

Special Report 88-25

November 1988



**US Army Corps
of Engineers**

Corps Regions Research &
Engineering Laboratory

(4)

Ice observations on the Allegheny and Monongahela Rivers

Michael A. Bilello, Lawrence W. Gatto, Steven F. Daly and John J. Gagnon

AD-A213 028

DEC 23 1989
10



Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

Approved for public release; distribution is unlimited.

89 9 28 08 9

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188
Exp. Date: Jun 30, 1985

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			Approved for public release; distribution is unlimited.		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Special Report 88-25			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Cold Regions Research and Engineering Laboratory		6b. OFFICE SYMBOL (if applicable) CECRL	7a. NAME OF MONITORING ORGANIZATION Office of the Chief of Engineers		
6c. ADDRESS (City, State, and ZIP Code) 72 Lyme Road Hanover, N.H. 03755-1290			7b. ADDRESS (City, State, and ZIP Code) Washington, D.C. 20314		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER CWIS 32227; CWIS 32228		
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
			WORK UNIT ACCESSION NO.		
11. TITLE (Include Security Classification) Ice Observations on the Allegheny and Monongahela Rivers					
12. PERSONAL AUTHOR(S) Bilello, Michael A.; Gatto, Lawrence W.; Daly, Steven F. and Gagnon, John J.					
13a. TYPE OF REPORT		13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) November 1988		15. PAGE COUNT 47
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Allegheny River River ice		
			Ice Winter navigation		
			Monongahela River		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) ➤ Corps of Engineers and National Weather Service records of ice conditions on the Allegheny and Monongahela Rivers in Pennsylvania and West Virginia were analyzed for seven recent winters. The on-ground observations recorded daily at a number of lock and dam locations were issued in the form of alphanumeric ice codes that included the coverage, type, thickness, structure and extent of river ice. These codes were used to graph ice conditions throughout the rivers to allow easier analysis of historical ice conditions. In addition, comparisons were made between these observations and aerial videotapes and satellite images of the ice. Results of these comparisons illustrate that ice data from these three sources are complementary and should be used together whenever possible.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Lawrence W. Gatto			22b. TELEPHONE (Include Area Code) 603-646 4100		22c. OFFICE SYMBOL CECRL-RE

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

PREFACE

This report was prepared by Michael A. Bilello, Meteorologist, Science and Technology Corporation, Hampton, Virginia; Lawrence W. Gatto, Geologist, Geological Sciences Branch, Steven F. Daly, Research Hydraulic Engineer, Ice Engineering Research Branch, and John J. Gagnon, Civil Engineering Technician, Ice Engineering Research Branch, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by the Office of the Chief of Engineers, Directorate of Civil Works, under the River Ice Management (RIM) Program, CWIS 32228, *Remote Ice Monitoring System*, and CWIS 32227, *Forecasting Ice Conditions on Inland Rivers*.

The excellent cooperation received from U.S. Army Corps of Engineers District, Pittsburgh, and U.S. National Weather Service personnel in Pittsburgh, Pennsylvania, who provided the river-ice data, is greatly appreciated. The authors thank the following CRREL personnel: Kevin Carey and Dr. George Ashton for their technical reviews of the paper; Mark Hardenberg for his editorial work; Edward Foltyn for assisting in preparing the tables in Appendix A; William Bates, Edward Perkins and Eleanor Huke for drawing the figures; Jacqueline Castor and Donna Harp for typing the manuscript; and Guenther Frankenstein, Chief, Ice Engineering Research Branch, for providing the opportunity to conduct the research.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
inch	25.4	millimeter
foot	0.3048	meter
foot ³ /second	0.02831685	meter ³ /second
mile	1609.347	meter
degrees Fahrenheit	$T^{\circ}\text{C} = (T^{\circ}\text{F} - 32)/1.8$	degrees Celsius

Accession for	
NTIS	☒
DTIC	☐
Unannounced	☐
Classification	
By	
Distribution/	
Availability Codes	
Initial and/or	
Dist Special	
A-1	

Ice Observations on the Allegheny and Monongahela Rivers

MICHAEL A. BILELLO, LAWRENCE W. GATTO, STEVEN F. DALY AND JOHN J. GAGNON

INTRODUCTION

Detailed information on daily ice conditions along entire lengths of navigable rivers is often nonexistent or difficult to recover from data archives. In this report ground observations of ice conditions recorded at a series of U.S. Army Corps of Engineers Lock and Dam sites along the Allegheny River in Pennsylvania and the Monongahela River in Pennsylvania and West Virginia were compiled from archives, graphed, analyzed and compared to ice data obtained from aerial videotapes and Landsat images.

The objectives of this study were 1) to determine the annual variability in river ice conditions for selected winters as observed from the ground, 2) to compare ice data acquired from the ground, videotapes and Landsat images, and 3) to develop a computer program to graphically portray the ground data so that these data, when collected in the future, could be quickly displayed and disseminated as an aid for navigation during the winter. This study was a part of the CRREL River Ice Management (RIM) program, a program that examined several rivers in the United States where ice causes winter navigation problems.

DATA SOURCES, COMPILATION AND ANALYSIS

Ground observations

Ground observations of river ice conditions were routinely obtained from eight U.S. Army Corps of Engineers Lock and Dam (L&D) sites on the Allegheny River and nine L&D sites on the Monongahela River, and occasionally from three National Weather Service (NWS) sites located above L&D 9 on the Allegheny

River. These Corps and NWS sites cover the rivers from Pittsburgh to West Hickory, Pennsylvania, about 158 miles upstream on the Allegheny River, and from Pittsburgh to Opekiska, West Virginia, about 115 miles upstream on the Monongahela River (Fig. 1).

The Corps ground observers use a five-element alphanumeric code (Table 1) to describe ice conditions each day and send the codes to Corps and NWS central offices located around Pitts-

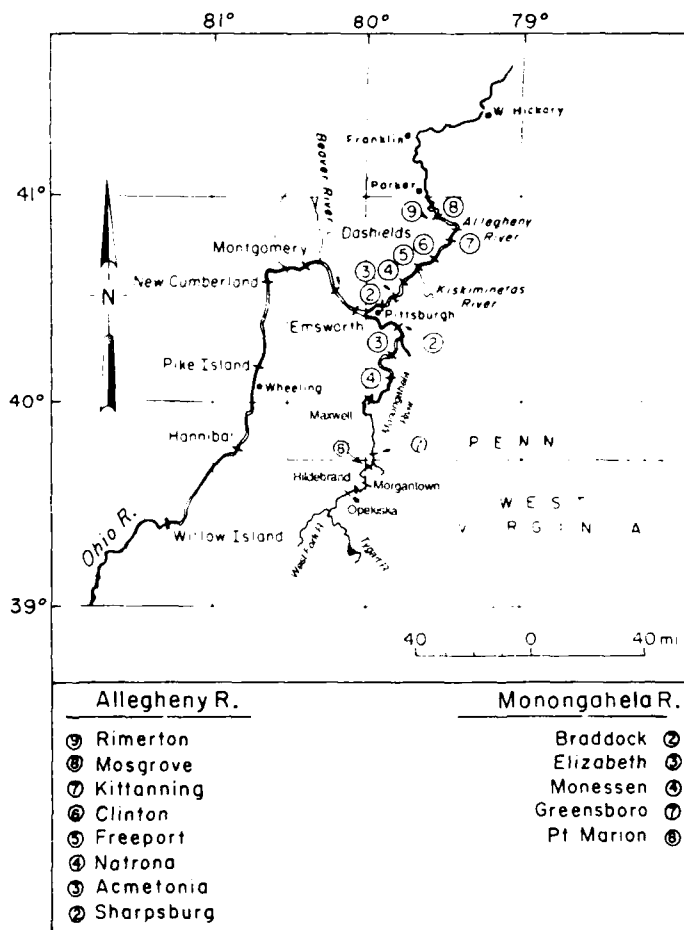


Figure 1. Location map (circled numbers are L&D numbers).

Table 1. Corps of Engineers alphanumeric ice code.

<i>Amount (coverage)</i>	<i>Type</i>	<i>Thickness</i>	<i>Structure</i>	<i>Extent</i>
0-None	R-Running (floating)	In inches	B-Breaking	In miles
1-Scattered	A-Stationary		H-Honeycombed	upstream
2-2 tenths	P-Stopped		T-Rotten	
3-3 tenths	J-Jammed		L-Layered	
4-4 tenths	F-Formed locally		C-Clear	
5-5 tenths	S-Shore			
6-6 tenths				
7-7 tenths	Examples:			
8-8 tenths				
9-9 tenths				
10-10 tenths, full	1 S 1/2 T X means scattered shore ice, 1/2 in. thick, rotten and extending an unknown distance upstream; unknown data in any category are shown as "X"; 3 R 2 H 4 means 3 tenths of the river is covered by running ice, 2 in. thick, honeycombed, and extending 4 miles upstream.			

Table 2. Partial record of ice conditions on the Monongahela River, January 1985.

<i>Date</i>	<i>Braddoc.</i>	<i>Elizabeth</i>	<i>Monessen</i>	<i>Maxwell</i>	<i>Greensboro</i>	<i>Pt. Marion</i>	<i>Morgantown</i>	<i>Hildebrand</i>	<i>Opekisa</i>
19									7F 1/2 CX
20						1F 1/8 CX	1F 1/4 CX		9A 1 CX
21	9A 1/2 CX	2F 1/2 CX	10A 1 CX	10A 2 CX	10F 1 CX	10F 1 CX	10F 2 CK	10F 2 CX	10A 2 CX
22	10A 1 CX	6R 1 CX	10A 2 CX	10A 3 CX	10F 1 CX	10F 4 CX	10F 4 CX	10F 4 CX	10A 3 CX
23	10A 1 CX	5R 2 CX	10A 2 1/2 CX	10A 3 1/2	10R BX	10F 5 CX	10F 5 CX	10F 4 CX	10A 3 CX
24	10A 1 CX	5R 2 C10	10A 3 C18	10A 3 1/2 CX	1R 1 C2	10F 5 C11	10F 4 C6	10F 3 C7	10A 4 C14
25	9A 2 C5	6R 3 C10	10R 3 L18	10A 3 C22	1R 1 B5	10F 5 C10	10F 4 C6	10F 3 C7	10A 3 CX
26	9A 2 C5	6R 2 C10	10R 3 L18	10A 1 C22	10A 1 C1	10F 5 B10	10F 5 B6	10F 3 C7	10A 4 C14
27	9A 2 C4	2R 2 C10	10A 3 L18	10A 3 L22	5A 1 B2	10F 5 C10	10F 5 C6	10F 4 C8	10A 5 C14
28	8A 2 B2	2R 2 C10	10P 4 L18	10A 3 L22	8R 2 B3	10F 5 C10	10F 4 1/2 C6	10F 4 C8	10A 7 C14
29	no ice	5R 2 B10	10P 4 L18	10A 3 L22	10A 2 L5	10F 4 C10	10F 4 C6	10F 4 C8	10A 6 C14

burgh. The data are then issued to users by computer modem and are archived at Corps and NWS offices as chronological listings of the ice observations at each of the sites (e.g., Table 2; Appendix A). The data, however, have two major omissions. The ice observers at some sites often did not collect data on weekends, and they frequently could not determine how far upstream a particular ice type existed. We hope that these data gaps can be reduced in the future. Although these ground observations are available beginning with the 1961-62 winter, the records for the seven consecutive winters from 1979-80 to 1985-86 are most complete and are used in this study.

Since it is difficult for a user to visualize and understand the distribution of ice conditions from tables, we developed a way to graph the data. Graphs of ice observations for the Allegheny (Fig. 2a) and Monongahela (Fig. 2b) Rivers during the 1985-86 winter that employ our method

are shown here. Other methods have been used in the past to graph river-ice conditions (Bates et al. 1968, Michel 1971, Starosolszky 1985, Canadian Coast Guard 1986).

Our review of the Corps' ice code (Table 1) indicated that most of the information given can be displayed graphically, although in preparing the hand-drawn graphs (Fig. 2a and b), it was necessary to drop the ice structure element of the code, and to reduce the number of amount and type categories for the sake of readability. Amount was reduced from eleven categories to four: 0 (area clear of ice), 1 through 5 tenths (10-50%), 6 through 9 tenths (60-90%), and 10 tenths (100%). Type was reduced from six to three: running or floating ice; stationary, stopped, jammed or formed locally (any one of the four); and shore ice. We also included discharge and air temperature data to show the relationships between temperature, discharge and ice conditions.

Aerial videotapes

Videotapes (1/2-in. VHS) of the rivers were taken vertically with a Panasonic 777 video camera fitted with a 12:1 zoom lens. A Cessna 172 fixed-wing aircraft, flying at an altitude between 2000 and 3500 ft above the river, depending on cloud conditions and the width of the river, carried the camera. An experienced ice interpreter viewed the tapes on a TV monitor and visually classified ice conditions into six units (Table 3) that were readily identifiable, that satisfactorily described the range of ice that usually occurs on these rivers, and that did not require ground truth data for verification. The interpreter did not attempt to infer characteristics from the tapes that could only be measured on the ground (e.g., porosity, strength or ice thickness).

Boundaries between the units were mapped and the area of each unit was measured. For units comprising both ice and open water—*solid ice cover with open-water areas, fragmented ice with open-water areas and ice floes or frazil slush and pans*—the surface concentration of ice was also visually estimated.

Table 3. Ice conditions as observed on videotapes (from Gatto et al. 1986).

Map unit	Description
	River is ice-free, no ice apparent.
	River is completely covered (100%) with ice; no individual ice pans, blocks or chunks are visible; ice may be snow-covered.
	River is partially covered with solid ice (as described above) but has open (ice-free) areas.
	River is completely covered (100%) with ice that has distinct, variably sized, individual ice pans, blocks or chunks.
	River is partially covered with fragmented ice (as described above) but has open (ice-free) areas.
	River is primarily open (ice-free) with floating ice floes, slush or pans.

