Variations of a Mississippi River Crossing with Stage

James V. Hines III
U.S. Army Corps of Engineers
Vicksburg District
Vicksburg, Mississippi

INTRODUCTION

In the study of sediment transport by rivers, most of the emphasis has been directed toward bendways and channels having a smooth, regular shape. Very little investigation has covered crossings. One possible explanation for this is that flow characteristics do not differ much among different bends, but crossings may be found which are quite unique within relatively long reaches of river.

A crossing is generally defined as that reach of river within which the thalweg, or deepest bottom trace, shifts from one side of the channel to the other. If this is accomplished in a short distance, then the crossing will generally be well-defined and would require little or no maintenance for navigation. On the other hand, if the distance required for crossing is allowed to stretch out too far, middle bars will tend to form, decreasing sediment transport capability at that section. This causes aggradation in the channel, a condition implying deterioration of navigation depths and flood conveyance capacity. The precise distance for an effective crossing appears to be some one to two top bank widths for the Lower Mississippi River, but depends upon a number of factors which vary among locations.

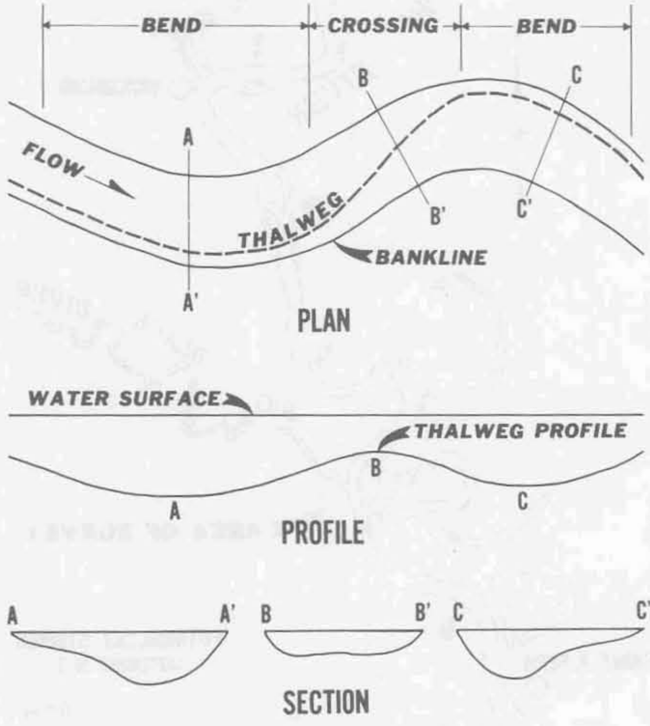
A generalized example of the bed profile for bend-crossing sequence is shown at Figure 1. Also shown is an unscaled comparison of the shape of typical cross-sections at a bend and a crossing. As the flow enters and passes through a bend, centrifugal forces tend to concentrate a major portion of it to the outside of the bend. As the flow leaves the bend and enters the crossing, this portion becomes less restricted to one bank, implying a greater width of concentrated flow. Following the principle of continuity, a greater width of flow requires that average depth must decrease. The concentrated portion of flow provides the main forces for sediment transport. Also, during periods of high flow the energy grade line is flattened somewhat. A decrease in slope and depth will result in a decrease in sediment transport capability, and may cause aggradation. As a flood hydrograph passes, it carries a much higher sediment load and the effects of the crossing on sediment transport are aggravated. After the stage has crested, the water surface generally begins to fall at a rate faster than the bed in the crossing can scour to its normal low-water elevation. During the highest stages of the 1973 flood, one of the most severe of recent history, dredging was required at some crossings to maintain the nine-foot minimum depths for navigation.

The purpose of this study was to observe the change in bed elevation of a crossing as affected by a flood hydrograph.

SELECTION OF SURVEY SITE

The two primary criteria used in selecting an appropriate site for the study were that the crossing should be well defined and located within approximately one hour's boat travel from Vicksburg. The latter consideration was due primarily to cost and convenience. It was felt that in order to obtain a maximum amount of data that as little as possible of an eight-hour workday should be used for travel.

The selection of a well-defined crossing was intended to provide clarity in defining the extent of the survey area. This required a reach containing a single thalweg between two bends of opposite direction. Divided flow reaches, or those containing middle bars, are under the influence of additional transport phenomena which would supply extraneous information. One further consideration, having to do with the operation of the



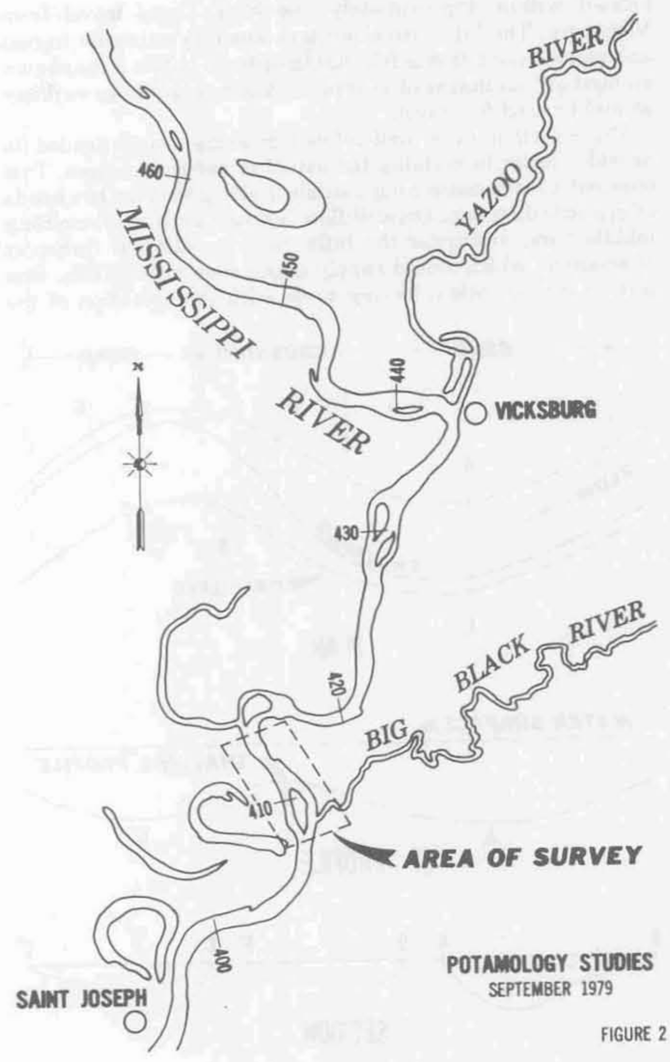
TYPICAL CHANNEL GEOMETRY

POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 1

survey system, required an accessible area for equipment setup and water surface elevation measurements.

