) = VelChange(TowLocPnt+1)

c***** Interpolation from Tow RVel to Original NAVEFF RVels *****
c      IF(VLM(2) .EQ. 0.0) THEN
c        NBNum = (TowLocPnt-1) - LeftNear + 2.0
c        NBIncVal = (VelChange(TowLocPnt)-VelChange(LeftNear-1))/NBNum
c        DO i = LeftNear, (TowLocPnt-1)
c          VelChange(i) = VelChange(i-1) + NBIncVal
c        END DO
c
c        NBNum = RightNear - (TowLocPnt+1) + 2.0
c        NBIncVal = (VelChange(RightNear+1)-VelChange(TowLocPnt))/NBNum
c        DO i = (TowLocPnt+1), RightNear
c          VelChange(i) = VelChange(i-1) + NBIncVal
c        END DO
c      ELSE
c        NBNum = (TowLocPnt-2) - LeftNear + 2.0
c        NBIncVal = (VelChange(TowLocPnt-1)-VelChange(LeftNear-1))/NBNum
c        DO i = LeftNear, (TowLocPnt-2)
c          VelChange(i) = VelChange(i-1) + NBIncVal
c        END DO
c
c        NBNum = RightNear - (TowLocPnt+2) + 2.0
c        NBIncVal = (VelChange(RightNear+1)-VelChange(TowLocPnt+1))/NBNum
c        DO i = (TowLocPnt+2), RightNear
c          VelChange(i) = VelChange(i-1) + NBIncVal
c        END DO
c      ENDIF

C     ==================================================================
C     ==         Initialize Variables and Call Scour Routines         ==
C     ==                                                              ==

      IF(KOLocId .EQ. 1) AKO = "k"    ! kort or open
      IF(KOLocId .EQ. 2) AKO = "o"    ! kort or open
C      DP = 2.74       ! propeller diameter
      vg = (Velocity(VelLocId) * Direction) + AveVel ! vessel speed
relative to ground
      DIRECT = Direction       ! -1 = upbound, +1 = downbound
      barbeam = TowSize(SizeLocId,1) ! total width of barges
      DRAFTc = Draft(DraftLocId)      ! draft of barges
      barlen = TowSize(SizeLocId,2)  ! total length of barges
      tbl = 52.0        ! length of towboat- keep constant for all tows
C      THRUST = 300000.0 ! thrust for each props in newtons
      VNU = .000001   ! kinematic viscosity- fix for all conditions?????
      Ylamb = .3      ! porosity of sediment- fix for all ??????????????

c*******************************************************************
c////////////////////////////////\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
c\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\////////////////////////////////////
c*******************************************************************


      iTRANTYPE = 2   ! ACKER-WHITE(1) OR GARCIA(2) TRANSPORT

      va = AveVel                     ! ambient average channel velocity
      dep = WaterDepth(TowLocPnt)     ! local depth at centerline of tow
      deptmp = WaterDepth(TowLocPnt)
      if ( deptmp .LT. 3.5 ) dep = 3.5

      D50 = D50Size(TowLocPnt)        ! SEDIMENT DIAMETER IN M
      VS = D50Vel(TowLocPnt)          ! SEDIMENT FALL VELOCITY IN M/SEC
      Y = 3.0                         ! distance from centerline for near
vessel scour only
      VRMAX = VelChange(TowLocPnt)   ! max return vel at point of interest
      VACell = Tabs(LevelId,TowLocPnt)
      VABOTT = 0.7 * VACell   ! bottom velocity- set equal to .7*va
      deltime = .1    ! time step for computations- fix at .1 unless too
slow
      IF( D50 .LT. 999.0 ) THEN
```

```
          call propscou(ako, dp, vg, va, direct, barbeam, draftc, barlen,
     *                 tbl, thrust, dep, vabott, d50, y, ETAMAX, VNU,
     *                 YLAMB, VS, deltime, iTRANTYPE, TauMax, PSPACE,
     *                 VACell,CNewMax,Camb, TauAmb)
          MaxScour(TowLocPnt) = ETAMAX
          ShearStress(TowLocPnt) = TauMax
          AmbFlux(TowLocPnt) = CAMB
          MaxFlux(TowLocPnt) = CNEWMAX
          ShearAmb(i) = TauAmb
        ELSE
          MaxScour(TowLocPnt) = 9999.0
          ShearStress(TowLocPnt) = 9999.0
          AmbFlux(TowLocPnt) = 9999.0
          MaxFlux(TowLocPnt) = 9999.0
          ShearAmb(i) = 9999.0
        ENDIF

        va = AveVel              ! ambient average channel velocity
        dep = WaterDepth(TowLocPnt)    ! local depth at centerline of tow
        deptmp = WaterDepth(TowLocPnt)
        if ( deptmp .LT. 3.5 ) dep = 3.5