Landsat images

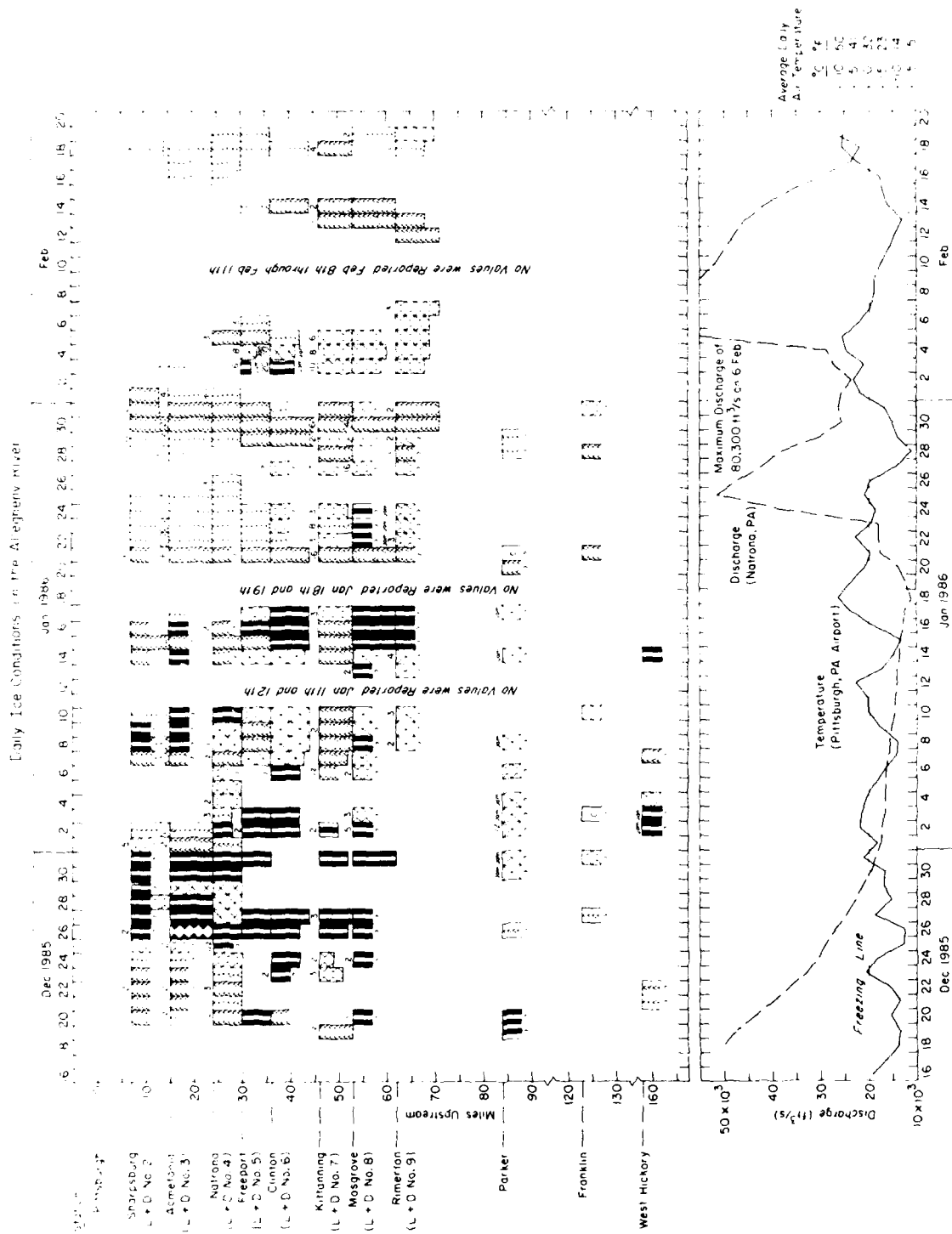
Five Landsat satellites have provided images of the rivers since 1972. Each Landsat has two imaging sensors: either a Multispectral Scanner (MSS) with an Instantaneous Field of View (IFOV) of approximately 260 by 260 ft and a Return Beam Vidicon (RBV) with an IFOV of either 262 by 262 ft or 131 by 131 ft, or a MSS (same IFOV) and a Thematic Mapper (TM), with an IFOV of 98 by 98 ft. Gray tones and patterns in river ice are most visible to the eye on images from the 0.6- to 0.7- μ m MSS, 0.580- to 0.680- μ m RBV (Landsat 1 and 2), 0.505- to 0.750- μ m RBV (Landsat 3), and 0.63- to 0.69- μ m TM (Landsat 4 and 5).

Images of the same location were taken every 18 days by Landsat 1, 2 and 3. When more than one was operating simultaneously, images of the same location were taken about every 9 days. During simultaneous Landsat 4 and 5 operations, images of the same location were taken every 8 days; images were taken every 16 days when one satellite was operating.

We analyzed black and white Landsat film positives (9 by 9 in.) using traditional photographic interpretation techniques. No special computer enhancements or analytical techniques were used (Gatto 1985). Reaches of the rivers appeared as black, gray or white with textures and patterns within these tones sometimes apparent, but the subtleties that differentiate the six ice conditions that are visible on videotapes were not apparent on Landsat images. To determine which types of river ice usually produced these tones, textures and patterns, we compared ice conditions shown on aerial photographs (Gatto and Daly 1986) and videotapes taken on dates as close as possible to those for which Landsat images were available.

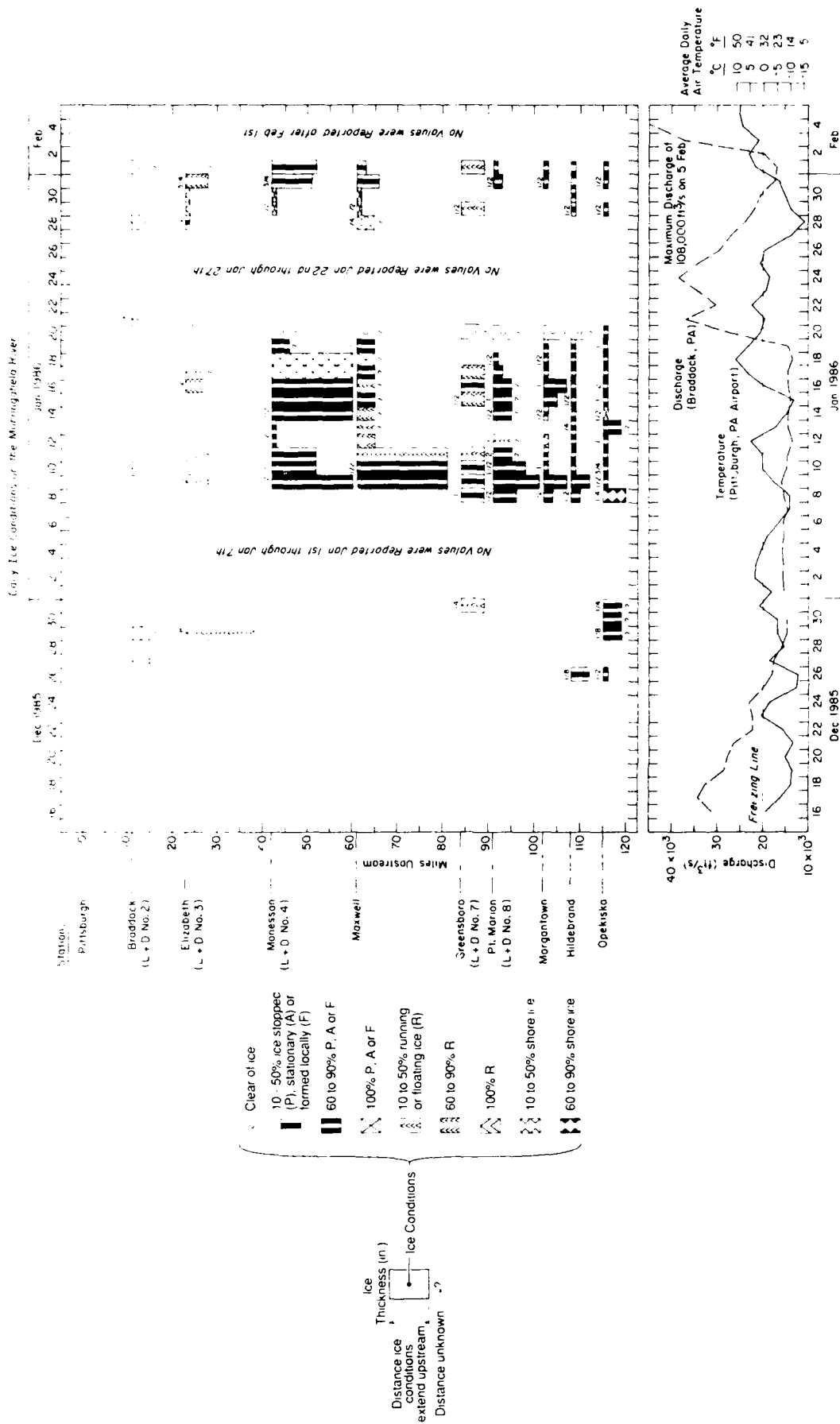
These comparisons show that when the river appeared black on an image and had no discernible textures and patterns, the river was open (ice free). It is possible, however, that thin, transparent ice, which appears black from above and cannot be distinguished from open water in Landsat images, covered part or all of particular river reaches in some instances. Ice conditions that appear gray on Landsat images can vary from fragmented ice (usually thin) with large, interspersed open areas to ice floes, pans or slush mixed with open areas. The gray tone usually had a patchy or mottled appearance, or showed textures or patterns.

When the river appeared white (or nearly white), ice conditions could vary from solid to



a. Allegheny River.

Figure 2. Daily ice conditions observed during the 1985-86 winter with air temperatures (U.S. Department of Commerce 1985 and 1986) and river discharges (U.S. Department of the Interior 1985 and 1986).



b. Monongahela River.

Figure 2 (cont'd).

fragmented ice (usually thicker than gray ice). A white tone could include scattered open water areas that are smaller than the Landsat sensor IFOVs, or fewer open water areas than occur where a gray tone is observed. A white tone could also mean that the ice was snow-covered. For example, thin ice in a Landsat scene may be transparent, appear black and be classified as open water. This same ice cover viewed after a light snowfall would appear white.

RESULTS

Ice conditions from ground observations

The Corps and NWS ice observations for the winters from 1979–80 through 1985–86 (Appendix A) were examined to determine the dates of initial ice formation and final clearance of ice on the Allegheny and Monongahela Rivers. First ice occurred as early as 19 December and as late as 20 January on the Allegheny, and as early as 21 December and as late as 3 February on the Monongahela. Final ice was observed as early as 8 February and as late as 20 March on the Allegheny, and as early as 20 January and as late as 4 March on the Monongahela.

Although ice formed on the rivers during all seven winters, the severity of the ice conditions varied each season. Both rivers had the least ice cover in the 1982–83 winter, and the most in 1983–84. During four of the winters, ice formed on the Allegheny River earlier than on the Monongahela, and during all seven winters, ice remained on the Allegheny from 1 to 20 days longer than on the Monongahela. An inspection of the total number of days that ice was observed at each of the L&D sites revealed that approximately the lower 20 miles of the Monongahela and the lower 10 miles of the Allegheny River have the fewest number of days with ice.

The type and structure of ice given in the ice code (Table 1) made it possible to note the times and locations of ice jams and the frequency of running or stationary ice throughout the winter. Also, we could statistically summarize the percent of ice coverage on the rivers.

Ice jams were recorded on the Allegheny at the following locations (Fig. 1): above Rimerton in January 1981, above Mosgrove in March 1982, at Parker in January 1985, and near Natrona in February 1985. An ice jam was observed on the Monongahela in January 1984 at Maxwell.

Ice on both rivers is generally in motion; there are frequently changing intervals of either solid

or partial ice cover with occasional occurrences of open water throughout the winter. A comparison between complete and partial ice covers indicates that, on the Allegheny River above Rimerton, a complete ice cover occurs approximately during 75% of the total days when ice is reported. In contrast, below Acmetonia, a complete ice cover is observed during only about 27% of the total days. On the Monongahela River near Opekiska, a complete ice cover occurs during about 70% of the days when ice is reported, and near Elizabeth and Braddock, about 21%.

Comparisons of river ice observations

It is clear that information on ice type (including movement), thickness and structure (Table 1) can only be obtained by ground observations, although inferences regarding some of these characteristics could be made from aerial videotapes by an experienced interpreter. Because of the dynamic nature of river ice and the limited view upstream of a ground observer, the ground observations apply only for the location near the observation site and only as far upstream as is visible, although the ice conditions as seen near the dams were usually assumed to persist upstream. Sometimes other upstream observers reported ice conditions beyond the view of the observer at the locks and dams.

The aerial videotapes give more accurate information on the areal coverage and extent of different ice types than do the ground observations. Landsat images also show the areal distributions of ice as do the videotapes, but with much less detail and frequency. We have compared data from these three data sets collected during 1984–85 and 1985–86 to illustrate their advantages and disadvantages.

Winter of 1984–85

Ground observers reported ice on the Allegheny River for 49 days from 10 January to 25 February (Fig. A6) and on the Monongahela River for 37 days from 14 January to 20 February (Fig. A13). Ice was observed on videotapes taken of the lower 7 miles of the Allegheny River on 11 days from 23 January to 24 February. A 28 February tape showed no ice. Ice was apparent on videotapes of the lower 66 miles of the Monongahela River taken on five days from 28 January to 24 February. A 16 January Landsat image was the only one taken this entire winter when ice was present. There were no days this winter when ground observations, videotapes and Landsat images were acquired on the same day.