The reach between river mile 409 AHP and mile 412 AHP, near Point Pleasant, La., and the mouth of the Big Black River was chosen and a reconnaissance trip by boat was undertaken to verify that the above criteria were satisfied. The choice was well suited to the requirements of geometry and also had one high bank line which was not expected to be inundated by any but extreme flood levels. Furthermore, a permanent benchmark was located near top bank, thus providing easy measurement of stage. Prior to 1971 the selected reach had been under the influence of divided flow caused by Middle Ground Island. At that time, the back channel flow was restricted by the construction of two stone dikes, which have effectively caused sediment transport to be contained within the main channel for the most part. This was verified by examining old hydrographic surveys. A map of the survey area is shown at Figure 2.



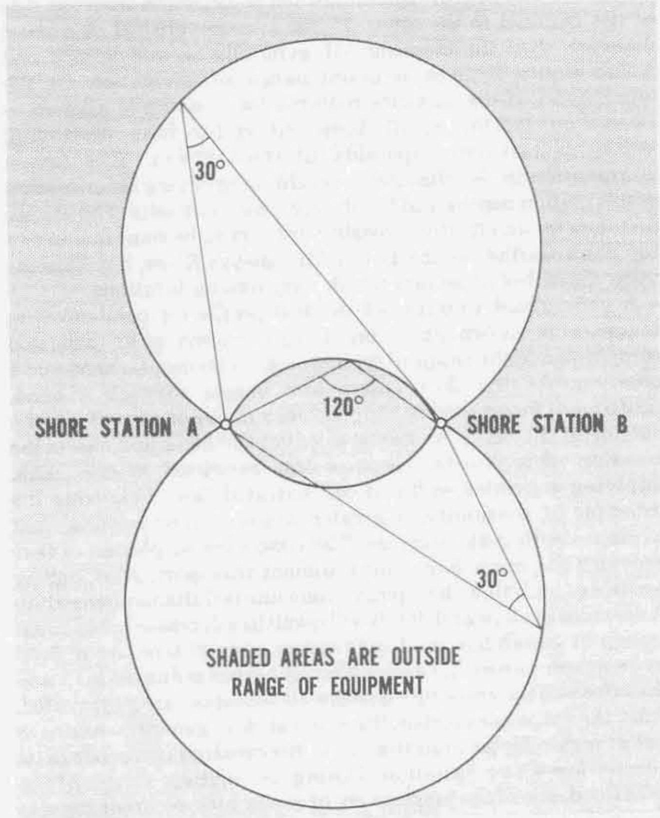
POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 2

METHOD OF DATA COLLECTION

As mentioned, one criteria to be met in site selection was accessibility for equipment. The system is centered around a Mini-Ranger III automatic positioning system. This system consists of a control unit with an omni-directional receiving antenna mounted on a survey boat and two transponders located on the bank such that the entire survey area falls under line-of-sight conditions. Additionally, the system is governed by geometrical restrictions, which must also be considered when selecting a site. The angle formed by shore station 1, the boat, and shore station 2 must be no less than 30°, nor no more than 120°. Thus, an elliptical area located directly between the two shore stations is excluded from the area which can be surveyed. Figure 3 shows an example of the "dead" or unusable areas. Figure 4 shows the limits of the selected survey area. Dike design procedures generally followed by the Vicksburg District call for the alignment of the dikes to be perpendicular to the direction of flow. Therefore, it follows that survey track lines which are perpendicular to the dike will be approximately parallel to the flow lines. This not only allows for more accurate study of the bed forms, but also makes proper operation of the boat easier, since boat control is more accurate when moving directly into the current.

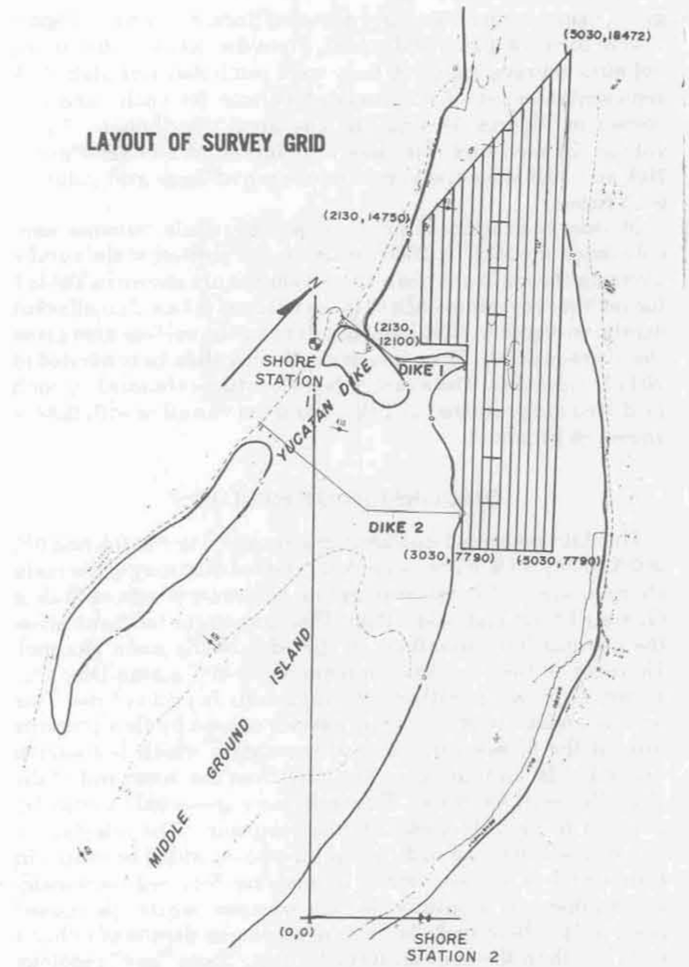
The procedure that was followed for the majority of the data collection evolved from several days of trial work. The survey area was divided into a series of 30 parallel "track lines", varying in length from 3000 to 10,000 feet. The lines are defined by an X-Y coordinate system, also shown on Figure 4, with the beginning and end points of each line stored on magnetic tape, and in the microprocessor unit. This unit contains the hard-wired software which governs the positioning system and other peripheral equipment. By repositioning the shore transponders in exactly