        D50 = D50Size(TowLocPnt-1)  ! SEDIMENT DIAMETER IN M
        VS = D50Vel(TowLocPnt-1)    ! SEDIMENT FALL VELOCITY IN M/SEC
        Y = ABS(Distance(TowLocPnt-1))   ! distance from centerline for near
vessel scour only
        VRMAX = VelChange(TowLocPnt-1)   ! max return vel at point of
interest
        VACell = Tabs(LevelId,TowLocPnt-1)
        VABOTT = 0.7 * VACell   ! bottom velocity- set equal to .7*va
        deltime = .1    ! time step for computations- fix at .1 unless too
slow
        IF( D50 .LT. 999.0 ) THEN
          call propscou(ako, dp, vg, va, direct, barbeam, draftc, barlen,
     *                 tbl, thrust, dep, vabott, d50, y, ETAMAX, VNU,
     *                 YLAMB, VS, deltime, iTRANTYPE, TauMax, PSPACE,
     *                 VACell,CNewMax,Camb, TauAmb)
          MaxScour(TowLocPnt-1) = ETAMAX
          ShearStress(TowLocPnt-1) = TauMax
          AmbFlux(TowLocPnt-1) = CAMB
          MaxFlux(TowLocPnt-1) = CNEWMAX
          ShearAmb(i) = TauAmb
        ELSE
          MaxScour(TowLocPnt-1) = 9999.0
          ShearStress(TowLocPnt-1) = 9999.0
          AmbFlux(TowLocPnt-1) = 9999.0
          MaxFlux(TowLocPnt-1) = 9999.0
          ShearAmb(i) = 9999.0
        ENDIF

        va = AveVel              ! ambient average channel velocity
        dep = WaterDepth(TowLocPnt)    ! local depth at centerline of tow
        deptmp = WaterDepth(TowLocPnt)
        if ( deptmp .LT. 3.5 ) dep = 3.5

        D50 = D50Size(TowLocPnt+1)  ! SEDIMENT DIAMETER IN M
        VS = D50Vel(TowLocPnt+1)    ! SEDIMENT FALL VELOCITY IN M/SEC
        Y = ABS(Distance(TowLocPnt+1))   ! distance from centerline for near
vessel scour only
        VRMAX = VelChange(TowLocPnt+1)   ! max return vel at point of
interest
        VACell = Tabs(LevelId,TowLocPnt+1)
        VABOTT = 0.7 * VACell   ! bottom velocity- set equal to .7*va
        deltime = .1    ! time step for computations- fix at .1 unless too
slow
        IF( D50 .LT. 999.0 ) THEN
          call propscou(ako, dp, vg, va, direct, barbeam, draftc, barlen,
     *                 tbl, thrust, dep, vabott, d50, y, ETAMAX, VNU,
     *                 YLAMB, VS, deltime, iTRANTYPE, TauMax, PSPACE,
     *                 VACell,CNewMax,Camb,TauAmb)
          MaxScour(TowLocPnt+1) = ETAMAX
          ShearStress(TowLocPnt+1) = TauMax
          AmbFlux(TowLocPnt+1) = CAMB
          MaxFlux(TowLocPnt+1) = CNEWMAX
          ShearAmb(i) = TauAmb
```

```
      ELSE
        MaxScour(TowLocPnt+1) = 9999.0
        ShearStress(TowLocPnt+1) = 9999.0
        AmbFlux(TowLocPnt+1) = 9999.0
        MaxFlux(TowLocPnt+1) = 9999.0
        ShearAmb(i) = 9999.0
      ENDIF

      DO i = LeftBankPnt, TowLocPnt-2
        va = Tabs(LevelId,i)   ! ambient average channel velocity
        dep = WaterDepth(i)    ! local depth at centerline of tow
        D50 = D50Size(i)  ! SEDIMENT DIAMETER IN M
        VS = D50Vel(i)    ! SEDIMENT FALL VELOCITY IN M/SEC
        Y = ABS(Distance(i))   ! distance from centerline for near vessel
scour only
        VRMAX = VelChange(i) * direct * (-1.0)   ! max return vel at point
of interest
        VACell = Tabs(LevelId,i)
        VABOTT = 0.7 * VACell   ! bottom velocity- set equal to .7*va
        deltime = .1    ! time step for computations- fix at .1 unless too
slow
        IF( D50 .LT. 999.0 ) THEN
          CALL VRSCOUR(VG,VRMAX,VA,DEP,BARLEN,DELTIME,D50,VS,VNU,YLAMB,
     *                 ETAMAX,iTRANTYPE,TauMax,VACell,CNewMax,Camb,
     *                 TauAmb)
          MaxScour(i) = ETAMAX
          ShearStress(i) = TauMax
          AmbFlux(i) = CAMB
          MaxFlux(i) = CNEWMAX
          ShearAmb(i) = TauAmb
        ELSE
          MaxScour(i) = 9999.0
          ShearStress(i) = 9999.0
          AmbFlux(i) = 9999.0
          MaxFlux(i) = 9999.0
          ShearAmb(i) = 9999.0
        ENDIF
      END DO

      DO i = TowLocPnt+2, RightBankPnt
        va = Tabs(LevelId,i)   ! ambient average channel velocity
        dep = WaterDepth(i)    ! local depth at centerline of tow
        D50 = D50Size(i)  ! SEDIMENT DIAMETER IN M
        VS = D50Vel(i)    ! SEDIMENT FALL VELOCITY IN M/SEC
        Y = ABS(Distance(i))   ! distance from centerline for near vessel
scour only
        VRMAX = VelChange(i) * direct * (-1.0)   ! max return vel at point
of interest
        VACell = Tabs(LevelId,i)
        VABOTT = 0.7 * VACell   ! bottom velocity- set equal to .7*va
        deltime = .1    ! time step for computations- fix at .1 unless too
slow
        IF( D50 .LT. 999.0 ) THEN
          CALL VRSCOUR(VG,VRMAX,VA,DEP,BARLEN,DELTIME,D50,VS,VNU,YLAMB,
     *                 ETAMAX,iTRANTYPE,TauMax,VACell,CNewMax,Camb,
     *                 TauAmb)
          MaxScour(i) = ETAMAX
          ShearStress(i) = TauMax
          AmbFlux(i) = CAMB
          MaxFlux(i) = CNEWMAX
          ShearAmb(i) = TauAmb
        ELSE
          MaxScour(i) = 9999.0
          ShearStress(i) = 9999.0
          AmbFlux(i) = 9999.0
          MaxFlux(i) = 9999.0
          ShearAmb(i) = 9999.0
        ENDIF
      END DO

c*********************************************************************
c/////////////////////////////////\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
c\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\/////////////////////////////////
c*********************************************************************
```