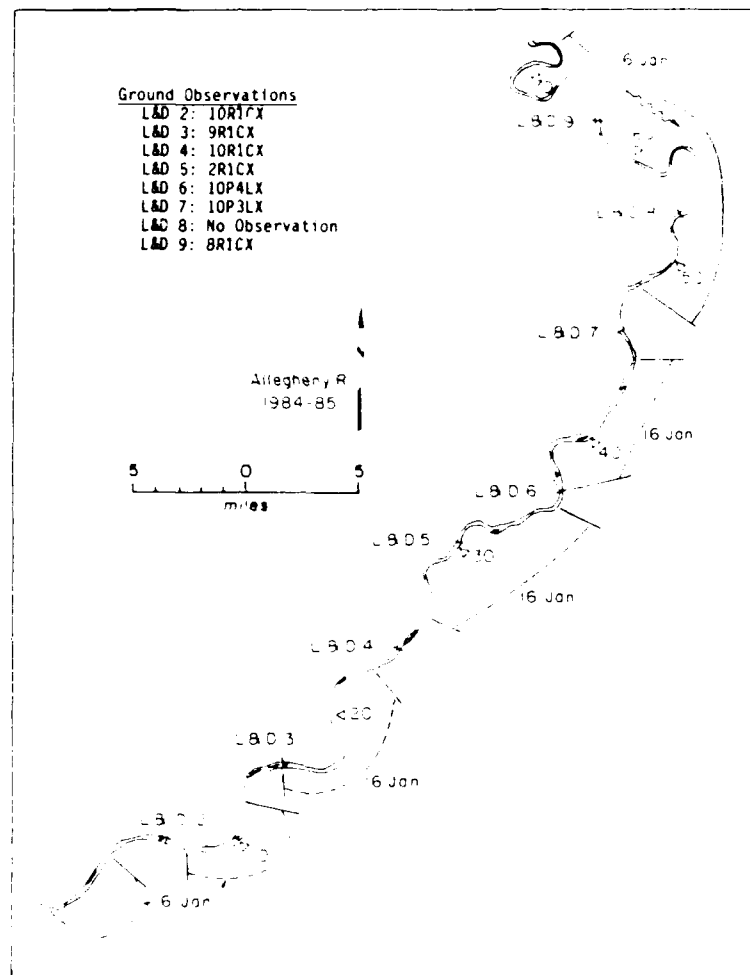
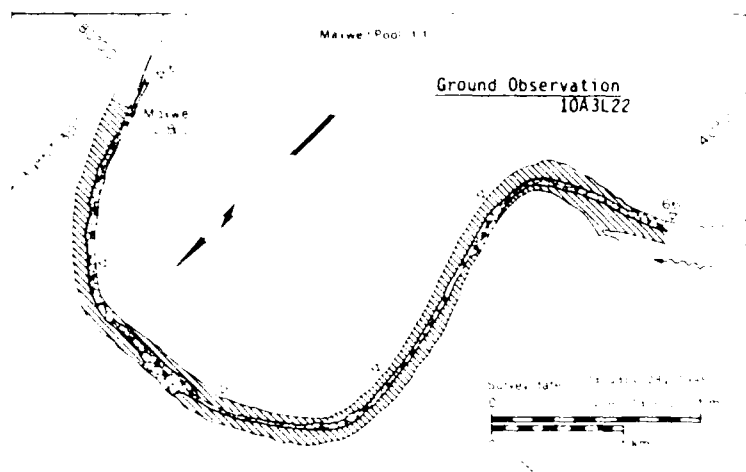


Figure 3. Ice conditions on the Allegheny River on 16 January 1985 as observed by ground observers and on a Landsat image (dashed line is gray ice, solid line is white ice).

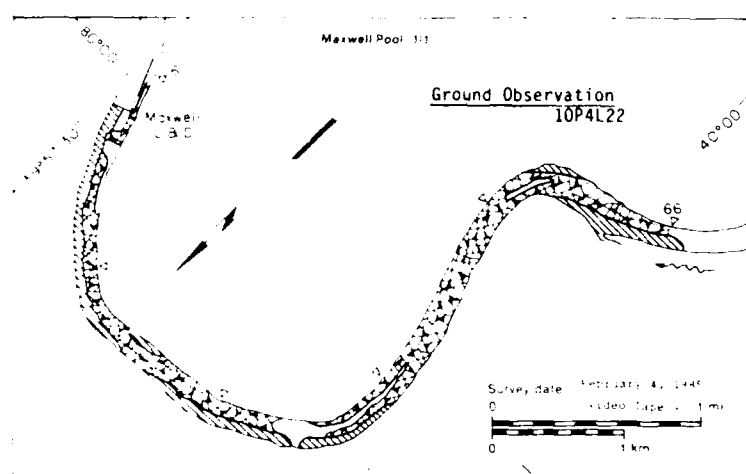
The 16 January Landsat image showed that 70% of the Allegheny River below L&D 6 was covered with gray ice and 30% was open (Fig. 3). White ice and gray ice covered 88% of the river upstream of L&D 6 to river mile 72, while 12% of this section was open. Ground observations made on 16 January at the four L&D sites below L&D 6 showed 1-in.-thick, clear, running ice covering 20–100% (average coverage 80%) of the river some unknown distance upstream from each site. Between L&D 6 and L&D 8 was 3- to 4-in.-thick, layered, stopped ice covering all of the river and extending upstream an unknown distance. Above L&D 9 (some unknown distance) was 1-in.-thick, clear, running ice covering 80% of the river.

The gray ice apparent on the Landsat image was composed of this thin, clear, moving ice, while the white ice consisted of the thicker, layered ice that was stopped. When used together, Landsat and ground observations provide details of the ice and its extent upstream not available from either source alone.

The 16 January Landsat image showed only 6 miles of gray ice on the Monongahela River above Opekiska L&D. The ground observation at Opekiska L&D showed shore ice, $\frac{1}{2}$ in. thick and clear, covering 70% of the river some unknown distance upstream. Ground observers also reported $\frac{1}{8}$ - to $\frac{1}{4}$ -in.-thick, clear, locally formed ice and shore ice covering 10% of the river for unknown distances upstream of L&D 7, L&D 8 and



a. 28 January 1985.



b. 4 February 1985.

Figure 4. Ice conditions on the lower 5 miles of Maxwell Dam pool, Monongahela River, as observed on videotapes and by ground observers (see Table 3 for definitions of ice symbols).

Morgantown L&D. No other ground observations were made. It is not surprising that this thin, clear ice below Opekiska L&D was not apparent on the Landsat image.

Ice conditions 5 miles upstream of Maxwell L&D on the Monongahela River as observed from videotape and the ground were compared for 28 January and 4 February. The videotape from 28 January shows 69% of this reach covered with solid ice, 28% with fragmented ice with interspersed open areas and 3% open water. The ground observer at Maxwell reported 100% of the

river covered with stationary ice, 3 in. thick and layered, and extending 22 miles upstream (Fig. 4a). The 4 February tape shows 27% of this reach covered with solid ice, 62% covered with fragmented ice with interspersed open areas and 11% being open water (Fig. 4b). A Maxwell ground observer reported on 4 February that 100% of the river was covered with stopped ice that was 4 in. thick and layered, extending 22 miles upstream.

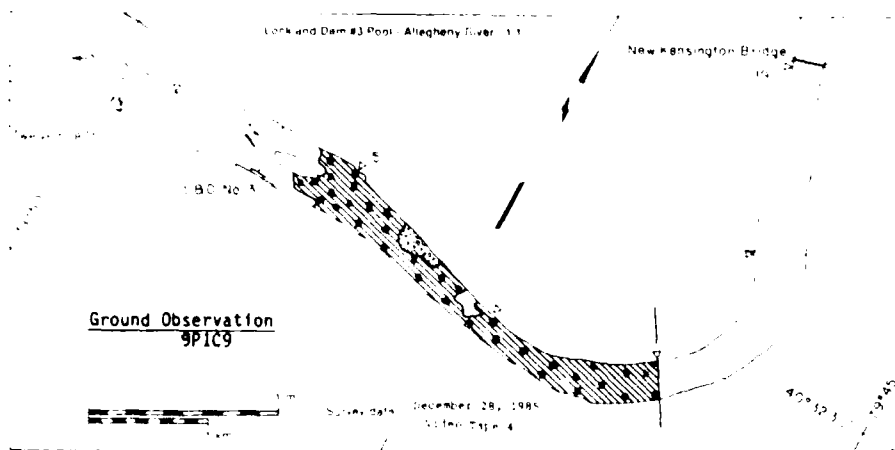
For the first 5 miles upstream of Maxwell L&D, the tapes and ground observations showed nearly complete ice cover on both dates, with the ground observer reporting stationary ice on 28 January and stopped ice on 4 February. This suggests that the ice was moving between 28 January and 4 February, which would explain why the 4 February tape (Fig. 4b) showed more fragmented ice than the 28 January tape (Fig. 4a). As with Landsat and ground observations, the videotapes and ground observations are also complementary and provide a more detailed view of ice conditions than either one alone.

Winter of 1985–86

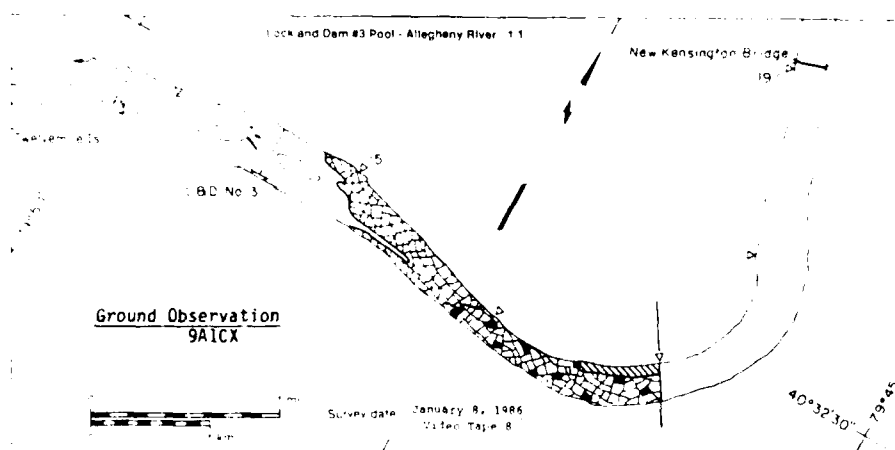
Ground observers reported ice on the Allegheny River for 63 days from 19 December to 19 February (Fig. 2a, A7) and on the Monongahela River for 39 days from 26 December to 1 February (Fig. 2b, A14). Videotapes were

taken of the lower 17 miles of the Allegheny River and of the lower 13 miles of the Monongahela River on 9 days when ice was apparent from 28 December to 28 January. Landsat images taken on 3 and 19 January and 4 and 20 February were not useful because the ground was cloud-covered. The only Landsat image that showed ice was taken on 8 March 1986, after the last videotape was taken and the last ground observation was made.

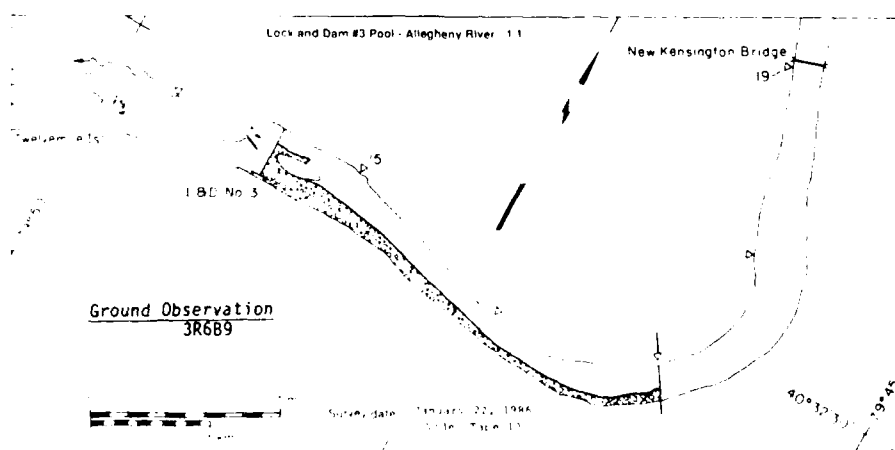
The 8 March Landsat image showed gray ice on 92% of the Allegheny River above L&D 8, on



a. 28 December 1985.



b. 8 January 1986.



c. 22 January 1986.

Figure 5. Ice conditions on the lower 2.5 miles of L&D 3 pool, Allegheny River, as observed on videotapes and by ground observers (see Table 3 for definitions of ice symbols).

32% of the Allegheny at L&D 4 pool, and on 11% of the Monongahela River at L&D 2 pool. Since no ground observations or videotapes were taken on this day, we cannot compare them to the Landsat-derived data. However, we can compare data from videotapes and ground observations from other days.

Ground observers at the Allegheny River L&D 3 would have a visual range of at least 2.5 miles upstream of the dam, which is the extent of the videotape coverage for this pool. On 28 December 1985, the videotape showed 82% of this reach covered by solid ice with interspersed open areas, 4% covered by ice floes, slush and pans, and 14% open water (Fig. 5a). The ground observer reported 90% of the river covered with 1-in.-thick, clear ice that was stopped, and that extended upstream 9 miles. On 8 January, the videotape showed 4% solid ice, 33% fragmented ice, 37% fragmented ice with interspersed open areas, and 26% open water (Fig. 5b). The ground observer reported a 90% cover of stationary, 1-in.-thick, clear ice that extended an unknown dis-

tance upstream. On 22 January (Fig. 5c), video showed 39% covered with ice floes, slush and pans, and 61% open water. The ground observer reported 30% coverage with running ice that was 6 in. thick and breaking, and that extended 9 miles upstream.

Computer-generated graphs

It became obvious during preparation of Figure 2 that because of the extensive hand-drafting required, use of the future ground observations would be limited. To expedite preparation of graphs of future data, a computer graphics program was developed to use the same ice codes as were used to prepare the hand-drawn graphs. In the computer-generated graphs (Fig. 6; Appendix A), the order of the L&D locations is reversed (see Fig. 1), the ice code symbols are slightly different (see Fig. 2), and ice thicknesses were not included because of space limitations. The use of a multi-colored diagram will allow thickness to be added (Bilello et al. 1988).