LIMITS OF SURVEY
(MINI-RANGER III POSITIONING SYSTEM)

POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 3

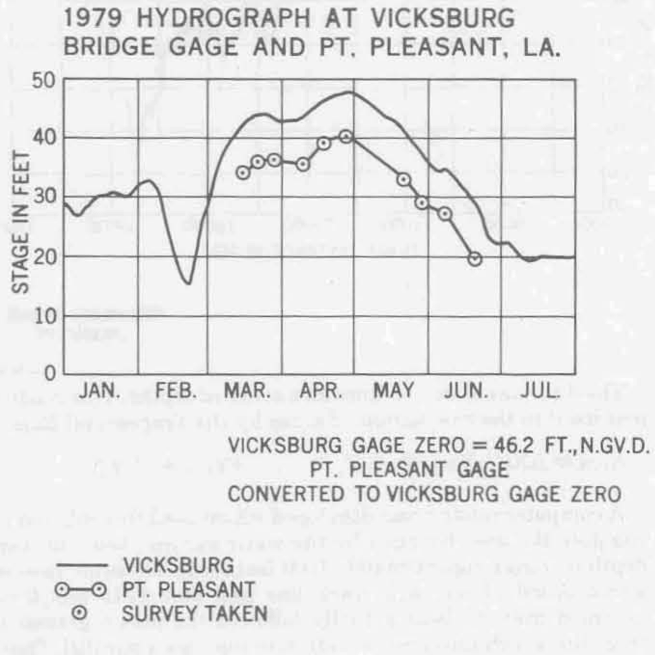


POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 4

the same location for each successive survey, the repeatability is dependent only on the boat operator's skill. The boat operator is directed by a left-right indicator mounted within his view, which also shows the percentage of track line length covered. It was originally planned to run each of the thirty lines; however, it was found that better coverage of the entire area could be obtained in a shorter period by surveying all the even-numbered lines and then filling in with selected odd-numbered lines. As the boat moves along the track line, soundings are taken by a Raytheon Fathometer and digitized at a rate of 10 soundings per second. For each two-second interval, the maximum depth, minimum depth, average depth over the interval, and ending X-Y coordinates are recorded on standard magnetic tape data cartridges and simultaneously printed at the operator's terminal. Following completion of the survey, the data may be plotted in the form of depths or bed elevations, with the decimal point representing the precise location of the reading. At maximum boat speed of about 30 fps, this survey technique gives one data point for each 6000 sq. ft. over a total survey area of 22.6×10^6 sq. ft., or a total of approximately 3700 data points per square mile. This compares with approximately 100 points per square mile in a standard hydrographic survey. The survey work and data plotting can be accomplished during a normal eight-hour workday.

It was originally planned to take a survey of the area at an interval corresponding to a change of five feet (rise or fall) in water surface elevation. However, the 1979 flood hydrograph went for an extended period without a significant change in stage. Therefore, a survey was planned for each week until a falling river was observed. The 1979 water surface hydrograph at Vicksburg Bridge gage, with a relation of the stage at Point Pleasant adjusted to the Vicksburg gage zero, is shown for each of the survey dates at Figure 5.



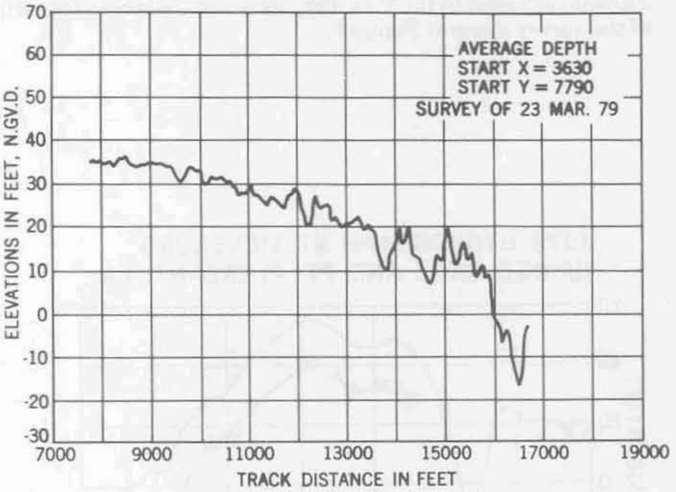
POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 5

ANALYSIS OF DATA

Although the Mini-Ranger data processor unit has some analysis capability, it is intended to be used primarily for before- and after-dredging surveys. The available procedures were not general enough for the crossing study, so the data were loaded and stored on the Boeing Computer Services CDC Cyber 175 mainframe computer. An insignificant amount of data was obviously erroneous. However, the error was such that these data required deletion. Due to the irregularities of these errors, editing was best accomplished manually, using the standard EDIT routines.

In order to present an areal representation of the data, it was decided that volumes would best portray the channel changes taking place as the hydrograph passed. To standardize the data, a constant which would convert each water surface elevation to a datum of 100 ft., NGVD (National Geodetic Vertical Datum) was added to every depth reading. A simple plot routine was used to display the data in profile form. An example of a profile plot is given at Figure 6.



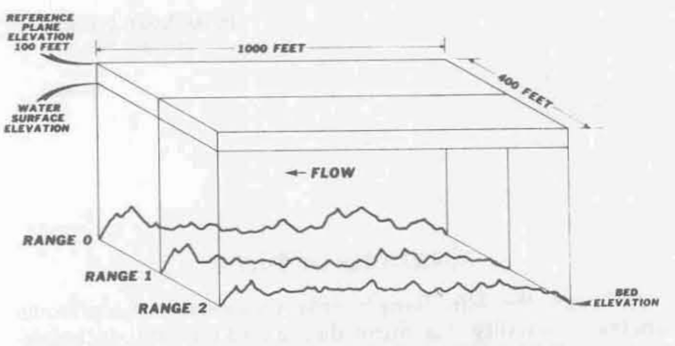
POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 6

The data was stored by lines as a series of depths. This readily lent itself to the calculation of areas by the Trapezoidal Rule:

$$\text{Area} = \Delta X(^1/_2 Y_0 + Y_1 + Y_2 + \ . \ . \ . \ + Y_{n-1} + {^1/_2} Y_n)$$

A computer routine was developed which used this relation to compute the area bounded by the water surface, bed, and two depth readings approximately 1000 feet apart. These areas were accumulated along each track line and stored. It was then assumed that the boat actually followed the pre-programmed track lines such that any two adjacent lines were parallel. Thus, with two known areas, and a fixed distance between them, volume could be computed. Volumes contained by 400' X 1000' grids, using depths from three adjacent lines, as shown in Figure 7 were then computed and stored. From the accumulated areas, volumes between adjacent lines were computed and plotted. A representative set of accumulated volume for each survey is shown in Figures 8A and 8B. The areal distribution of grid volume for each survey is shown in Figures 9A and 9B. Figures 10A and 10B show the variation of each of these grid volumes with time.