```
C     ==                                                              ==
C     ==         Initialize Variables and Call Scour Routines         ==
C     ==================================================================


      DO i = LeftBankPnt, RightBankPnt
        IF(VelChange(i) .GE. 10.0) GOTO 855
        IF(DrawDown(i) .GE. 2.0) GOTO 856
        IF(Distance(i) .GE. 10000.0) GOTO 857
        IF(SecWaveHgt(i) .GE. 0.42) GOTO 858
      END DO

c      WRITE(8,880) ErrorCode,RiverMile,DirLoc,VelLoc,SizeLoc,
c     *             DraftLoc,KOLoc,PoolLevel,TowLoc,DirLoc,VelLoc,
c     *             SizeLoc,DraftLoc,KOLoc,PoolLevel,TowLoc,ATOTAL,
c     *             ALEFT,BTOTAL,BLEFT,B,L,D,V,VAM,
c     *             MaxDepth,HSave1,HSave2,U1,ZT


      DO i = LeftBankPnt, RightBankPnt
        WRITE(9, 950) RiverMile, DirLoc, VelLoc, SizeLoc, DraftLoc,
     *                KOLoc, PoolLevel, TowLoc, DirLoc, VelLoc,
     *                SizeLoc, DraftLoc, KOLoc, PoolLevel, TowLoc,
     *                BinLabel(i), WaterDepth(i), VelChange(i),
     *                DrawDown(i), Distance(i), SecWaveHgt(i),
     *                MaxScour(i), ShearStress(i), AmbFlux(i),
     *                MaxFlux(i), ShearAmb(i)
      END DO
 950  format(f5.1,',',a1,',',a1,',',a1,',',a1,',',a1,',', a1,',',
     *       a1,',',a1,a1,a1,a1,a1,',', a1,a1,',',a10,',',f5.2,',',
     *       f6.3,',',f6.3,',',f8.1,',',f6.3,',',f9.4,',',f9.4,',',
     *       f11.6,',',f11.6,',',f9.4)
      GOTO 99

 862  CONTINUE
      ErrorCode = 'RBnk' !Could not find Right Bank
      GOTO 850
 861  CONTINUE
      ErrorCode = 'LBnk' !Could not find Left Bank
      GOTO 850
 860  CONTINUE
      ErrorCode = 'TLoc' !Could not find Tow Loc
      GOTO 850
 859  CONTINUE
      ErrorCode = 'Tran' !Could not find Transect
      GOTO 850
 858  CONTINUE
      ErrorCode = 'SecW' !Secondary Wave Height is to high
      GOTO 850
 857  CONTINUE
      ErrorCode = 'Dist' !Distance is to high
      GOTO 850
 856  CONTINUE
      ErrorCode = 'DDwn' !DrawDown is to high
      GOTO 850
 855  CONTINUE
      ErrorCode = 'RVel' !Return Velocity is to high
      GOTO 850
 854  CONTINUE
      ErrorCode = 'TDep' !Water depth at the Tow is too shallow
      GOTO 850
 853  CONTINUE
      ErrorCode = 'LP3 ' !Endless Loop Occured in Loop 3
      GOTO 850
 852  CONTINUE
      ErrorCode = 'LP2 ' !Endless Loop Occured in Loop 2
      GOTO 850
c851  CONTINUE
c     ErrorCode = 'LP1 ' !Endless Loop Occured in Loop 1
c     GOTO 850
 850  CONTINUE
      ErrorCount = ErrorCount + 1
      WRITE(8,880) ErrorCode,RiverMile,DirLoc,VelLoc,SizeLoc,
     *             DraftLoc,KOLoc,PoolLevel,TowLoc,DirLoc,VelLoc,
     *             SizeLoc,DraftLoc,KOLoc,PoolLevel,TowLoc,ATOTAL,
```