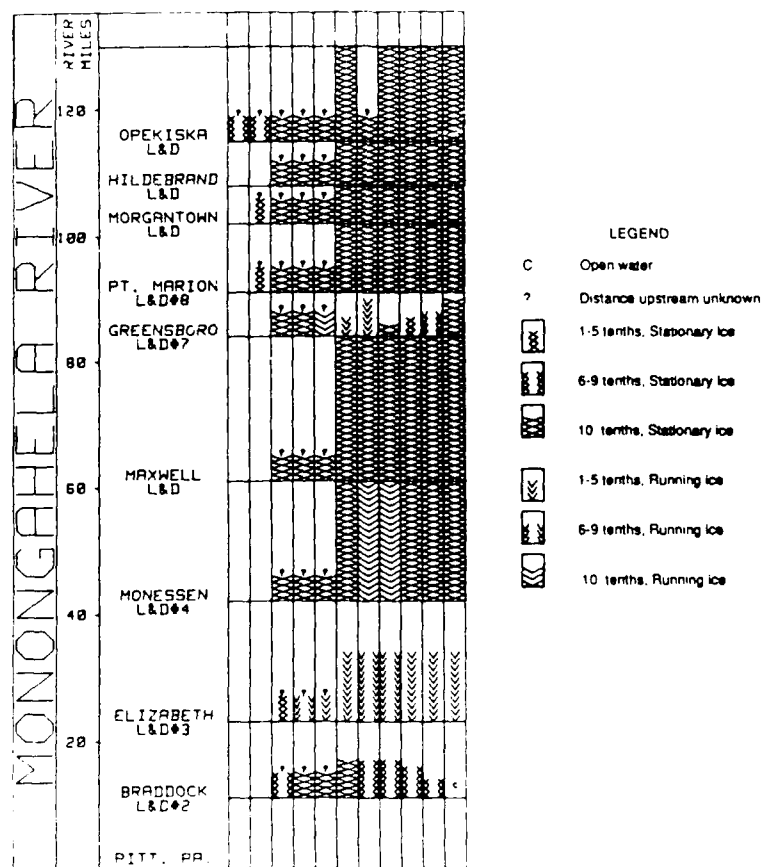


Figure 6. Part of the computer-generated diagram of daily ice conditions, Monongahela River, January 1985.

SUMMARY AND CONCLUSIONS

The river ice conditions on the Allegheny and Monongahela Rivers were highly variable, as shown by the graphs of the ground observations. The observed ice was largely in motion, although there was much stationary ice and major periods of open water. The graphs provide a convenient way of showing these wide variations, in space and time.

Each method of observation—ground, aerial video and Landsat—has certain advantages and disadvantages (Table 4). Ground observations have the advantage that data on thickness, movement and structure can be frequently obtained, and, generally, ground observations are not affected by the weather. The major limitation of ground observation is the line-of-sight of the observer, which is often no more than several miles. Given the wide variability of ice conditions, this limitation can be critical.

Aerial video observation has the advantages of providing detailed views of large river reaches, at frequent intervals, and at reasonable cost. The video image is relatively easy to interpret, but training or experience is essential. The disadvantages are the lack of ice thickness and the adverse effect of bad weather, especially low cloud ceilings. Given these restrictions, aerial video is perhaps the best means of closely observing ice conditions on large rivers and, when

combined with ground observations, the two methods provide an excellent means of recording and analyzing river ice.

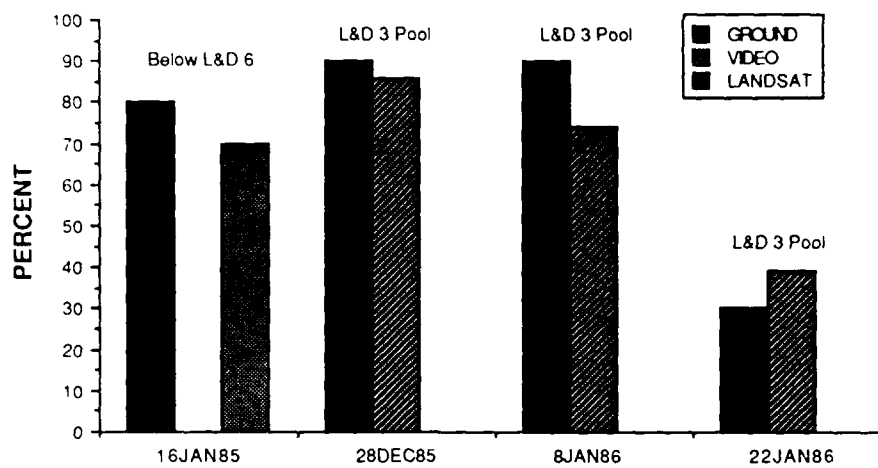
Landsat imagery has the advantage of providing images of large reaches of a river that can be easily interpreted. There is a good data base of usable images starting in 1972. Disadvantages are the infrequent coverage, the obscuration by clouds and poor resolution of the images, which limit the level of detailed information. Thin, clear ice, for example, is often undetected. Ice conditions determined from Landsat are recorded as either white or gray in tone so that ice details that are obtained by either ground observers or aerial videos are not apparent from Landsat images.

Despite differences in the detail obtainable from the three methods, they generally agree on the overall extent of ice coverage. For example, the total percentage of selected pools covered by ice as determined on selected dates is shown in Figure 7. It can be seen that, except for 16 January 1985 on the Monongahela River, the methods are within 15% of each other. The Landsat observation on 16 January 1985 (Fig. 7b) indicates much more ice than the ground observation.

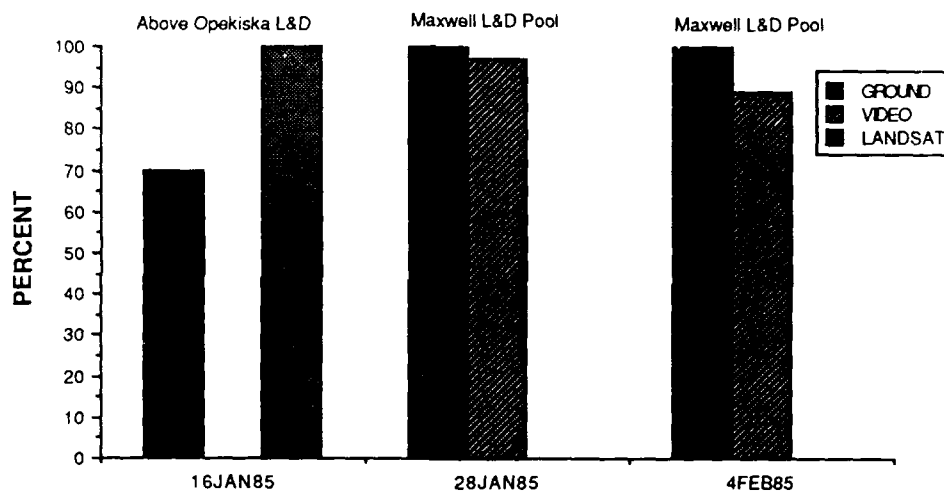
This study has illustrated the importance of three observation techniques for monitoring river-ice conditions. Each method provides useful data and, when analyzed together, they give a more

Table 4. Advantages and disadvantages of the three data sets.

		<i>Advantages</i>		<i>Disadvantages</i>
Landsat	-	Synoptic view of large reaches of the river	-	Poor IFOV gives limited, not detailed information
	-	Good data base of images since 1972	-	Infrequent acquisition
	-	Easy to interpret images	-	Cloud cover can obscure river
Video	-	View of large reaches of the river	-	Snow cover obscures ice
	-	Good IFOV gives as much detail as is required	-	Cannot provide ice thickness
	-	Easy to interpret, but experienced interpreter is required	-	Cannot acquire tapes if cloud ceiling is too low
	-	Frequent acquisition	-	Snow cover obscures ice
Ground	-	Detailed ice data	-	Limited horizontal view
	-	Frequent observations	-	Data quality depends on observer
	-	Not weather-dependent	-	Data must be graphed to be useful



a. Allegheny River.



b. Monongahela River.

Figure 7. Percent of river ice cover as observed on the ground, from videotapes and from Landsat images.

complete understanding of a dynamic river-ice regime than would be possible with one method alone.

With the computer-graphics capability developed for this study, there may be increased use of the ground observations if they are quickly graphed and available for rapid dissemination where navigation on ice-prone rivers throughout the winter is required. This potential for expanded use of these data may result in the receipt of better and more complete information from the ice observers.

LITERATURE CITED

- Bates, R.E., D. Saboe and M. Bilello (1968) Ice conditions and prediction of freeze-over on streams in the vicinity of Ft. Greely, Alaska. USA Cold Regions Research and Engineering Laboratory, Special Report 121.
- Bilello, M.A., J.J. Gagnon and S.F. Daly (1988) Computer-generated graphics of river ice conditions. Hampton, Virginia: Science and Technology Corporation, STC Technical Report 2280.

Canadian Coast Guard (1986) Ice maps for Trois Rivières Sorel et Grondines. Quebec, Canada: Garde Cotière, Bureau des Glaces.

Gatto, L.W. (1985) Ice conditions on the Ohio and Illinois Rivers, 1972-85. *IEEE International Geoscience and Remote Sensing Symposium Digest*, 2:856-961.

Gatto, L.W., and S.F. Daly (1986) Ice conditions along the Allegheny, Monongahela and Ohio Rivers, 1983-84. USA Cold Regions Research and Engineering Laboratory, Internal Report 930 (unpublished).

Gatto, L.W., S.F. Daly and K.L. Carey (1986) Ice atlas, 1984-85, Ohio, Allegheny and Monongahela Rivers. USA Cold Regions Research and Engineering Laboratory, Special Report 86-23.

Michel, B. (1971) Winter regime of rivers and

lakes. USA Cold Regions Research and Engineering Laboratory, Monograph III-B1a.

Starosolszky, O. (1985) Ice and river engineering. In *Developments in Hydraulic Engineering-3* (P. Novak, Ed.). New York: Elsevier Applied Science Publishers, pp. 175-219.

U.S. Department of Commerce (1985 and 1986) Climatological Data, Pennsylvania—Monthly and Annual Summaries. Asheville, N.C.: National Oceanic and Atmospheric Administration Environmental Data Service, National Climatic Center.

U.S. Department of Interior (1985 and 1986) U.S. Geological Survey—Water Resources Data for Pennsylvania. Water year 1985 and 1986, Allegheny River at Natrona, Pennsylvania, and Monongahela River at Braddock, Pennsylvania.

APPENDIX A: ICE CODE RECORDS AND COMPUTER-GENERATED GRAPHS OF DATA

LEGEND

C	Open water
?	Distance upstream unknown
	1-5 tenths, Stationary ice
	6-9 tenths, Stationary ice
	10 tenths, Stationary ice
	1-5 tenths, Running ice
	6-9 tenths, Running ice
	10 tenths, Running ice

Allegheny River

1979-80

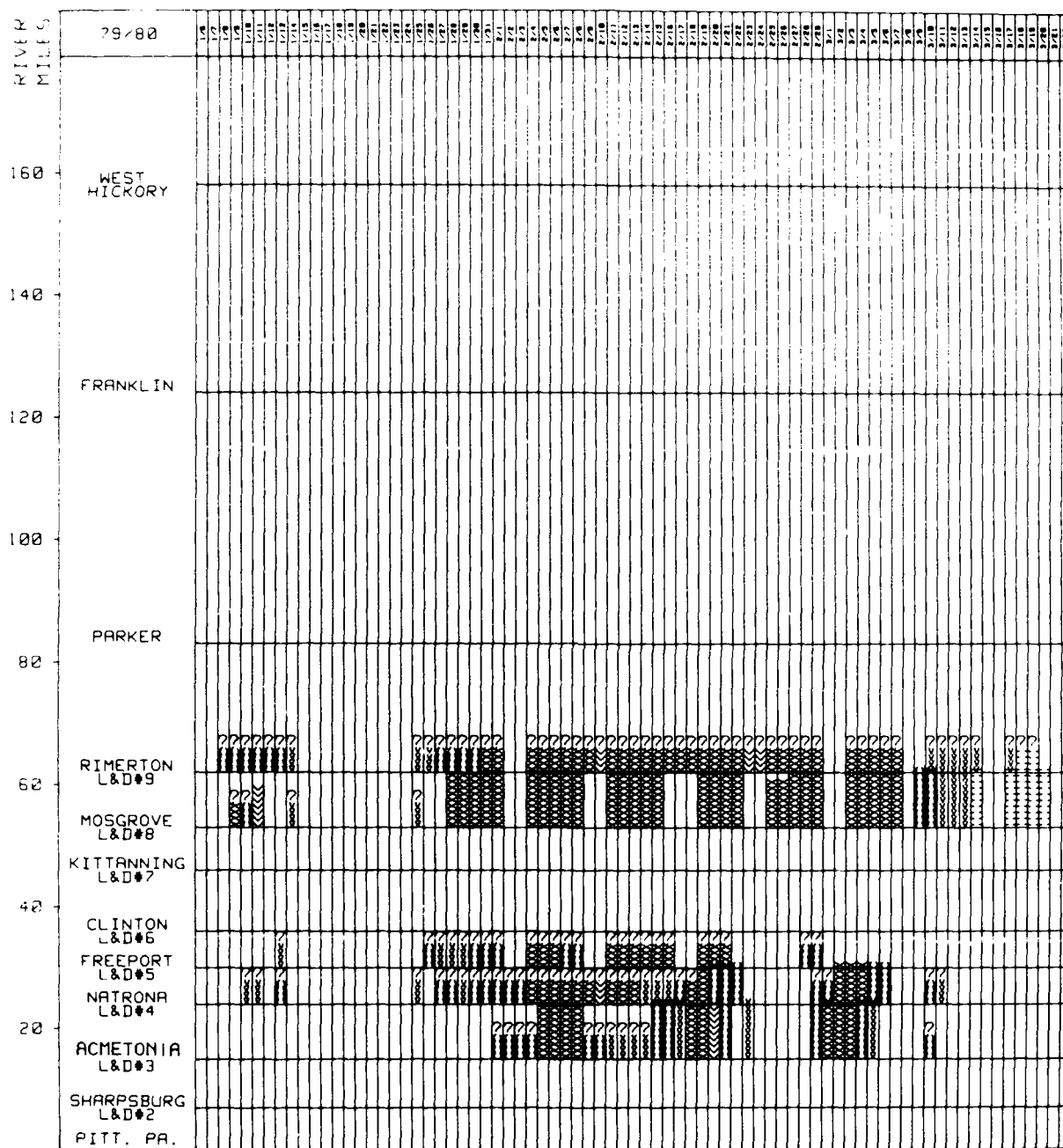


Figure A1.