SCHEMATIC OF PROFILE SURVEY FOR VOLUME COMPUTATION

POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 7

In order to examine the data on a larger scale, volumes were calculated for 2000' X 2000' grids for the portion of the survey covering the main channel. These volumes are shown in Table 1 for each survey. Since each of these volumes is based on all point depths surveyed in that area, dividing by the surface area gives the average depth. The average depth may then be converted to NGVD elevation. The average bed elevations obtained in each grid area are presented in Table 2 and the variation with time is shown in Figure 11.

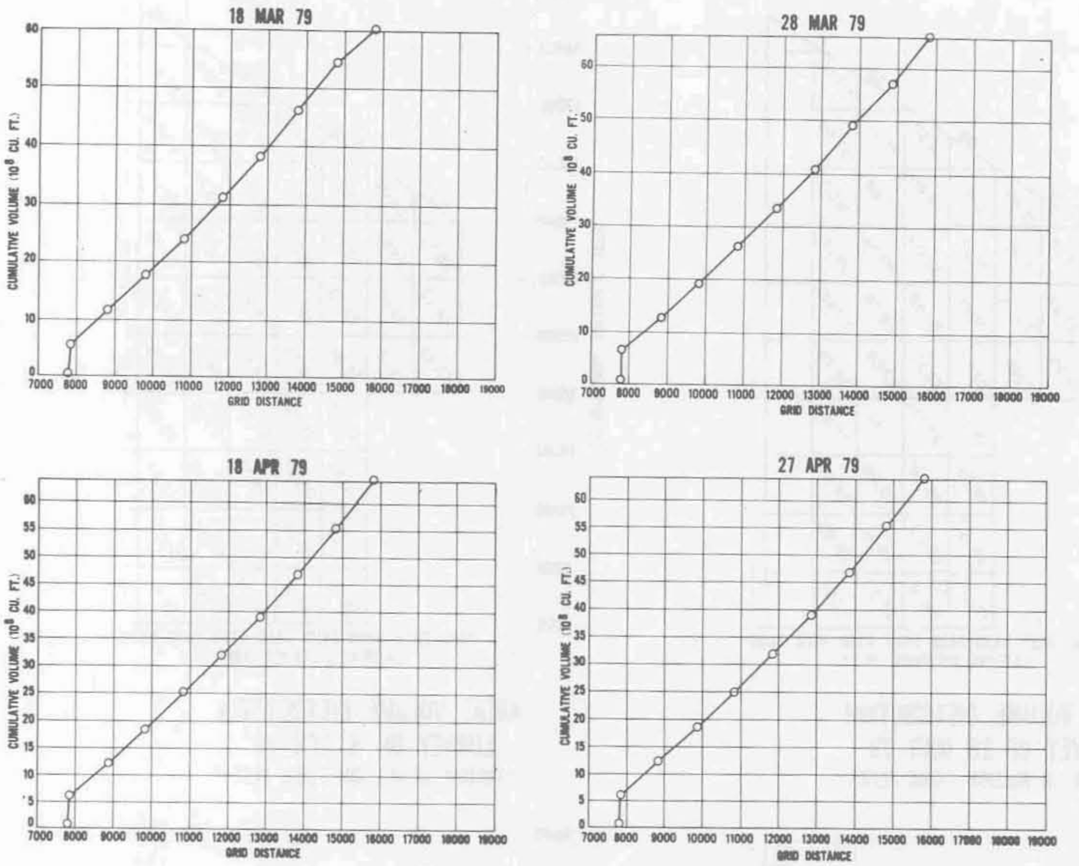
DISCUSSION OF RESULTS

The data presented no surprising results. Figures 9A and 9B, 400 X 1000' grid volumes, show very good consistency in the main channel area. The grid volumes on the eastern side of Middle Ground Island and below Point Pleasant on the left bank show the obvious bar formations at the edge of the main channel. However, in the area just upstream of the #1 Yucatan Dike (See Figure 4), there are rather wide variations in grid volume. This area is under the effects of turbulence caused by flow patterns around the #1 dike, the zone of separation which is common below bends, and the scour resulting from the lower end of the Point Pleasant revetment. This turbulence presented a particular problem to the fathometer-digitizer sequence. The interface of two flow jets moving in different directions, which is normal in turbulent flow, can apparently be mistaken for a solid surface by the equipment, resulting in the obvious errors mentioned previously. These took the form of measured depths of either 4 feet (less than the boat draft) or 417 feet. These "bad" readings often occurred in groups and could thus be significant if allowed to remain in the file. There were other data errors, insignificant in number, which were of a consistency which allowed automatic deletion. These errors also originated in the digitizing process.

It should be noted that the survey resolution of 3700 points per square mile is quite sufficient to show bed forms in the channel. Dune heights of 15' to 20' were not uncommon. The increased number of points which could be obtained by operating the boat at a slower speed or recording data at shorter intervals would significantly add to the detail obtained from the existing collection method, but would not improve the results.