```
     *             ALEFT,BTOTAL,BLEFT,B,L,D,V,VAM,
     *             MaxDepth,HSave1,HSave2,U1,ZT
c      WRITE(8,881) RiverMile
c      WRITE(8,*) ' '
c      WRITE(8,882) ATOTAL, ALEFT
c      WRITE(8,883) BTOTAL, BLEFT
c      WRITE(8,*) ' '
c      WRITE(8,884) B, D
c      WRITE(8,885) L
c      WRITE(8,*) ' '
c      WRITE(8,886) VG
c      WRITE(8,887) VAM
c      WRITE(8,*) ' '
c      WRITE(8,888) DirLoc, VelLoc, SizeLoc
c      WRITE(8,889) DraftLoc, KOLoc, PoolLevel
c      WRITE(8,890) TowLoc
c      WRITE(8,*) ' '
c      WRITE(8,*) ' '
c      WRITE(8,*) ' '
 880  FORMAT(a4,',',f5.1,',',a1,',',a1,',',a1,',',a1,',',a1,',',a1,
     *       ',',a1,',',a1,a1,a1,a1,a1,',',a1,a1,',',f9.1,',',f9.1,
     *       ',',f9.1,',',f9.1,',',f8.2,',',f8.2,',',f8.3,',',f8.3,
     *       ',',f8.3,',',f8.3,',',f5.2,',',f5.2,',',f6.3,',',f6.3)
 881  FORMAT('Transect: ', f5.1)
 882  FORMAT('     CHANNEL TOTAL AREA   ', f8.1, ' SQ M  ',
     *       '     AREA LEFT OF TOW           ', f8.1, ' SQ M  ')
 883  FORMAT('             TOTAL WIDTH  ', f8.1, ' METERS',
     *       '     DISTANCE, LEFT BANK TO TOW ', f8.1, ' METERS')
 884  FORMAT('     TOW     WIDTH        ', f8.1, ' METERS',
     *       '     DRAFT                      ', f8.1, ' METERS')
 885  FORMAT('             LENGTH       ', f8.1, ' METERS')
 886  FORMAT('     TOW SPEED RELATIVE TO GROUND      ', f8.1, ' M/SEC')
 887  FORMAT('     AVERAGE CHANNEL VELOCITY(+=U,-=D) ', f8.1, ' M/SEC')
 888  FORMAT('     Direction: ', a1, '     Speed:     ', a1,
     *       '     Size:      ', a1)
 889  FORMAT('     Draft:     ', a1, '     K/O:       ', a1,
     *       '     Stage:     ', a1)
 890  FORMAT('     Tow Loc:   ', a1)

  99  CONTINUE
      END DO
 149  CONTINUE

      CLOSE(1)
      CLOSE(8)
      CLOSE(9)


C     ==================================================================
C     ==                 Program Termination Point                    ==
C     ==                                                              ==

      STOP ' NORMAL STOP CONDITIONS '
      END

C     ==                                                              ==
C     ==                 Program Termination Point                    ==
C     ==================================================================



      subroutine vrscour(vg,vrmax,va,dep,barlen,deltime,d50,vs,vnu,
     & Ylamb, ETAMAX, iTRANTYPE,TauMax,VACell,CNewMax,Camb, TauAmb)
*
*     SUBROUTINE VRSCOUR DEFINES THE SCOUR FOR THE ZONE AWAY FROM THE
VESSEL
*
      DIMension vrhis(19, 2)
*
*     DIMENSIONLESS RETURN VELOCITY DISTRIBUTION FROM KAMPSVILLE REPORT
*
      vrhis(1, 1) = 0
      vrhis(1, 2) = 0
      vrhis(2, 1) = .2
      vrhis(2, 2) = .02
```

```
      vrhis(3, 1) = .4
      vrhis(3, 2) = .1
      vrhis(4, 1) = .6
      vrhis(4, 2) = .21
      vrhis(5, 1) = .7
      vrhis(5, 2) = .34
      vrhis(6, 1) = .8
      vrhis(6, 2) = .5
      vrhis(7, 1) = .9
      vrhis(7, 2) = .64
      vrhis(8, 1) = 1.0
      vrhis(8, 2) = .77
      vrhis(9, 1) = 1.1
      vrhis(9, 2) = .83
      vrhis(10, 1) = 1.2
      vrhis(10, 2) = .86
      vrhis(11, 1) = 1.3
      vrhis(11, 2) = .9
      vrhis(12, 1) = 1.4
      vrhis(12, 2) = .95
      vrhis(13, 1) = 1.5
      vrhis(13, 2) = 1.0
      vrhis(14, 1) = 1.6
      vrhis(14, 2) = .92
      vrhis(15, 1) = 1.8
      vrhis(15, 2) = .65
      vrhis(16, 1) = 2
      vrhis(16, 2) = .36
      vrhis(17, 1) = 2.2
      vrhis(17, 2) = .07
      vrhis(18, 1) = 2.3
      vrhis(18, 2) = .001
      vrhis(19, 1) = 50
      vrhis(19, 2) = 0
*
*    INITIALIZE VARIABLES
*
c      GRAV = 9.805
      TauMax = 0.0
      CNewMax = 0.0
      rho = 1000
      cold = 0
      ETA = 0.0
      ETAMAX = 0.0
      TIMSCOUR = 0
      timbarge = barlen / ABS(vg)
      numtime = INT(2.3 * timbarge / deltime) + 2
      cfc = .06 / (LOG10(12.0 * dep / (3.0 * d50))) ** 2
      cfr = (2.87 + 1.58 * LOG10(1.0 / (3.0 * d50))) ** (-2.5)

*
*     BEGIN ITERATION AT EACH TIME STEP
*
      DO 45, I = 1,numtime
      timerat = TIMSCOUR / timbarge
      vrrat = 0.0
      IF (timerat.EQ.0) GOTO 20
*
*    THIS LOOP FINDS VRRAT AT EACH TIMERAT
*
      DO 10, II = 1,19
      IF (timerat.GT.vrhis(II, 1)) GOTO 10
      VRAT = (timerat - vrhis(II - 1, 1)) /(vrhis(II,1)-vrhis(II-1,1))
      VRRAT = vrhis(II - 1, 2) + VRAT * (vrhis(II, 2) -vrhis(II-1, 2))
      GOTO 20
10    CONTINUE
20    CONTINUE
      vr = VRRAT * VRMAX
*
*     COMPUTE SHEAR USING BLAAUW ET AL (1984)
*
      TAU = .5 * rho * cfc * (VaCell + (cfr / cfc) ** .5 * vr) ** 2  !!!
max(tau) = shear factor
      IF(TAU .GT. TauMax) TauMax = TAU
      USTAR = (TAU/RHO)**.5
```