DATE	SHARPSBURG	ACHTONIA	HARRISON	FREEPORT	CLINTON	KITTANNING	MOSGROVE	REHERTON	PARKER	FRANKLIN	J. HICK
1/6											
1/7											
1/8											
1/9							10P1LX	9R1CX			
1/10			SR1CX				9R1CX	9R1CX			
1/11			1R1CX				10J3LX	6R1CX			
1/12								6R1CX			
1/13			9R2TX	2R2CX				6R1CX			
1/14							1R1CX	1R1CX			
1/15											
1/16											
1/17											
1/18											
1/19											
1/20											
1/21											
1/22											
1/23											
1/24											
1/25			1R1CX				SR1CX	4R1CX			
1/26				BR1CX				4R1CX			
1/27			BR1CX	SR1CX				9R1CX			
1/28			6R1CX	SR1CX			10P3CB	9R1CX			
1/29			SR1CX	SR1CX			10P3CB	9R1CX			
1/30			BR1CX	BR1CX			10P3CB	9R1CX			
1/31			BR1CX	9R1CX			10P3CB	10J6LX			
2/1		7P2CX	BR1CX	BR1CX			10P3CB	10J6LX			
2/2		7P2CX	9R1CX								
2/3		9R2CX	9R2CX								
2/4		9R2CX	10P2CX	10P1CX			10P5CB	10J6LX			
2/5		10R2CB	10P2CX	10P1CX			10P5CB	10J6LX			
2/6		10R2CB	10P2CX	10P1CX			10P5CB	10J6LX			
2/7		10R2CB	10P2CX	BR1CX			10P5CB	10J6LX			
2/8		10R2CB	10P2CX	BR1CX			10P5CB	10J6LX			
2/9		7R2CX	10P2CX					10J6LX			
2/10		6R4CX	10R1CX					10J6LX			
2/11		SP4CX	10P1CX	10P2CX			10P6CB	10J6LX			
2/12		SP4CX	10P1CX	10P3CX			10P6CB	10J6LX			
2/13		SP4CX	10P1CX	10P3CX			10P6CB	10J6LX			
2/14		SP5CB	SP2CX	10P3CX			10P6CB	10J9LX			
2/15		6R4CB	SP4CX	10P3CX			10P6CB	10J9LX			
2/16		6R4CB	SP4CX	10P3CX				10J9LX			
2/17		4R4CB	7P4CX					10J9LX			
2/18		10P4CB	10P4CX					10J9LX			
2/19		10P4CB	10P4CB	10P3CX			10P6CB	10J9LX			
2/20		10R4CB	8P4CB	10P3CX			10P6CB	10J9LX			
2/21		9R6CB	8P4CB	10P2CX			10P6CB	10J9LX			
2/22			8P4CB				10P6CB	10J9LX			
2/23		3R2T9						10J9LX			
2/24								10J9LX			
2/25							10P4CB	10J9LX			
2/26							10P4CB	10J9LX			
2/27							10P4CB	10J9LX			
2/28				9R1CX			10P4CB	10J9LX			
2/29		9R1CB	9R1CX	9R1CX			10P4CB	10J9LX			
3/1		10P1CB	9R2CX								
3/2		10P2CB	10P2CB								
3/3		10P2CB	10P2CB				10P5CB	10J10LX			
3/4		9P2CB	10P2CB				10P5CB	10J10LX			
3/5		5R2T9	9P2T6				10P4CB	10J10LX			
3/6			7P2T6				10P4CB	10J10LX			
3/7							10P4CB	10J10LX			
3/8											
3/9							9R4CB				
3/10		7R4T9	9R2T9				8P4T9	1R5LX			
3/11			1R2T9				5R4T9	1R5LX			
3/12							5R4T9	5R1CX			
3/13							5R4T9	3R2LX			
3/14							25R4T9	1R2LX			
3/15											
3/16											
3/17							25R4T9	1R2T9			
3/18							25R4T9	1R2T9			
3/19							25R4T9	1R2T9			
3/20							15R4T9				
3/21											
3/22											

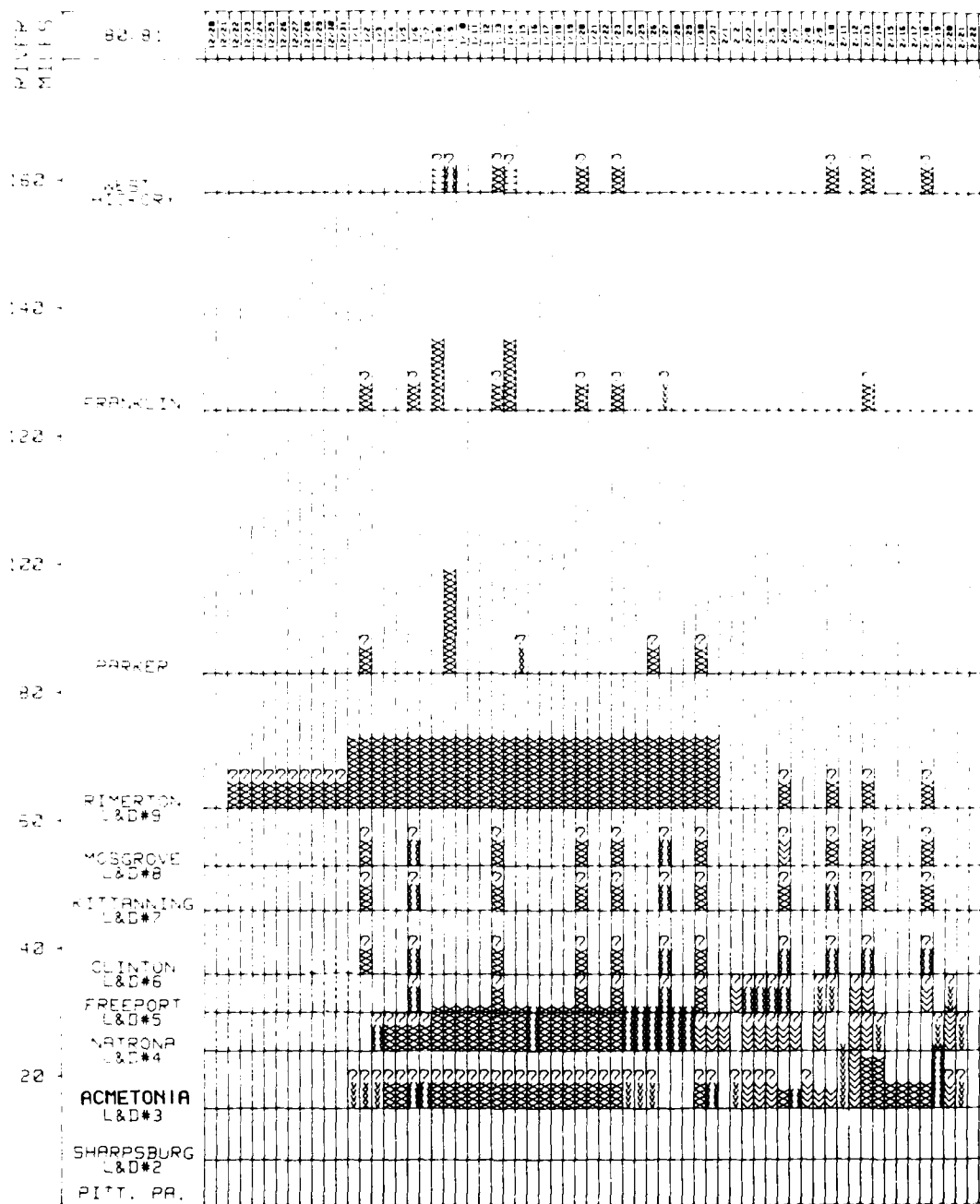


Figure A2.

DATE	SHARPSBURG	ACHTONIA	NATRONA	FREEPORT	CLINTON	KITTANNING	MOSGROVE	RIEMERTON	PARKER	FRANKLIN	W. HICK
12/20											
12/21											
12/22								10F2CX			
12/23								10F2CX			
12/24								10F2CX			
12/25								10F2CX			
12/26								10F2CX			
12/27								10F2CX			
12/28								10F2CX			
12/29								10F2CX			
12/30								10F2CX			
12/31								10F2CX			
1/1		1R3CX						10F1C10			
1/2		1P2CX			10F1XX	10F1XX	10F1XX	10F1C10	10J10XX	10J10XX	
1/3		5R3CX	6R1CX					10F5C10			
1/4		10P1CX	10P1CX					10F5C10			
1/5		10P2CX	10F2LX					10F5C10			
1/6		9R2CX	10F3LX	8P3XX	8P3XX	9P3XX	9P3XX	10F5C10	10J10XX		
1/7		6P2CX	10F3LX					10F6C10			
1/8		10P3CX	10F4L6					10F6C10		10J30L10	10S12LX
1/9		10P4CX	10F4L6					10F6C10	10P20X15		2P10XX
1/10		10P4CX	10F5L6					10F6C10			
1/11		10P5CX	10F6L6					10F6C10			
1/12		10P5CX	10F7L6					10F6C10			
1/13		10P6LX	10F7L6	10P6XX	10P6XX	10P6XX	10P6XX	10F6C10		10J10XX	10J10XX
1/14		10P9LX	10F7L6					10F6C10		10J30L10	1S1XX
1/15		10P9LX	10F7L6					10F6C10	5P10BX		
1/16		10P9LX	9F7L6					10F6C10			
1/17		10P9LX	10F7L6					10F6C10			
1/18		10P7LX	10F7L6					10F6C10			
1/19		10P7LX	10F7L6					10F9C10			
1/20		10P7LX	10F7L6	10P5XX	10P5XX	10P5XX	10P5XX	10F9C10	10J10XX	10J10XX	
1/21		10P7LX	10F7L6					10F9C10			
1/22		10P7LX	10F6L6					10F9C10			
1/23		10P7LX	10F6L6	10P6XX	10P6XX	10P6XX	10P6XX	10F9C10	10J10XX	10J10XX	
1/24		2R7TX	7F6L6					10F9C10			
1/25		2R7TX	7F6L6					10F9C10			
1/26		1R7TX	7F6L6					10F9C10	10F10XX		
1/27			7F6L6	8R6XX	8R6XX	8R6XX	8R6XX	10F9C10		3R8XX	
1/28			7F6L6					10F9C10			
1/29			6F5L6					10F7C10			
1/30		10P1CX	10R1CX	10P1CX	10P4XX	10P4XX	10P4XX	10F7C10	10J10XX		
1/31		8R2CX	10R1CX					10F7C10			
2/1			10R1CX								
2/2		4R2TX		10R1CX							
2/3		10R1CX	10R1CX	8R1CX							
2/4		10R2CX	10R1CX	8R3CX							
2/5		10R2CX	10R1CX	8R3CX							
2/6		10P6L2	10R1CX	8R3CX	8P5XX	10P5XX	10P5XX	10P5XX			
2/7		6J6L2	10R1CX								
2/8		10J8LX									
2/9		10J6L2	10R2CX	4R2TX							
2/10		10J6L2		4R2TX	6P5XX	8P5XX	10P5XX	10P5XX			10J8XX
2/11		1R679									
2/12		10R1C9	10R2CX	10R1CX							
2/13		10R1C7	10R1CX	10R1CX	8P5XX	10P5XX	10P5XX	10P5XX	10R9XX	10J8XX	
2/14		10R1C7	3R1CX								
2/15		10P2L3									
2/16		10J5L3									
2/17		10J5L3									
2/18		10J5L3		10R13TX	8P5XX	10P5XX	10P5XX	10P5XX			10J8XX
2/19		7R6L9	5P5TX								
2/20		10R7LX	10R7L6	2R12TX							
2/21		3R3TX	1R3TX								
2/22											
2/23											

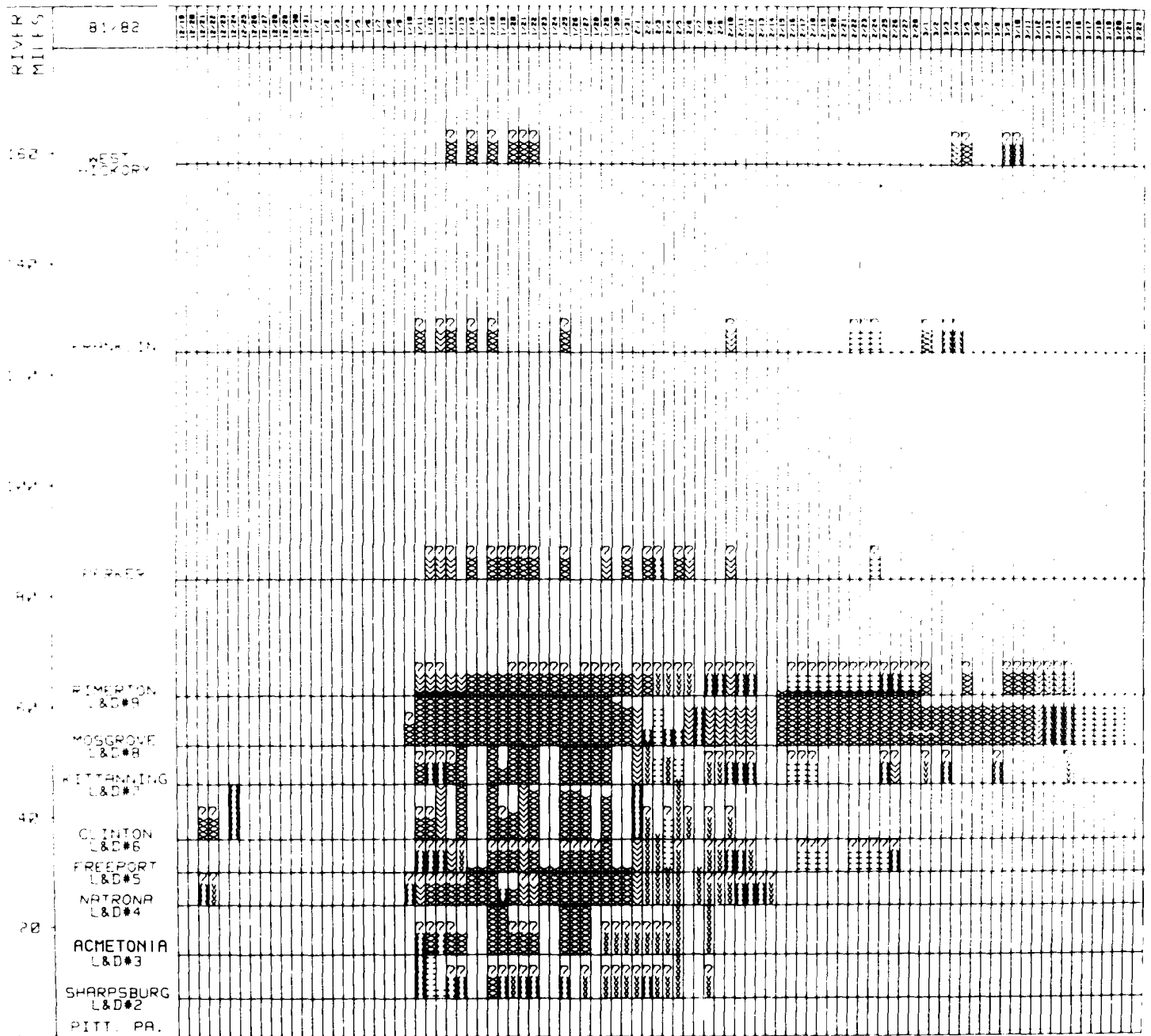


Figure A3.