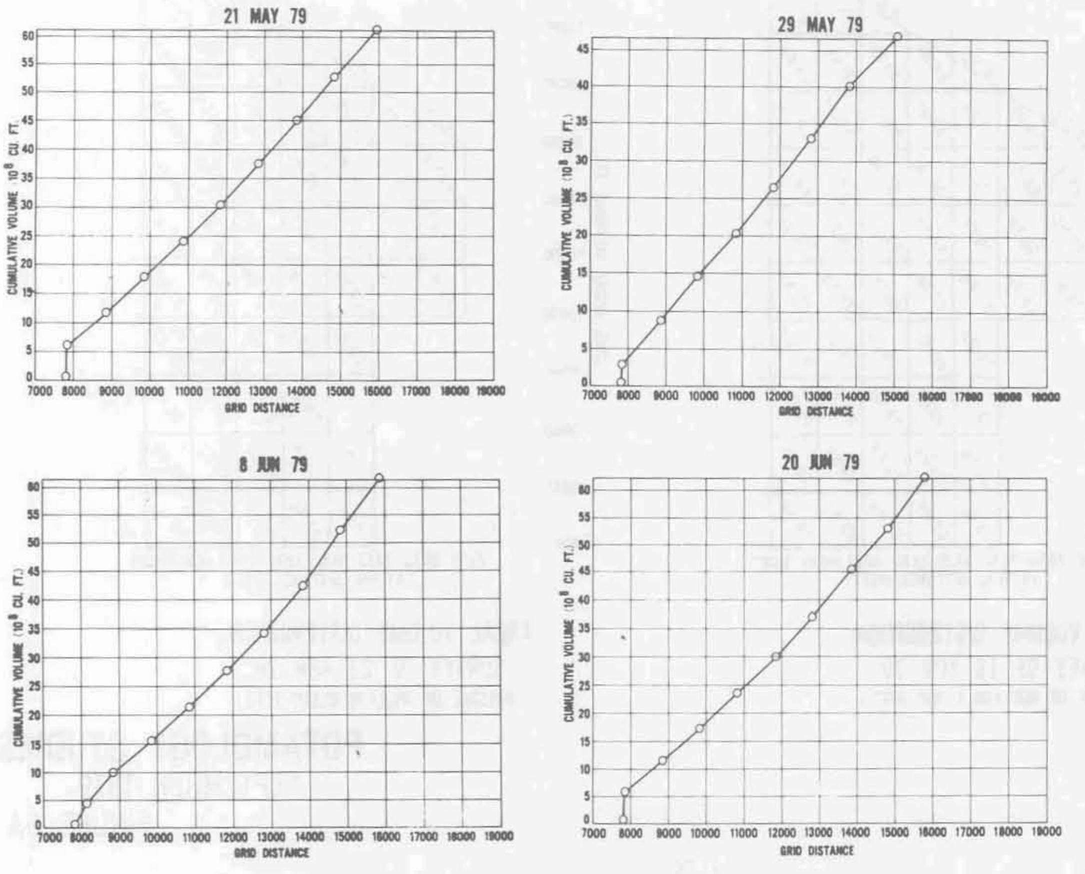
The only other error inherent in the method is due to the assumption that the boat operator was able to follow the trackline exactly. A boat operator familiar with the track indicator is able to consistently stay within ± 20 feet of the actual line. Therefore, the maximum error in distance between two adjacent track lines would be ± 40 feet in 400 feet, or 10%. Considering the number of other variables involved, this is not excessive for the purposes of the study.

The curves showing accumulated volume, Figures 8A and 8B, show an almost constant volume increase for any adjacent pair of track lines. All are slightly concave upward as would be expected when advancing from a crossing to a pool. The best indication of the effects of a hydrograph on a crossing is seen in Tables 1 and 2. The large grids and the average bed elevations show that in a well defined crossing, such as that in the study area, the bed elevation will follow a pattern similar to that of the stage hydrograph. The variation of volume for these areas shows that the upper end of the crossing is in a scouring process at the beginning of the series of surveys. As the stage rises the crossing moves upstream slightly as indicated by the decreasing volumes



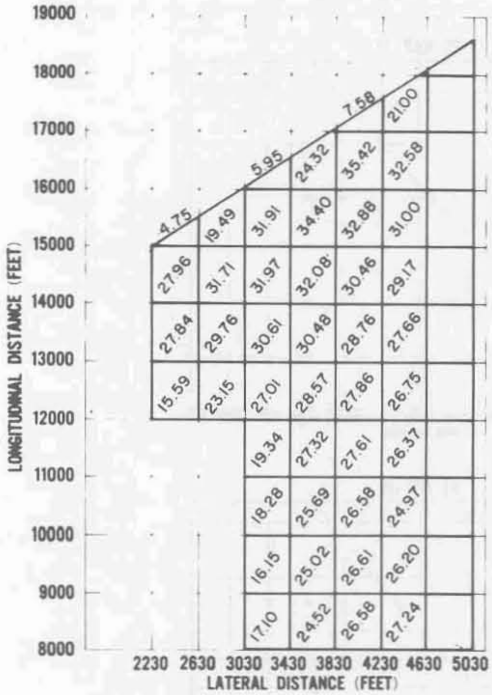
POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 8A