```
      VAcker = ABS(VaCell + (cfr / cfc) ** .5 * vr)
*
*     CALL DESIRED TRANSPORT EQUATION
*
      IF(iTRANTYPE.EQ.1)CALL ACKER(USTAR,DEP,D50,VNU,YLAMB,ETA,CNew,
     *                             VAcker)
      IF(iTRANTYPE.EQ.2)CALL GARCIA(USTAR,VS,DEP,D50,VNU,YLAMB,ETA,
     *  COLD,DELTIME,VG,CEQ,TROOLD,ESOLD)

      IF(CEQ .GT. CNewMax) CNewMax = CEQ

      IF(i .EQ. 1) THEN
        Camb = CEQ
        TauAmb = Tau
      END IF
*
*     TEST ETA TO SEE IF EQUAL TO MAX SCOUR
*
      IF(ETA.LT.ETAMAX) ETAMAX = ETA
30    TIMSCOUR = TIMSCOUR + deltime
45    CONTINUE
*
*
*
1000  END

*
      subroutine propscou(ako, dp, vg, va, direct, barbeam, draft,
     & barlen,tbl,thrust,dep, vabott, d50,y,ETAMAX,VNU,YLAMB,VS,
     & deltime,iTRANTYPE,TauMax,PSPACE,VACell,CNewMax,Camb,TauAmb)
*
*     SUBROUTINE PROPSCOU DEFINES SCOUR BENEATH VESSEL
*
      DIMension taup(12, 5), taub(9, 2)
      CHARACTER AKO * 5
*
*     DIMENSIONLESS ARRAY FOR BOW SHEAR DISTRIBUTION
*
      taub(1, 1) = 0.0
      taub(1, 2) = -1.17
      taub(2, 1) = .25
      taub(2, 2) = -.73
      taub(3, 1) = .5
      taub(3, 2) = -.51
      taub(4, 1) = .75
      taub(4, 2) = -.33
      taub(5, 1) = 1.0
      taub(5, 2) = 0.0
      taub(6, 1) = .75
      taub(6, 2) = .37
      taub(7, 1) = .5
      taub(7, 2) = .67
      taub(8, 1) = .25
      taub(8, 2) = 1.41
      taub(9, 1) = 0.0
      taub(9, 2) = 3.41
*
*     DIMENSIONLESS array for propeller SHEAR DISTRIBUTION
*
      taup(1, 1) = 0.0
      taup(1, 2) = -6.0
      taup(1, 3) = -25.0
      taup(1, 4) = -50.0
      taup(1, 5) = 0.0
      taup(2, 1) = .1
      taup(2, 2) = -3.3
      taup(2, 3) = -15.0
      taup(2, 4) = -30.0
      taup(2, 5) = 0.0
      taup(3, 1) = .25
      taup(3, 2) = -2.1
      taup(3, 3) = -6.4
      taup(3, 4) = -11
      taup(3, 5) = 0
```

```
      taup(4, 1) = .5
      taup(4, 2) = -1.4
      taup(4, 3) = -1.5
      taup(4, 4) = -2.7
      taup(4, 5) = 0
      taup(5, 1) = .75
      taup(5, 2) = -.54
      taup(5, 3) = -.6
      taup(5, 4) = -.7
      taup(5, 5) = 0
      taup(6, 1) = 1.0
      taup(6, 2) = 0
      taup(6, 3) = 0
      taup(6, 4) = 0
      taup(6, 5) = 0
      taup(7, 1) = .75
      taup(7, 2) = .6
      taup(7, 3) = 1.3
      taup(7, 4) = 1.7
      taup(7, 5) = 0
      taup(8, 1) = .5
      taup(8, 2) = 2.2
      taup(8, 3) = 9.2
      taup(8, 4) = 15
      taup(8, 5) = 0
      taup(9, 1) = .25
      taup(9, 2) = 11
      taup(9, 3) = 37
      taup(9, 4) = 60
      taup(9, 5) = 0
      taup(10, 1) = .1
      taup(10, 2) = 23
      taup(10, 3) = 93
      taup(10, 4) = 125
      taup(10, 5) = 0
      taup(11, 1) = .05
      taup(11, 2) = 75
      taup(11, 3) = 153
      taup(11, 4) = 175
      taup(11, 5) = 0
      taup(12, 1) = 0
      taup(12, 2) = 230
      taup(12, 3) = 230
      taup(12, 4) = 230
      taup(12, 5) = 0
*
*     BEGIN INPUT
*
*     OPEN(3,"temp.dat", FORM ='FORMATTED', STATUS = 'UNKNOWN')
*
      IF(AKO.EQ.'k') AKO = 'K'
      IF(AKO.EQ.'o') AKO = 'O'
      TauMax = 0.0
      CNewMax = 0.0
      cold = 0
c      vg = vg * DIRECT
c      PSPACE = 6        !!! FIX
c      GRAV = 9.805
      SETBACK = 5
c      THRUST = THRUST / 2
      hp = dep - DP / 2
*
*     TAUFAC IS THE RATIO USED TO ADJUST PHYSICAL MODEL VALUES FROM THE
*     SMOOTH BOUNDARY TO THE ROUGH BOUNDARY FOUND IN THE FIELD AND TO
*     ACCOUNT FOR THE GREATER TURBULENCE FOUND IN PROPELLER JETS
*     COMPARED TO OPEN CHANNEL FLOW USED TO DEVELOP TRANSPORT EQUATIONS
*
      taufac = 7.87*(d50)**(.18)
      ETAMAX = 0.0
      ETA=0.0
15    continue
      XSPc = ABS(deltime * vg)
      XBEGIN = 0
      numx = INT((barlen + tbl + .05/D50) / XSPc)
      NUMY = 1
```