21

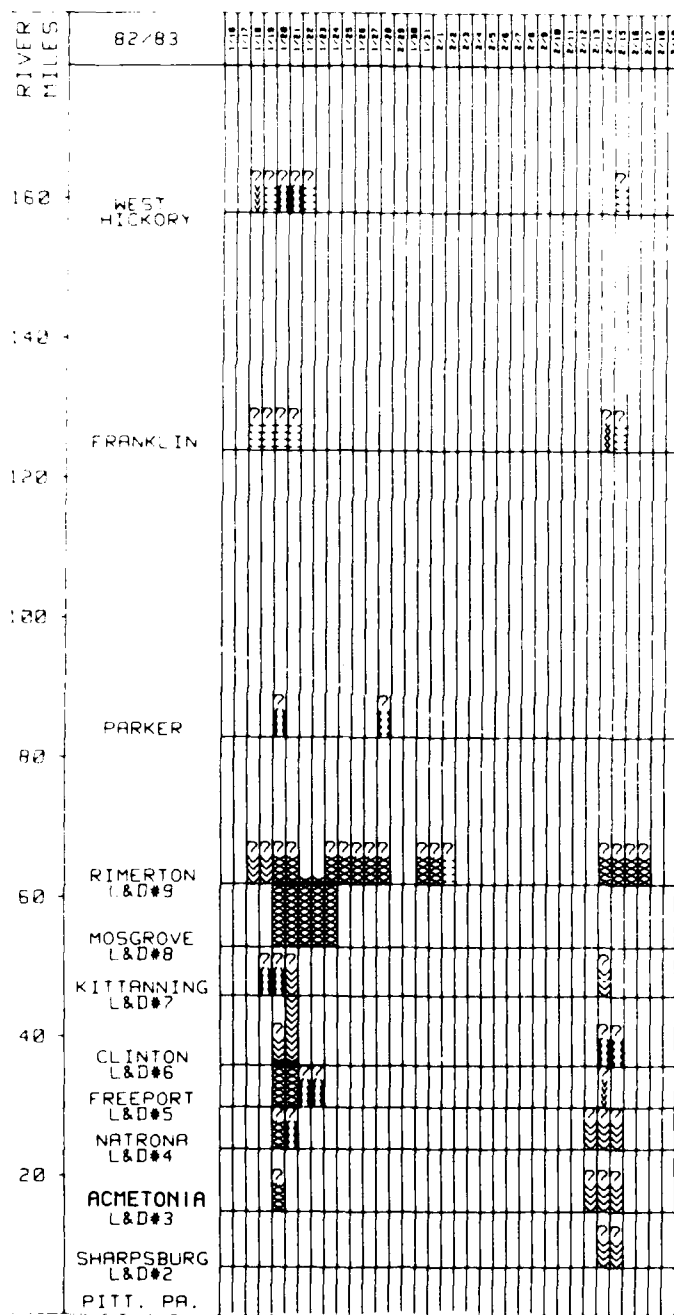


Figure A4.

DATE	WARREN	AMSTER	WATSON	FREEDPORT	LINTON	KOTTMAN	MOSEROWE	ROMERTON	PARKER	FRANKLIN	U. MICK
11-10											
11-11											
11-12								TOPICK		1STXK	1STXK
11-13						TRICK		TOPICK		2STXK	3STXK
11-14		TOPICK	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK	BRICK	4STXK	7STXK
11-15			TOPICK	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK		4STXK	7STXK
11-16				TOPICK			TOPICK				3STXK
11-17				TOPICK			TOPICK				
11-18							TOPICK				
11-19							TOPICK	TOPICK			
11-20								TOPICK			
11-21								TOPICK			
11-22								TOPICK	TOPICK		
11-23								TOPICK	TOPICK		
11-24								TOPICK	TOPICK		
11-25								TOPICK	TOPICK		
11-26								TOPICK	TOPICK		
11-27								TOPICK	TOPICK		
11-28								TOPICK	TOPICK		
11-29								TOPICK	TOPICK		
11-30								TOPICK	TOPICK		
12-1								TOPICK	TOPICK		
12-2								TOPICK	TOPICK		
12-3								TOPICK	TOPICK		
12-4								TOPICK	TOPICK		
12-5								TOPICK	TOPICK		
12-6								TOPICK	TOPICK		
12-7								TOPICK	TOPICK		
12-8								TOPICK	TOPICK		
12-9								TOPICK	TOPICK		
12-10								TOPICK	TOPICK		
12-11								TOPICK	TOPICK		
12-12								TOPICK	TOPICK		
12-13		TOPICK	TOPICK	TOPICK	TOPICK	TOPICK		TOPICK	TOPICK	2STXK	1STXK
12-14	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK		TOPICK	TOPICK	2STXK	1STXK
12-15	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK	TOPICK		TOPICK	TOPICK	2STXK	1STXK
12-16								TOPICK	TOPICK		
12-17								TOPICK	TOPICK		
12-18								TOPICK	TOPICK		
12-19								TOPICK	TOPICK		

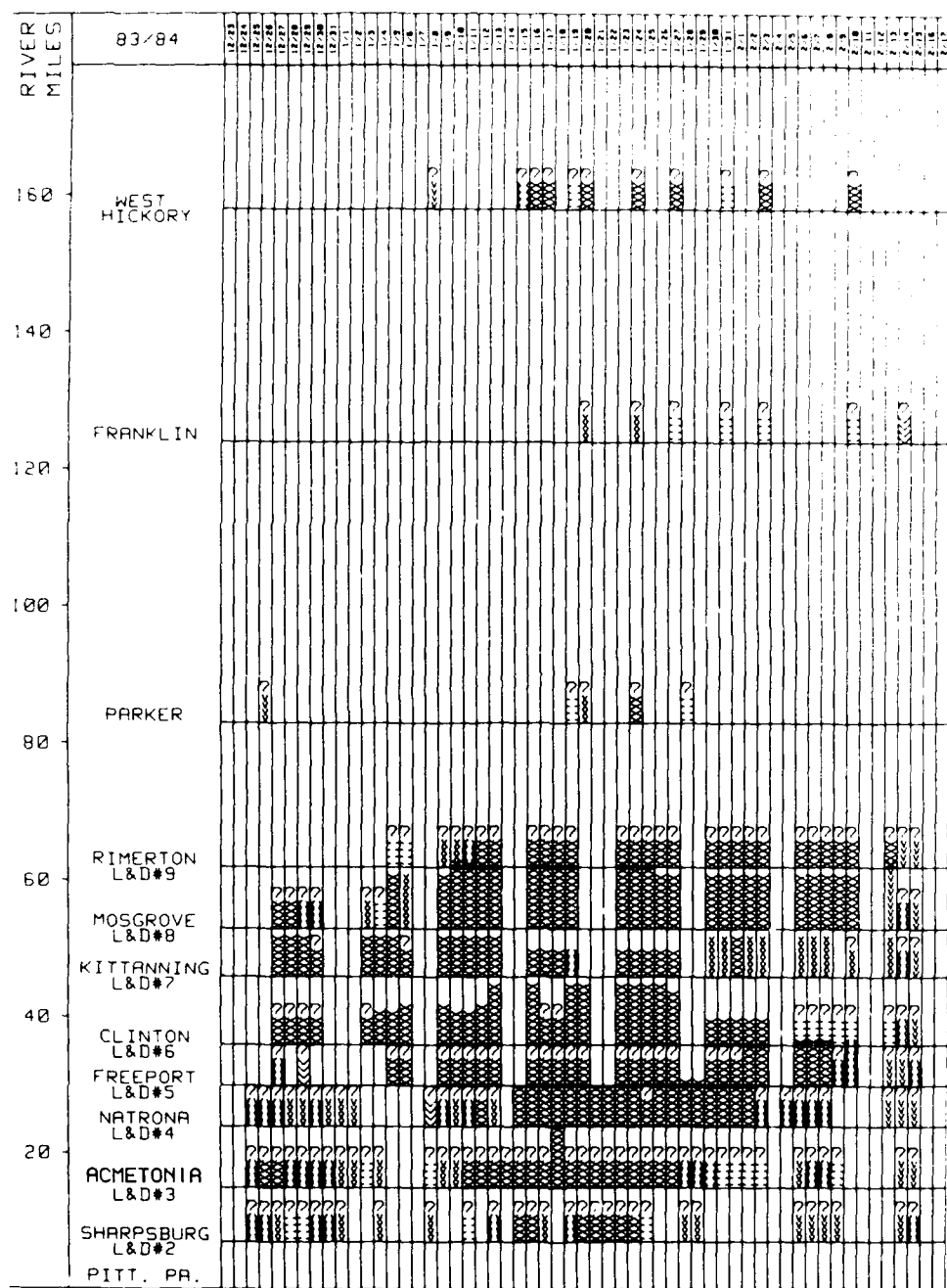


Figure A5.

DATE	WAPSBBS	ADMONIA	NATRONA	FREEPORT	CLINTON	KITTANNING	MOSGROVE	ROMERTON	PAPER	FRANKLIN	W. HICK
12/23											
12/24											
12/25	6P1CX	6P1CX	7P1CX								
12/26	6P2CX	10P2CX	8P2CX						4P1XX		
12/27	6P2CX	10P2CX	8P1CX	6P2CX	10P2CX	10P8LS	10P4LY				
12/28	354CX	7P2CX	4P1CX		10P2CX	10P8LS	10P4LY				
12/29	354CX	7P2CX	1P2CX	10P3TX	10P2CX	10P8LS	7P4LY				
12/30	4P5CX	7P2CX	7P2CX		10P4CX	10P8LY	9P4LY				
12/31	7P2CX	7P2LY	3P2CX								
1/1	7P2CX	3P2CX	1P1CX								
1/2		1P1CX	1P1CX								
1/3		1P3CX			10P5LY	10P8LS	5P48X				
1/4	1P5CX	1P5CX			10P5LY	10P8LS	3548X				
1/5				10P3CX	10P5LY	10P8LS	10J487	252LY			
1/6				10P3CX	10P5LS	10P8LY	3J487	252LY			
1/7											
1/8	7P3CX	252LY	10P2CX								5P1XX
1/9		1P2TX	7P1CX	10P3CX	10P5LS	10P8CS	10J487	4P1CX			
1/10		2P2TX	3P2TX	10P3CX	10P5LY	10P8LS	10J419	4P1LY			
1/11	352LY	10P1CX	9P1CX	10P3CX	10P5LY	10P8LS	10J489	8P1LY			
1/12	10P3CX	10P2CX	10P3CX	10P3CX	10P5LS	10P8LS	10J489	10P1CX			
1/13	7P1CX	10P3CX	3P1CX	10P3CX	10P5LY	10P8LS	10J489	10P1CX			
1/14		10P3CX									
1/15	10P1CX	10P3CX	10P4CS								851XX
1/16	10P1CX	10P4CX	10P4CS	10P3CX	10P5LY	10P1CX	10J4C9	10P2CX			10P1XX
1/17	5P1CX	10P4CX	10P4CS	10P3CX	10P5LY	10P1CX	10J4C9	10P2CX			10J1XX
1/18		10P4C9	10P4CS	10P3CX	10P5LY	10P1CX	10J4C9	10P4CX			
1/19	9P2CX	10P5CX	10P4CS	10P3CX	10P5LY	8P2CX	10J5C9	10P4LY	551XX		10J1XX
1/20	10P2CX	10P5CX	10P4CS	10P4CX	10P6LY				1P1XX	3P1XX	10P1XX
1/21	10P3CX	10P6CX	10P5CS								
1/22	10P4CX	10P7CX	10P6CS								
1/23	10P4CX	10P7CX	10P7CS	10P4CX	10P6LY	10P5B3	10J8LY	10P11LY			
1/24	10P4CX	10P7CX	10P7C6	10P4CX	10P6LY	10P5C3	10J8LY	10P11LY	10P1XX	3P1XX	10P1XX
1/25	354LY	10P7CX	10P7C6	10P3CX	10P5LY	10P5B3	10J7LY	10P11LY			
1/26		10P7CX	10P7C6	10P3CX	10P5LY	10P5B3	10J9LY	10P11LY			
1/27		10P7CX	10P7C6	10P4CX	10P5LY	10P5P3	10J9LY	10P11LY			
1/28	3P4CX	6P5CX	10P7C6						351XX		
1/29	1P5CX	8P7CX	10P7C6								
1/30		757CX	10P7C6	10P4CX	10P3LY	5P1QLS	10J9LY	10P11LY			
1/31		357CX	10P7C6	10P4CX	10P3LY	5P1QLS	10J9LY	10P11LY		251XX	10J1XX
2/1		357CX	10P7C6	10P4CX	10P3LY	10P1QLS	10J9LY	10P11LY			
2/2		357CX	10P7C6	10P4CX	10P4LY	5P1QLS	10J9LY	10P11LY			
2/3		357CX	7P7CX	10P4CX	10P4LY	5P1QLS	10J8LY	10P11LY		251XX	10P1XX
2/4											
2/5			7P7CX								
2/6	1P1CX	1P1CX	8P1CX	10P3C6	354LY	4P1QLS	10J8LY	10P11LY			
2/7	5P1CX	7P4CX	8P1CX	10P3C6	354LY	4P1QLS	10J8LY	10P11LY			
2/8	4P1CX	6P5CX	8P1CX	10P3C6	354LY	4P1QLS	10J8LY	10P11LY			
2/9	3P1CX	355CX		6P3CX	354LY		10P8LY	10P12LY			
2/10				6P2LY	354LY	4P4LY	10J8LY	10P12LY		251XX	10P1XX
2/11											
2/12											
2/13			1P1TX	1P3TX	354LY	4P1QLS	3P4LY	10P1QLY			
2/14	3P4CX	5P4TX	3P1TX	1P3LY	7P5LY	6P1QLY	6P9LY	3P4TX		10P1XX	
2/15	6P4TX	1P6TX	4P1TX	8P4TX	1P6TX	2P5TX	1P9TX	3P2TX			
2/16											
2/17											