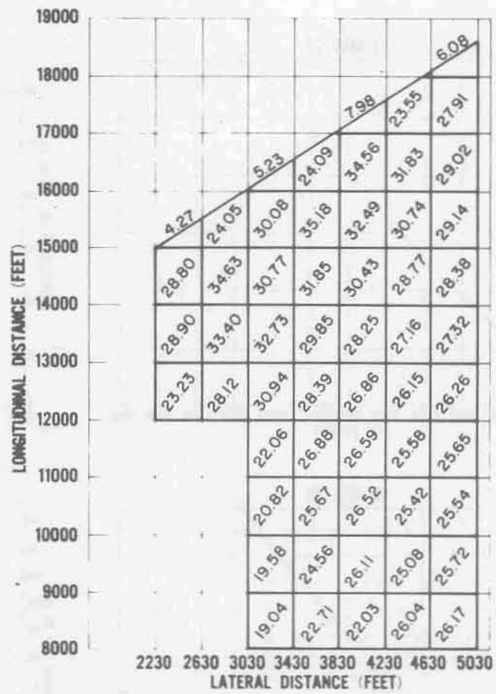


POTAMOLOGY STUDIES
SEPTEMBER 1979

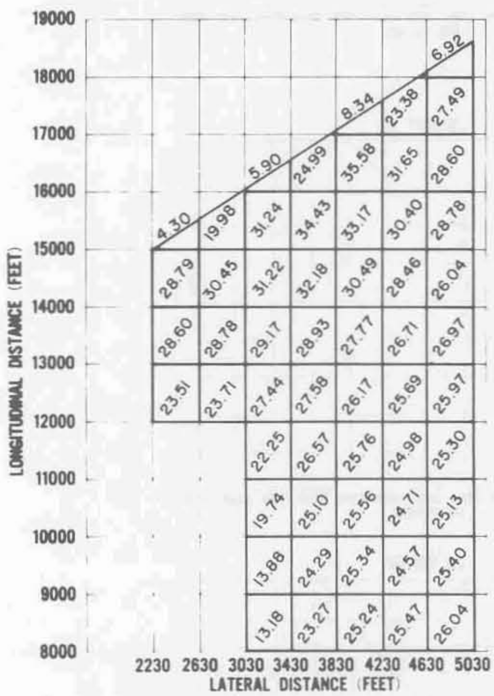
FIGURE 8B



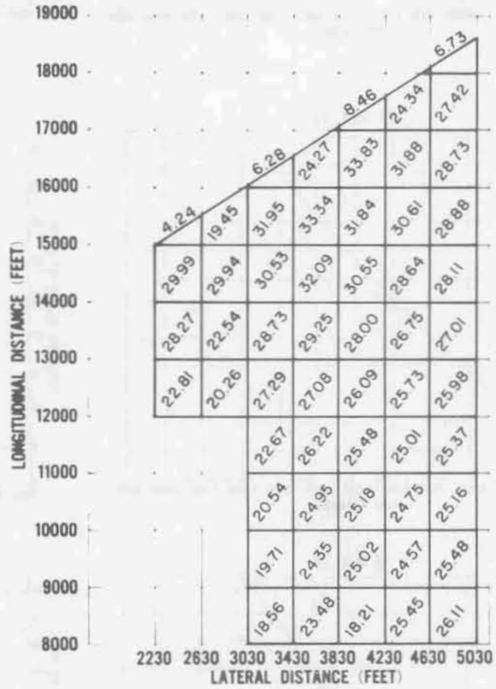
AREAL VOLUME DISTRIBUTION
SURVEY OF 28 MAR 79
(VOLUME IN MILLION CUBIC FEET)



AREAL VOLUME DISTRIBUTION
SURVEY OF 9 APR 79
(VOLUME IN MILLION CUBIC FEET)

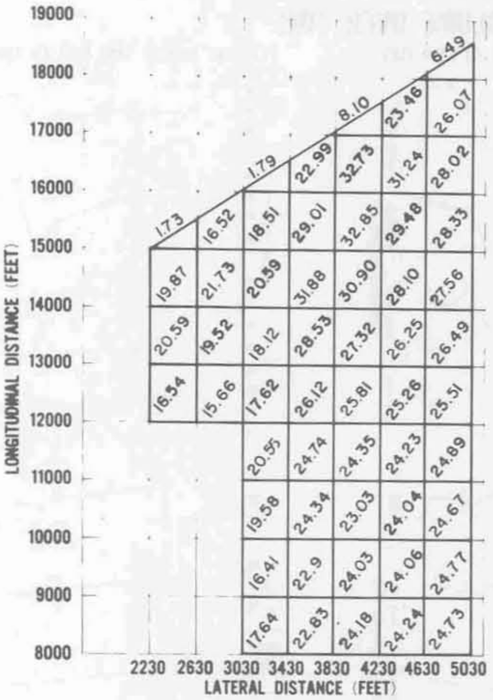


AREAL VOLUME DISTRIBUTION
SURVEY OF 18 APR 79
(VOLUME IN MILLION CUBIC FEET)

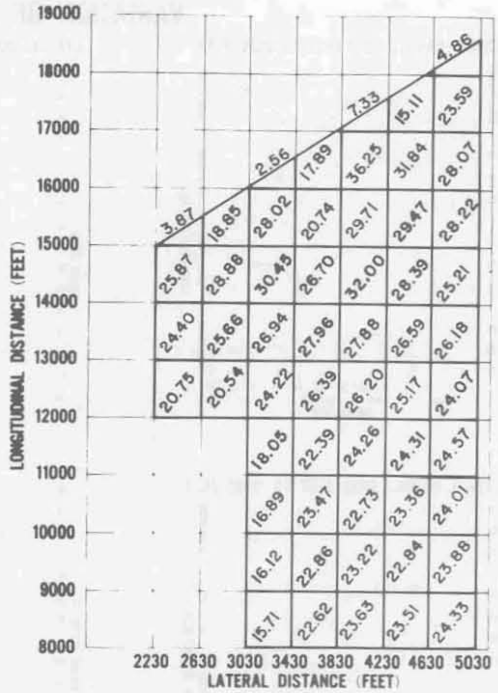


AREAL VOLUME DISTRIBUTION
SURVEY OF 27 APR 79
(VOLUME IN MILLION CUBIC FEET)

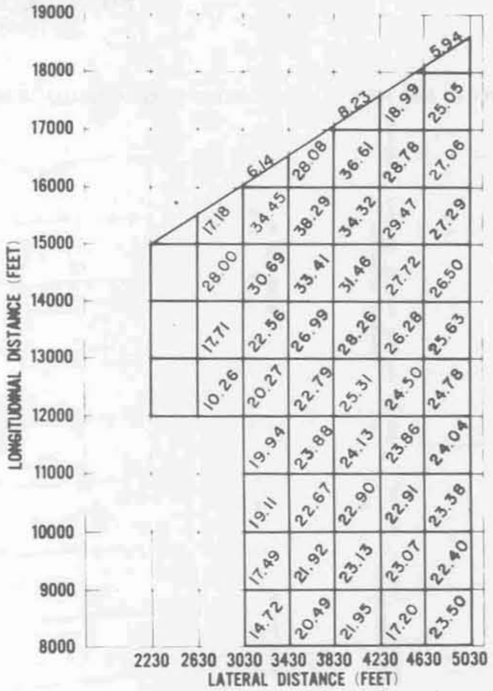
POTAMOLOGY STUDIES
SEPTEMBER 1979
FIGURE 9A