```
      rho = 999.8

      CFCamb = 0.06/(LOG10(12.0*DEP/(3.0*D50)))**2
      TAUAMB = 0.5*RHO*CFCAMB*VACell**2
      USTAR = (TAUAMB/RHO)**0.5
      VAcker = VACell
      CALL GARCIA(USTAR,VS,DEP,D50,VNU,YLAMB,ETA,
     *            COLD,DELTIME,VG,CEQ,TROOLD,ESOLD)
      CAMB = CEQ

*
*     SET KORT OR OPEN PARAMETERS
*
      IF(AKO.EQ.'K') GO TO 12
*
*     THIS SECTION FOR OPEN WHEEL
      D0 = .71 * DP
      E = .43
      CFUNC = .5
      GOTO 17
12    CONTINUE
*     THIS SECTION FOR KORT
      D0 = DP
      E = .58
      CFUNC = .25
17    CONTINUE
*
*     compute PEAK BOW SHEAR
*
      DOD = dep / DRAFT
      CBOWC = .0118
      CBOWP = -2.85
      IF (DIRECT.GT.0) GOTO 78
      CBOWC = .0148
78    CBOW = CBOWC * DOD** CBOWP
      TAUBOWP = taufac*10000 * CBOW * (va - vg) ** 2.0
*
*     END OF PEAK BOW COMPUTATIONS
*
*     COMPUTE VELOCITY EXITING PROPELLER
*
      U2 = 1.13 / D0 * (THRUST / rho) ** .5
ccc      PRINT *,'U2 = '
ccc      WRITE(*,*) U2
*
*     COMPUTE WAKE VELOCITY AT PEAK PROP VELOCITY
*
      xprmax = hp / .1
      vwakamax = -1.0 * (va - vg) * (.78) * (DRAFT / dep) ** (1.81)
ccc      PRINT
ccc      PRINT *, 'MAXIMUM WAKE VELOCITY REL TO AMB COND. = '
ccc      WRITE(*,*) VWAKAMAX
ccc      PRINT *, 'MAX WAKE VEL PLUS AMB BOT VEL = '
      TEMP = vwakamax + VABOTT
cc      WRITE(*,*) TEMP
      IF (U2.EQ.0) GOTO 40
*
*     COMPUTE PEAK PROPELLER VELOCITY
*
      f = (1.0 - CFUNC * (ABS(va - vg) / U2) * (hp / DP) ** 1.5)
      GOTO 45
40    f = 0
45    IF(f.LT.0)  f = 0
      vpropmax = E * (DP / hp) * U2 * f
*
*     compute wake vel at hp/.1 behind towboat
*
      vwake1 = (1.0 - .0075 * xprmax / DRAFT)
      vwakegx = vwakamax * vwake1 + VABOTT
30    CONTINUE
ccc      PRINT *, 'WAKE VEL AT HP/X=.1 PLUS AMBIENT BOT VEL = '
ccc      WRITE(*,*) vwakegx
*
*     compute max resultant vel VRES
*
```

```
ccc      VRES = -1 * DIRECT * vpropmax + vwakegx
ccc      PRINT *,'MAX PROPELLER/WAKE/AMB VEL AT HP/X = 0.1 '
ccc      WRITE(*,*) VRES
*
*     VELSHEAR IS THE VELOCITY USED TO DETERMINE THE SHEAR AND DEFINES
*     THE VELOCITY CHANGE FROM THE WAKE WHICH IS GOING ONE DIRECTION
*     AND THE PROPELLER JET WHICH IS GOING THE OPPOSITE DIRECTION
*
      Velshear = ABS(vpropmax) + .5 * ABS(vwakegx)
      CFPROP = .01 * DP / hp
      PROPSH = 0.5 * 10000.0 * CFPROP * Velshear ** 2.0
ccc      PRINT *,'MAXIMUM PROPELLER SHEAR IN PASCALS = '
ccc      WRITE(*,*) taufac*PROPSH/10     !!! Shear var
ccc      WRITE(*,*) 'SHEAR FACTOR = ',TAUFAC
*
*
*
*     start distribution- y measured from cl of tow, x measured
*     from bow of barges
*
*
36    CONTINUE
35    CONTINUE
*
*     START ITERATION ON X,Y
*
      DO 350, I = 1, NUMY
      X = XBEGIN
      DO 360, J = 1, numx
      tau = 0.0
*
*     COMPUTE BOW SHEAR DISTRIBUTION
*
      XPEAKBOW = 10
      IF (Y.GT.BARBEAM / 2) GOTO 229
      XRATBOW = (X - XPEAKBOW) / dep
      IF (XRATBOW.LE. - 1.17) GOTO 229
      IF (XRATBOW.GT.3.41) GOTO 229
      DO 222, JK = 1, 8
      IF (XRATBOW.GT.taub(JK + 1, 2)) GOTO 222
      TEMP1 = (taub(JK + 1, 1) - taub(JK, 1))
      TEMP2 = (XRATBOW - taub(JK, 2)) / (taub(JK + 1, 2) - taub(JK, 2))
      TAUBRAT = taub(JK, 1) + TEMP1 * TEMP2
      GOTO 228
222   CONTINUE
228   TAU = TAUBRAT * TAUBOWP
229   CONTINUE
*
*     END BOW SHEAR
*
*     compute wake dist
*
      vwakegx = 0.0
      IF (Y.GT.BARBEAM / 2) GOTO 100
      coef = X - barlen
      IF (coeF.LE.0) GOTO 100
      xlim = coef
      IF(xlim.GT.0.1)  xlim = .1
      cfc = .06 / (LOG10(12.0 * dep / (3.0 * d50))) ** 2.0
      cfr = (2.87 + 1.58 * LOG10(1.0 / (3.0 * d50))) ** (-2.5)
      IF((x - barlen).GT.tbl)  GO TO 110
      deca = coef / tbl
      vwakegx = vwakamax * deca + VABOTT
      GOTO 120
110   deca = (1.0+ .0075 * (tbl / DRAFT) - .0075 * (X - barlen) / DRAFT)
      IF(deca.LT.0.0)  deca = 0.0
      vwakegx = vwakamax * deca + VABOTT
120   ctemp = .5 * 10.0 * CFC * rho
      TAU = ctemp * (va + ((CFR/CFC)**.5) * vwakamax * deca) ** 2.0
*
100   CONTINUE
*     END WAKE DIST
*
*     BEGIN PROP DIST
*
```