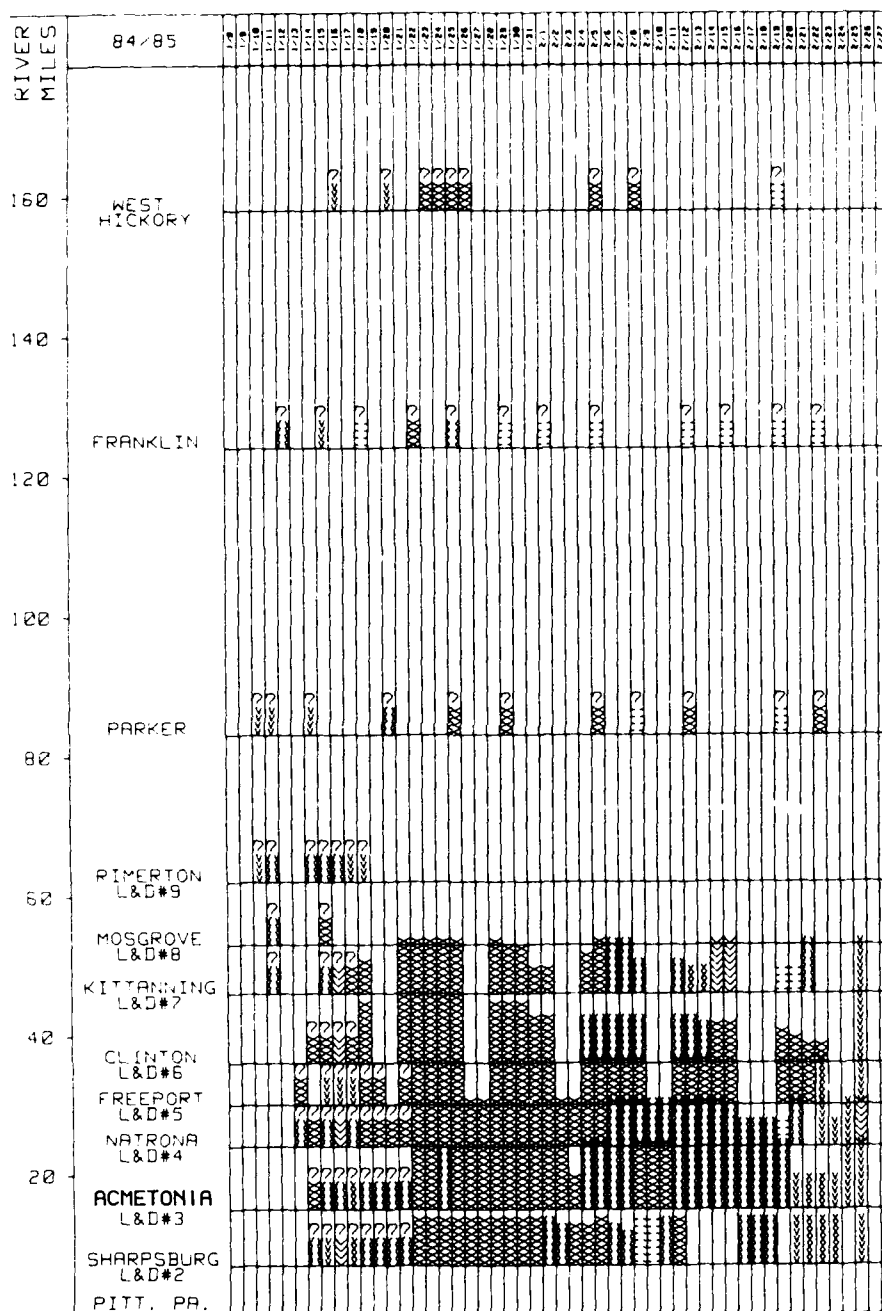


Figure A6.

DATE	SHARPSBURG	ACHTONIA	NATRONA	FREEDPORT	CLINTON	KILLBUCK	MOSEBROOK	WILMINGTON	PARKER	FRANKLIN	J. HICK
1/8											
1/9											
1/10								SR2BX	SR1XX		
1/11						BR1XX	BR1XX	BR1XX	BR1XX		
1/12										BR1XX	
1/13			BR1XX	BR1XX							
1/14	BR1XX	BR1XX	BR1XX		BR1XX			BR1XX	BR1XX		
1/15	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		SR1XX	
1/16	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			SR1XX
1/17	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/18	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
1/19	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/20	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
1/21	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/22	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/23	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
1/24	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/25	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
1/26	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/27	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/28	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/29	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
1/30	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
1/31	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/1	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
2/2	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/3	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/4	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/5	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
2/6	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/7	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/8	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/9	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/10	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/11	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/12	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
2/13	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/14	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/15	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
2/16	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/17	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/18	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/19	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
2/20	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/21	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/22	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX		SR1XX	
2/23	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/24	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/25	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/26	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			
2/27	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX	BR1XX		BR1XX			

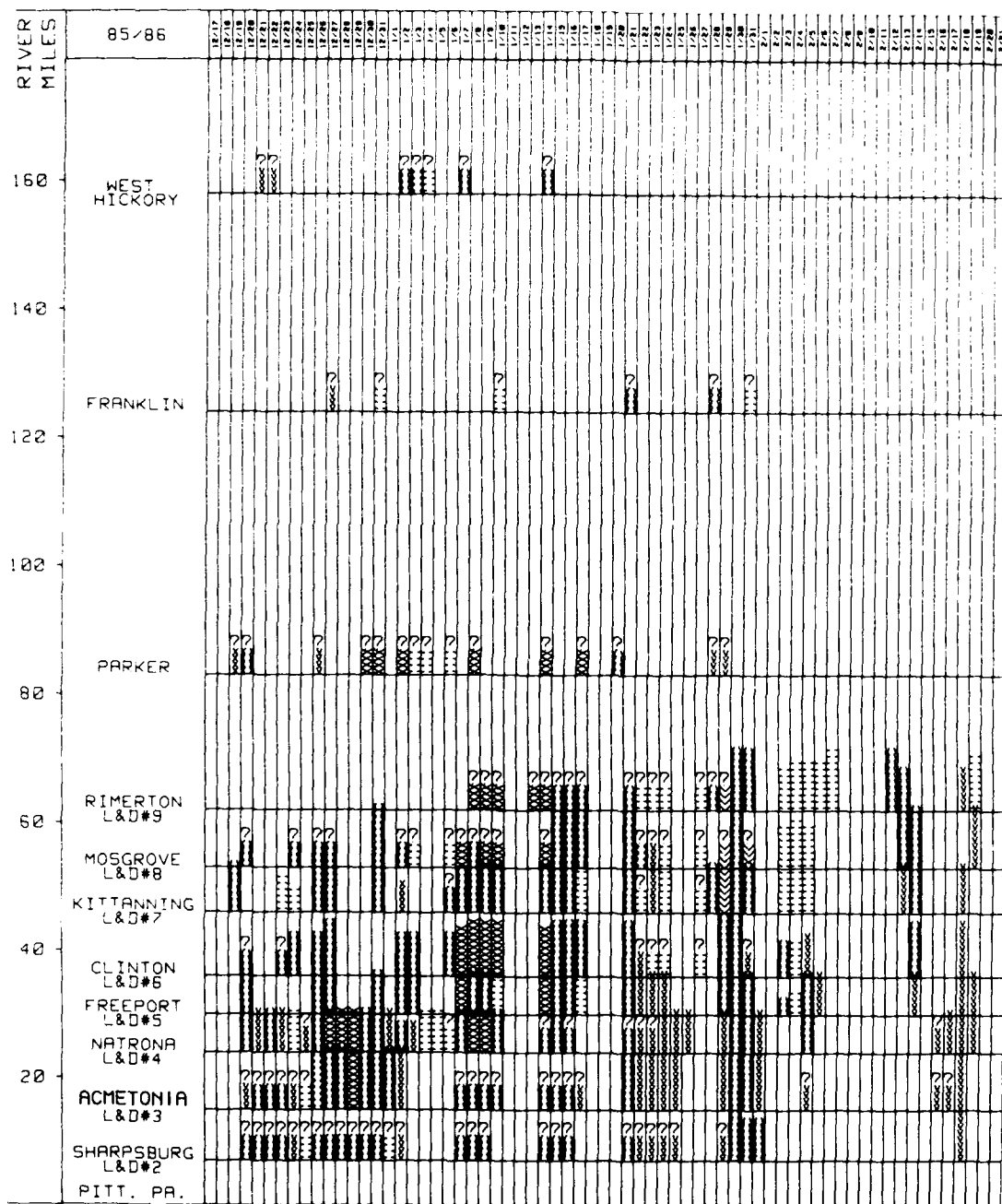
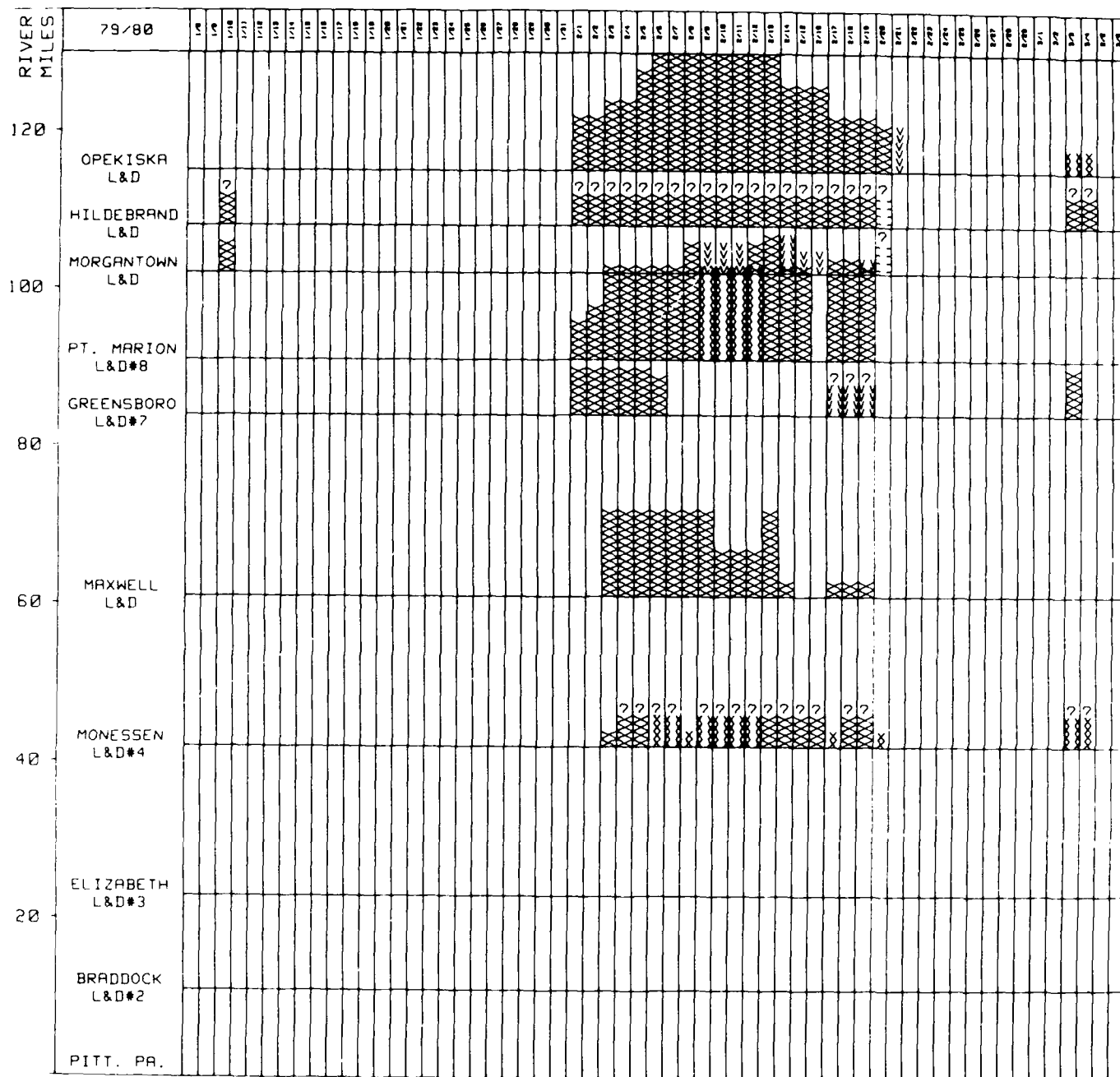


Figure A7.