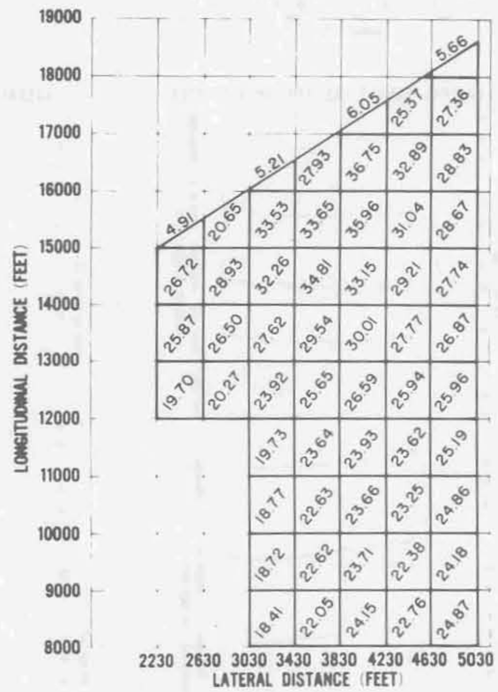
AREAL VOLUME DISTRIBUTION
SURVEY OF 21 MAY 79
(VOLUME IN MILLION CUBIC FEET)



AREAL VOLUME DISTRIBUTION
SURVEY OF 29 MAY 79
(VOLUME IN MILLION CUBIC FEET)



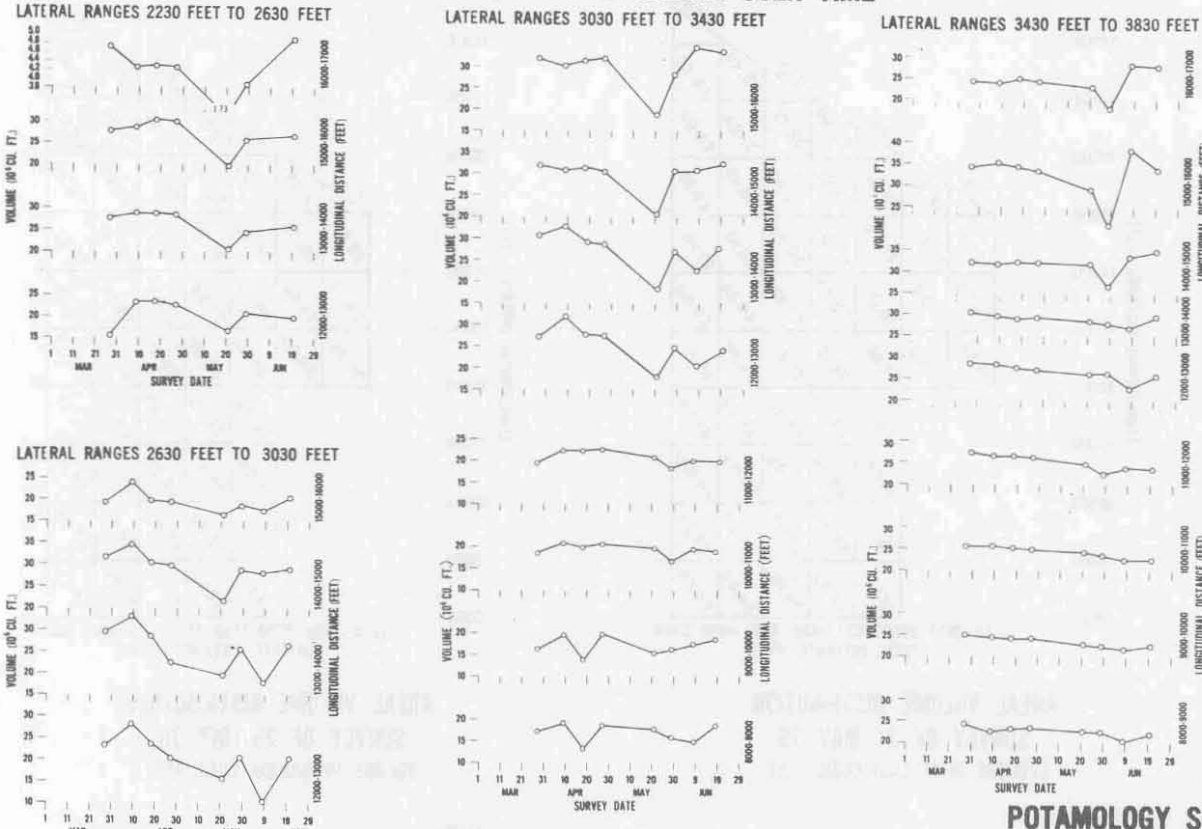
AREAL VOLUME DISTRIBUTION
SURVEY OF 8 JUN 79
(VOLUME IN MILLION CUBIC FEET)



AREAL VOLUME DISTRIBUTION
SURVEY OF 20 JUN 79
(VOLUME IN MILLION CUBIC FEET)