```
      taurat = 0.0
      IF (x.lt.barlen) GOTO 700
*
*     COMPUTE LATERAL PEAK SHEAR
*
      YDP = Y / DP
      DPHP = DP / hp
      IF (DPHP.gt.1.2)  DPHP = 1.2
      IF (DPHP.lt.0.48)  DPHP = .48
      IF (YDP.gt.0.547) GOTO 200
*     LINEAR PORTION HERE
      SHRATY0 = 1.207 - .653 * DPHP
      SHRATY = 1.0 - (.547 - YDP) / .547 * (1.0 - SHRATY0)
      peaksh = SHRATY * PROPSH
      GOTO 400
200   IF (YDP.gt.1.095) GOTO 300
*     SHEAR = PEAK SHEAR HERE
      peaksh = PROPSH
      GOTO 400
300   CONTINUE
*     EXPONENTIAL SHEAR HERE
      C5 = .0221 * 2.7183 ** (3.14 * DPHP)
      SHRATY = 2.7183 ** ((-1.0 * C5) * ((Y - PSPACE / 2) / DP) ** 2)
      peaksh = SHRATY * PROPSH
*
*     END FINDING LATERAL PEAK SHEAR
*
400   CONTINUE
*
*     COMPUTE LONGITUDINAL SHEAR FROM PEAK LATERAL SHEAR
*
      XPEAK = barlen + tbl + hp / .2 - SETBACK
      XRAT = (X - XPEAK) / hp
*
*     PS IS ONLY USED TO SELECT WHICH LONGITUDINAL DISTRIBUTION TO USE
*     ALL TAU IN THIS SECTION ARE IN DYNES/SQ CM AND HAVE NOT BEEN ADJUSTED
*     BY TAUFAC. THIS IS NECESSARY TO FIT THE RANGES OF PS FOR FITTING THE
*     DISTRIBUTIONS.
      PS = peaksh
      IF (peaksh.gt.1000.0)  PS = 1000.0
      IF (peaksh.lt.69.0)  PS = 69.0
      IF (PS.lt.215.0) GOTO 500
*     THIS PART IS FOR PS FROM 1000-215
      do 450, jj = 1,12
      TEMP = (1000.0 - PS) / 785.0 * (taup(JJ, 3) - taup(JJ, 2))
      taup(JJ, 5) = taup(JJ, 2) + TEMP
450   CONTINUE
      GOTO 600
500   CONTINUE
*     THIS PART FOR PS <215 TO 69
      DO 550, kk = 1,12
      TEMP = (215.0 - PS) / 146.0 * (taup(KK, 4) - taup(KK, 3))
      taup(KK, 5) = taup(KK, 3) + TEMP
550   CONTINUE
600   IF (XRAT.LE.taup(1, 5)) GOTO 900
      IF (XRAT.GE.230) GOTO 900
      DO 650 k = 1,11
      IF (XRAT.GT.taup(k + 1, 5)) GOTO 650
      TEMP1 = (taup(k + 1, 1) - taup(k, 1))
      TEMP2 = TEMP1 * (XRAT - taup(k, 5)) / (taup(k + 1, 5)-taup(k, 5))
      taurat = taup(k, 1) + TEMP2
      GOTO 700
650   CONTINUE
*
*     END LONGITUDINAL DISTRIBUTION
*
*     SET TAU TO MAX OF PROP OR WAKE SHEAR AND ADJUST BY TAUFAC
*     (TAU STILL IN DYNES/SQ CM)
*
700   IF (taufac*taurat * peaksh.GT.TAU)  TAU = taufac*
     & taurat * peaksh
900   CONTINUE
      IF((0.1*TAU) .GT. TauMax) TauMax = TAU*0.1
```

```
*
*     COMPUTE SHEAR VEL USING TAU IN PASCALS
*
      ustar = (0.1*TAU / rho) ** .5
*
      IF(iTRANTYPE.EQ.1)CALL ACKER(USTAR,DEP,D50,VNU,YLAMB,ETA,CNEW,
     * VACKER)
      IF(iTRANTYPE.EQ.2)CALL GARCIA(USTAR,VS,DEP,D50,VNU,YLAMB,ETA,
     & COLD,DELTIME,VG,CEQ,TROOLD,ESOLD)