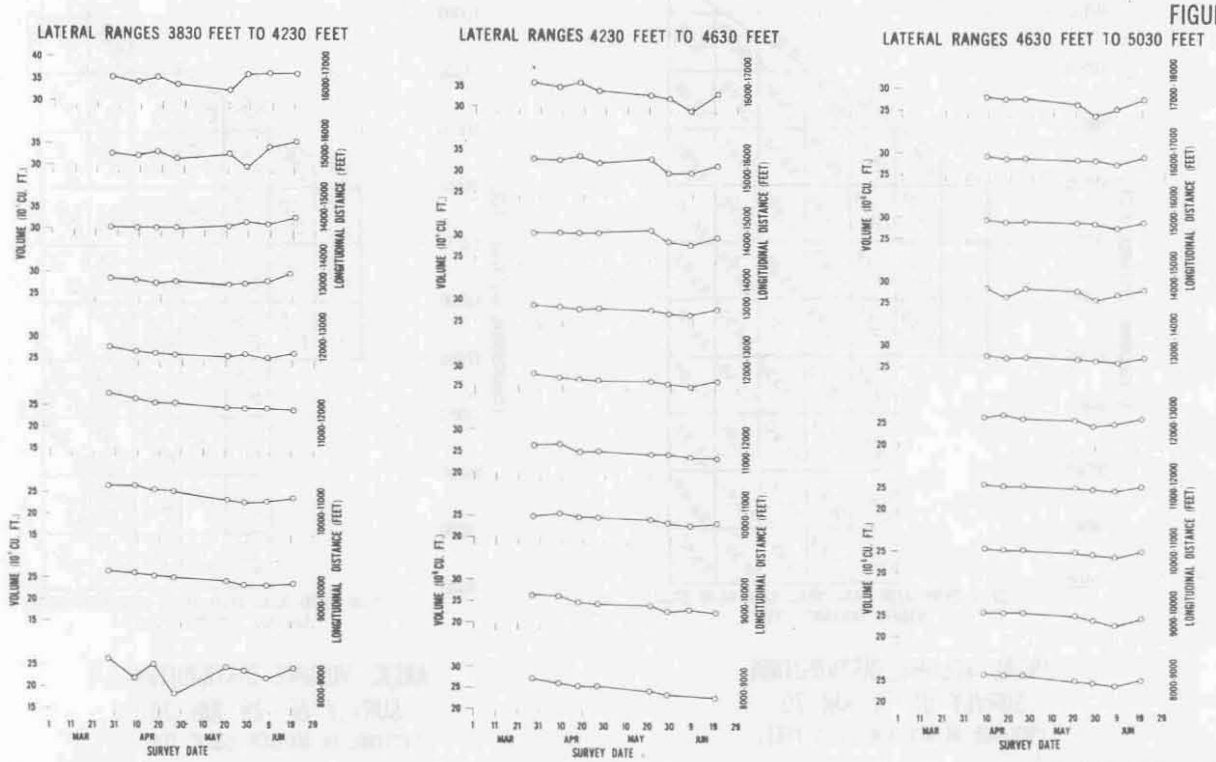
POTAMOLOGY STUDIES
SEPTEMBER 1979
FIGURE 9B

VARIATION OF WATER VOLUME OVER TIME



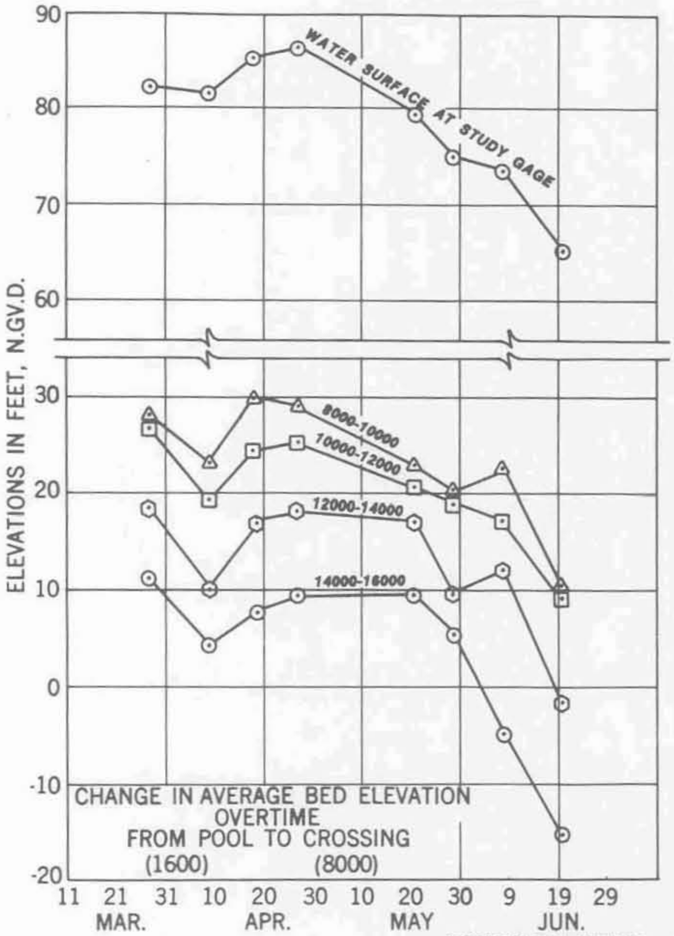
POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 10A



POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 10B



POTAMOLOGY STUDIES
SEPTEMBER 1979

FIGURE 11

between Ranges 10,000′ and 14,000′. As the stage crests, the volumes stabilize, amd then slowly increase with the falling limb of the hydrograph, showing a short time lag before the bed begins to scour.

CONCLUSIONS AND RECOMMENDATIONS

The methods introduced in this study are such that they will apply to any reach of river meeting the equipment requirements. The results of the study, however, should not be freely applied to all crossings, due to the complexity of the many other independent variables involved. In order to fully study the phenomena which occur in a river system of the magnitude of the Lower Mississippi, it is necessary to utilize information gathered from all channel configurations under the different flow conditions.

These methods of data collection and analysis have a number of other applications. With the addition of more data, the prediction of dredging needs based on channel forms and flows becomes a realistic possibility. Under different boat operation practice, the analysis provides a means of studying bed form migration. This could lead to the development of a new family of sediment transport "regime" equations. Another use of the system would be to accurately measure reservoir sedimentation in a swift, efficient manner.

ACKNOWLEDGEMENTS

The writer expresses his deep gratitude to Messrs. John H. Brooks of the Vicksburg District Potamology Section and Michael Cudo, of the Drafting Section for their aid in the preparation of the figures. The efficient computer software preparation of Mr Walter Enete, Waterways Experiment Station A.D.P. Center, was invaluable in the timely formation of the analysis.

The finding, opinions, and conclusions presented in the study are solely those of the author and do not necessarily represent the official view of the U.S. Army Corps of Engineers.

TABLE 1

2000' X 2000' GRID VOLUME (10^6 CU. FT.), BELOW 100 FT. NGVD*

Survey	Longitudinal Range (Ft.)				
	8-10,000	10-12,000	12-14,000	14-16,000	16-18,000
	215.96	221.96	254.66	283.20	156.27
2	234.40	249.30	286.37	309.23	171.13
3	221.97	243.82	273.61	310.07	173.13
6	229.10	244.23	272.96	308.10	172.40
7	226.09	235.09	248.67	278.89	170.68
8	218.72	224.03	261.60	279.92	162.64
9	203.60	225.32	245.51	316.87	167.91
10	220.08	225.79	269.87	324.35	171.28

*Surface area for Range 16-18,000 is 2.4×10^6 Sq. Ft.

TABLE 2

AVERAGE GRID BED ELEVATION BASED ON VOLUME (FT., NGVD)

Survey	Longitudinal Range (Ft.)				
	8-10,000	10-12,000	12-14,000	14-16,000	16-18,000
3	28.41	26.91	18.73	11.60	17.29
4	23.30	19.57	10.31	4.59	10.60
5	30.11	24.65	17.20	8.08	13.46
6	29.32	25.54	18.36	9.58	14.77
7	23.08	20.83	17.43	9.88	8.49
8	20.62	19.29	9.90	5.57	7.70
9	22.80	17.37	12.32	-5.52	3.74
10	10.68	9.25	-1.77	-15.39	-5.67