      IF(CEQ .GT. CNewMax) CNewMax = CEQ

*
*     TEST FOR MAX SCOUR
*
      IF(ETA.LT.ETAMAX) ETAMAX = ETA
      IF (TauMax .LT. TauAmb) TauMax = TauAmb
*
*     INCREMENT TIME AND X
*
29    TIMSCOUR = TIMSCOUR + deltime
      X = X + XSPc
360   CONTINUE
150   CONTINUE
350   CONTINUE
*
*     END ITERATION ON X,Y
*
1000  END


      SUBROUTINE ACKER(USTAR,DEP,D50,VNU,YLAMB,ETA,cnew,vacker)
      GRAV = 9.805
      IF (ustar.EQ.0.0) GOTO 25
*
*     compute equivalent vbar based on keulegan equation
*
c      vbar = ustar * 5.75 * LOG10(11.1 * dep / (3 * d50))
*
*     ackers white equation
*
      dgr = d50 * ((GRAV * 1.65 / VNU ** 2) ** .3333)
      IF(dgr.LE.60.0) GO TO 22
*     COARSE PARAMETERS
      EN = 0.0
      A = .17
      EM = 1.78
      C = .025
      GOTO 23
22    CONTINUE
*     TRANSITION PARAMETERS
      EN = 1 - .56 * LOG10(dgr)
      A = .23 / (dgr)**.5 + .14
      EM = 6.83 / dgr + 1.67
      Cc = 2.79 * LOG10(dgr) - 0.98*(LOG10(dgr)) ** 2 - 3.46
      C = 10 ** Cc
23    CONTINUE
*     SEDIMENT MOBILITY
      FGR1 = (GRAV * d50 * 1.65)**.5
      FGR11 = ustar ** EN / FGR1
      FGR2 = 10 * dep / d50
      FGR21 = 5.675 * LOG10(FGR2)
      FGR22 = (vacker / FGR21) ** (1 - EN)
      FGR = FGR11 * FGR22
*     TEST FOR ZERO TRANSPORT
      ZQS = FGR / A
      IF(ZQS.LE.1.0) GO TO 25
      GGR = C * (FGR / A - 1) ** EM
*     cnew = SED FLUX IN PARTS/PART by volume
      cnew = (GGR * d50) / (dep * (ustar / vacker) ** EN)
*
*     LIMIT CNEW TO 0.3
*
      if(cnew.gt.0.3) cnew=0.3
      GOTO 26
```

```
25    CNEW=0
26    CONTINUE
*
*     EXNER EQ
*
      ETA = -1.0 * (dep * cnew) / (1 - Ylamb)
*
      RETURN
      END
*
      SUBROUTINE GARCIA(USTAR,VS,DEP,D50,VNU,YLAMB,ETA,COLD,DELTIME,VG,
     *                  CEQ,TROOLD,ESOLD)
*     GARCIA FUNCTION FOR SCOUR
c      WRITE(8,*) VS,COLD,DELTIME,VG
      GRAV = 9.805
      RHO = 1000.0
      IF (ustar.EQ.0.0) GOTO 25
      TAU=RHO*USTAR**2.0
*
      RP = d50 * (1.65 * GRAV * d50) ** .5 / VNU
*
*     COMPUTE QB WITH ENGELUND AND FREDSOE
*
      taustar = TAU / (rho * GRAV * 1.65 * d50)
      IF(taustar .lt. 0.05) GOTO 25
      Tqstar = 18.74 * (taustar - .05) * (taustar ** .5 - .7 *.05**.5)
      Tqb = Tqstar * d50 * (GRAV * 1.65 * d50) ** .5
*
      ZU = (ustar / vs) * RP ** .6
      ACOEF = .00000013
      es = ACOEF * ZU ** 5.0 / (1.0 + (ACOEF / .3) * ZU ** 5.0)
      Tro = 1.0 + 31.5 * (ustar / vs) ** (-1.46)
*
*     TRO LIMITED TO MAX OF GARCIA DATA
*
      IF(TRO.GT.87.7) TRO = 87.7
      CEQ=ES/TRO
      cnew = cold * (1.0 - deltime * VS *TroOLD/ dep) +
     &       deltime * VS*esOLD/dep
      IF (cnew .LT. 0.0) cnew = 0.0
      GOTO 26
25    CNEW=0.0
      TQB=0.0
      ZU=0.0
      ES=0.0
      TRO=87.7
      CEQ=0.0
26    CONTINUE
*
*     EXNER EQ
*
      ETA = -1.0 * (Tqb / ABS(vg) + dep * cnew) / (1.0 - Ylamb)
*
      cold = cnew
      esOLD=ES
      troOLD=TRO
      RETURN
      END
```

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14. ABSTRACT
The Upper Mississippi River – Illinois Waterway (UMR-IWW) system model is comprised of the NAVEFF and NAVSED models and determines the physical forces for the entire UMR-IWW reach as well as the fleet of tows using the waterway. This report documents the geographical information system components of the system models, input and output files formats, and assumptions used in the application of the models to the UMR-IWW. The NAVEFF portion of the system model determines the maximum velocity change, tow drawdown of water level, wave height, bed scour, and bed shear stress. Many of these physical parameters provided input to various ecological models used in the System Feasibility study. NAVEFF output is also input to the NAVSED model that provides the time-history of sediment concentration as a result of tow passage. The NAVSED output also serves as input to various ecological models as well as sedimentation of secondary channels and backwaters.

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