29

Monongahela River

1979-80



DATE	BRADDOCK	ELIZABETH	HOMESSEN	MAXWELL	ORNSBORO	PT. BAR	HEARTOWN	HLDBRAND	OPKITSKA
1/8									
1/9									
1/10							10R1T3	10R1XX	
1/11									
1/12									
1/13									
1/14									
1/15									
1/16									
1/17									
1/18									
1/19									
1/20									
1/21									
1/22									
1/23									
1/24									
1/25									
1/26									
1/27									
1/28									
1/29									
1/30									
1/31									
2/1					10R1XS	10F1X4		10R1XX	10R1X6
2/2					10R1XS	10R1X6		10R1XX	10R1X6
2/3			10R1X1	10R1X10	10R1XS	10R1X11		10R1XX	10R1X8
2/4			10R1XX	10R1X10	10R2XS	10R1X11		10R1XX	10R1X8
2/5			10R1XX	10R1X10	10R1XS	10R2X11		10R1XX	10R1X12
2/6			10R1XX	10R1X10	10R1B4	10R2X11		10R2XX	10R2X14
2/7			10R1XX	10R1X10		10R1X11		10R2XX	10R2X14
2/8			10R1X1	10R1X10		10R1X11	10R2X3	10R2XX	10R2X14
2/9			10R1XX	10R1X10		10R1T1	10R2X3	10R2XX	10R2X14
2/10			10R1XX	10R2XS		10R1T1	10R2X3	10R2XX	10R2X14
2/11			10R1XX	10R1XS		10R1T1	10R2X3	10R2XX	10R2X14
2/12			10R1XX	10R1XS		10R1T1	10R2X3	10R2XX	10R2X14
2/13			10R2XX	10R1X10		10R1X11	10R2X4	10R2XX	10R3X10
2/14			10R2XX	10R1X1		10R1X11	10R2X4	10R3XX	10R3X10
2/15			10R2XX			10R1X11	10R1X2	10R2XX	10R3X10
2/16			10R2XX				10R1X2	10R2XX	10R3X10
2/17			10R2X1	10R1X1	10R1XX	10R1X11	10R1X1	10R2XX	10R3X6
2/18			10R2XX	10R1X1	10R1XX	10R1X11	10R1X1	10R3XX	10R3T6
2/19			10R2XX	10R1X1	10R1XX	10R1X11	10R1X1	10R3XX	10R3T6
2/20			10R2X1				10R1X1	10R3XX	10R3T5
2/21							10R1X1	10R3XX	10R3T5
2/22									10R3T5
2/23									
2/24									
2/25									
2/26									
2/27									
2/28									
2/29									
3/1									
3/2									
3/3			10R1XX		10R1XS			10R1XX	10R1X2
3/4			10R1XX					10R1XX	10R1X2
3/5									
3/6									

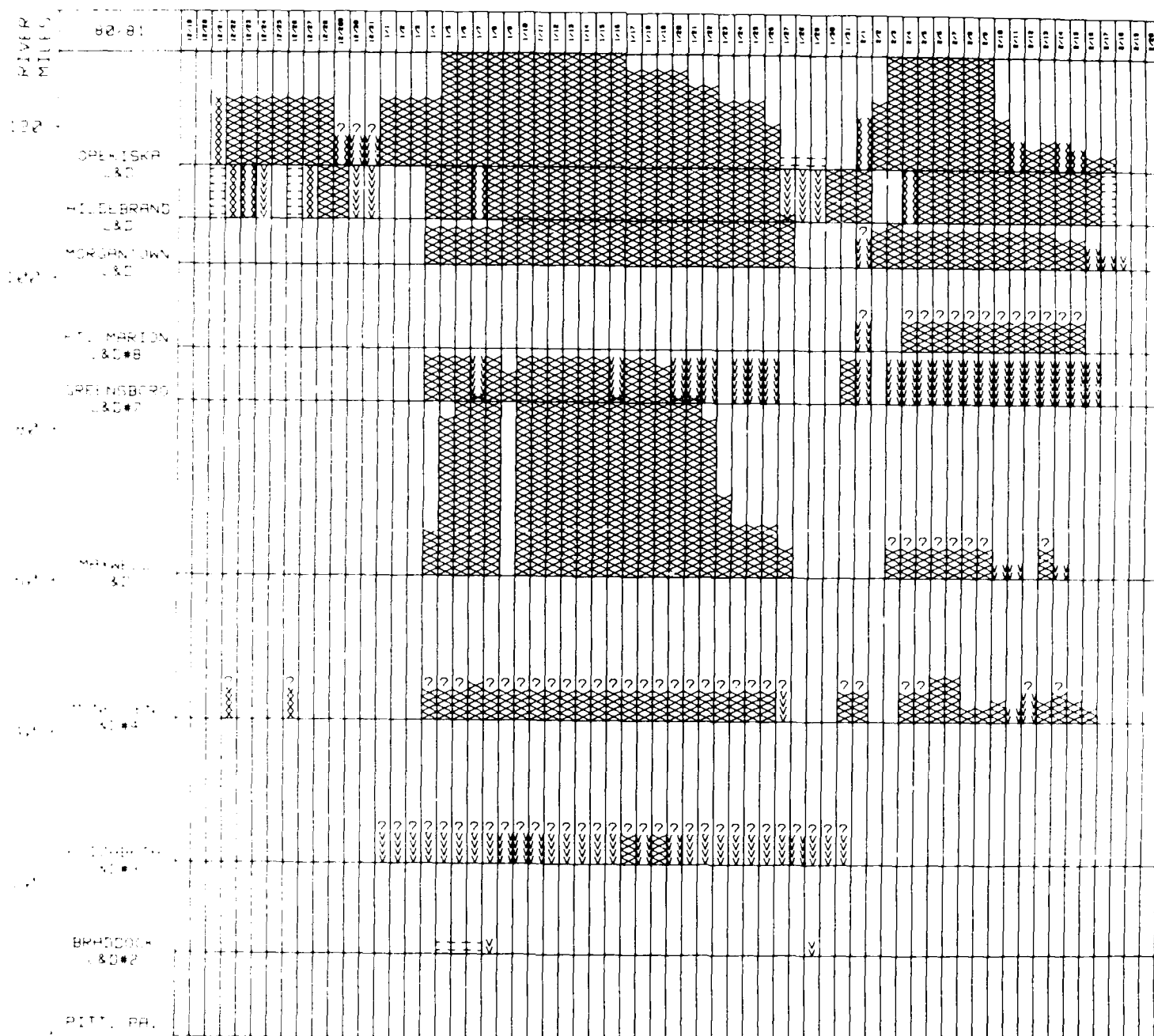


Figure A9.

DATE	BRADDOCK	ELLSBETH	MONROE	MADELL	BRNSBURG	PI MAR	MCANTON	HILBRAND	DEKESKA
12-18									
12-19									
12-20									
12-21								55106	55118
12-22								55106	100108
12-23								55106	100108
12-24								55106	100108
12-25									100108
12-26								55106	100108
12-27								55106	100108
12-28								100106	100108
12-29								100106	99106
12-30								55106	99106
12-31								100106	99106
1-1									100108
1-2									100108
1-3									100108
1-4								100106	100108
1-5	55106	55106	100106	100106	100106		100106	100106	100106
1-6	55106	55106	100106	100106	100106		100106	100106	100106
1-7	55106	55106	100106	100106	100106		100106	100106	100106
1-8	55106	55106	100106	100106	100106		100106	100106	100106
1-9								100106	100106
1-10								100106	100106
1-11								100106	100106
1-12								100106	100106
1-13								100106	100106
1-14								100106	100106
1-15								100106	100106
1-16								100106	100106
1-17								100106	100106
1-18								100106	100106
1-19								100106	100106
1-20								100106	100106
1-21								100106	100106
1-22								100106	100106
1-23								100106	100106
1-24								100106	100106
1-25								100106	100106
1-26								100106	100106
1-27								100106	100106
1-28								100106	100106
1-29								100106	100106
1-30								100106	100106
1-31								100106	100106
2-1								100106	99106
2-2								100106	100108
2-3								100106	100108
2-4								100106	100108
2-5								100106	100108
2-6								100106	100108
2-7								100106	100108
2-8								100106	100108
2-9								100106	100108
2-10								100106	100108
2-11								100106	100108
2-12								100106	100108
2-13								100106	100108
2-14								100106	100108
2-15								100106	100108
2-16								100106	100108
2-17								100106	100108
2-18								100106	100108
2-19								100106	100108
2-20								100106	100108

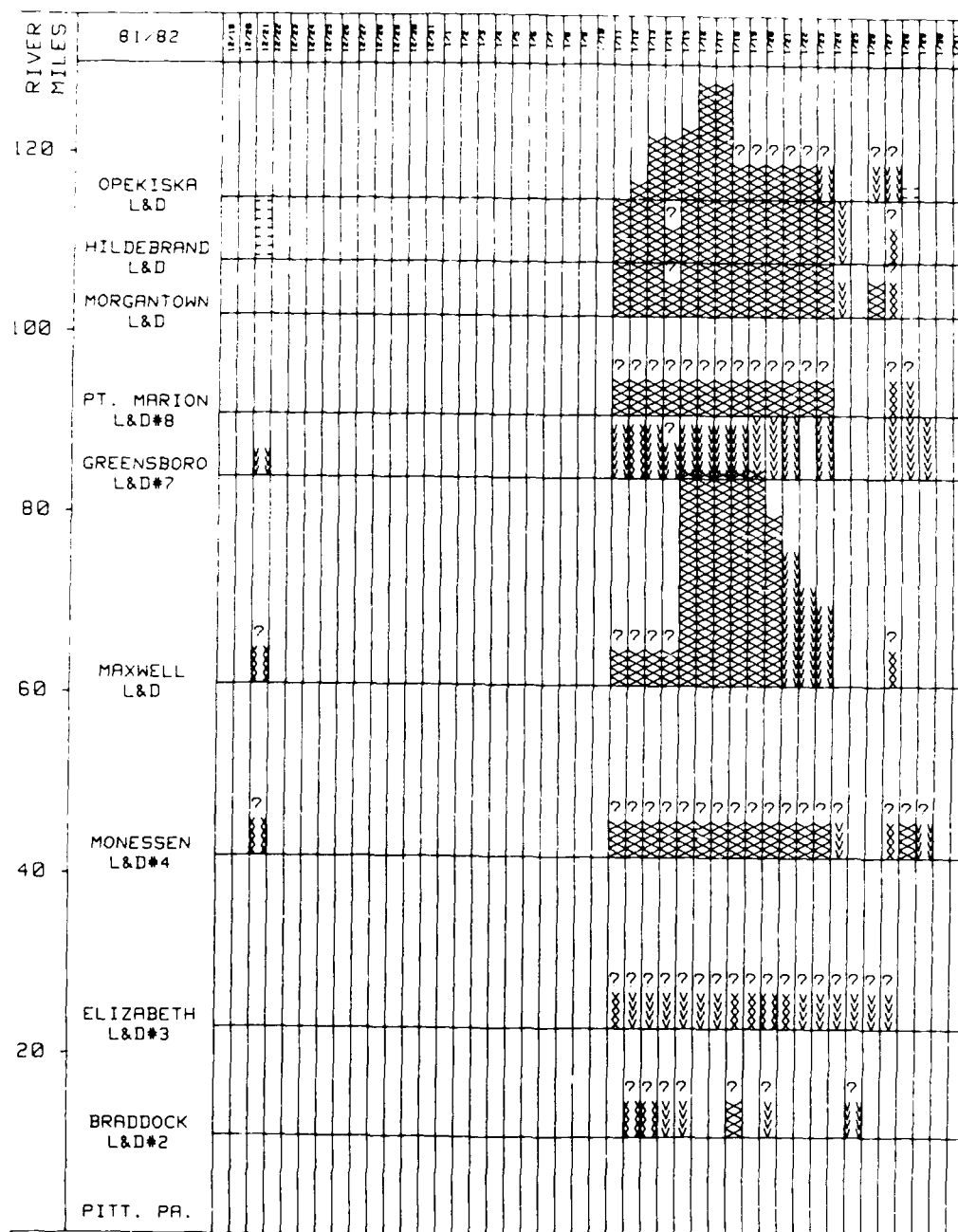


Figure A10.

DATE	SPROCKLY	ELIZBETH	WYNESSEN	WAMLELL	GRNSBORO	FL. MAR	MORANTOWN	WILSBAND	DEKESKA
12/19									
12/20									
12/21			771XX	771XX	781XZ			551X5	
12/22									
12/23									
12/24									
12/25									
12/26									
12/27									
12/28									
12/29									
12/30									
12/31									
1/1									
1/2									
1/3									
1/4									
1/5									
1/6									
1/7									
1/8									
1/9									
1/10									
1/11		1A2XX	10A1XX	10A1XX	9A1X5	10A1XX	10A1X5	10A1X6	
1/12	9P3XX	1A2CX	10A2CX	10A2CX	9A1L5	10A2CX	10A2C5	10A1C6	10A1H1
1/13	9P3XX	1A1XX	10A2XX	10A2XX	9A1X5	10A2XX	10A2X5	10A2X6	10A1X6
1/14	9P3BX	2A1BX	10A3CX	10A2CX	9A1BX	10A2CX	10A2CX	10A3CX	10A1C6
1/15	1A3XX	3A1BX	10A3LX	10A2LZ3	9A2B5	10A3CX	10A2C5	10A2C6	10A2C7
1/16		3A1XX	10A3XX	10A2LZ3	9A2B5	10A4CX	10A2C5	10A3C6	10A2C12
1/17		3A3XX	10A4XX	10A4XZ3	9A2X5	10A5XX	10A4X5	10A3X6	10A3X12
1/18	10A3CX	3A3BX	10A5LX	10A4LZ3	7A2B5	10A6CX	10A4C5	10A4C6	10A3CX
1/19		4A4XX	10A5XX	10A4XZ3	5A3X6	10A6XX	10A4X5	10A4X6	10A4XX
1/20	2A3LX	6P3XX	10A5LX	10A4L18	3A3B6	10A6CX	10A4C5	10A4C6	10A4CX
1/21		4A2XX	10A5XX	9A4X14	9A3X6	10A4XX	10A4X5	10A4X6	10A4XX
1/22		4A2XX	10A5XX	9A4X10		10A5XX	10A5X5	10A5X6	10A3XX
1/23		4A2XX	10A7XX	9A4XB	9A3X6	10A5XX	10A5X5	10A5X6	9A4XX
1/24		4A6XX	4A7XX				2A5X3	2A5X6	
1/25	5A3BX	1A3BX							
1/26		1A2XX					10A1X3		1A1XX
1/27		1A2BX	1A1BX	1A1BX	4A1B6	5A1CX	5A1CX	5A1CX	8A1CX
1/28			10A2XX		3A1X6	3A1XX			55111
1/29			7A2LX		1A1B6				
1/30									
1/31									

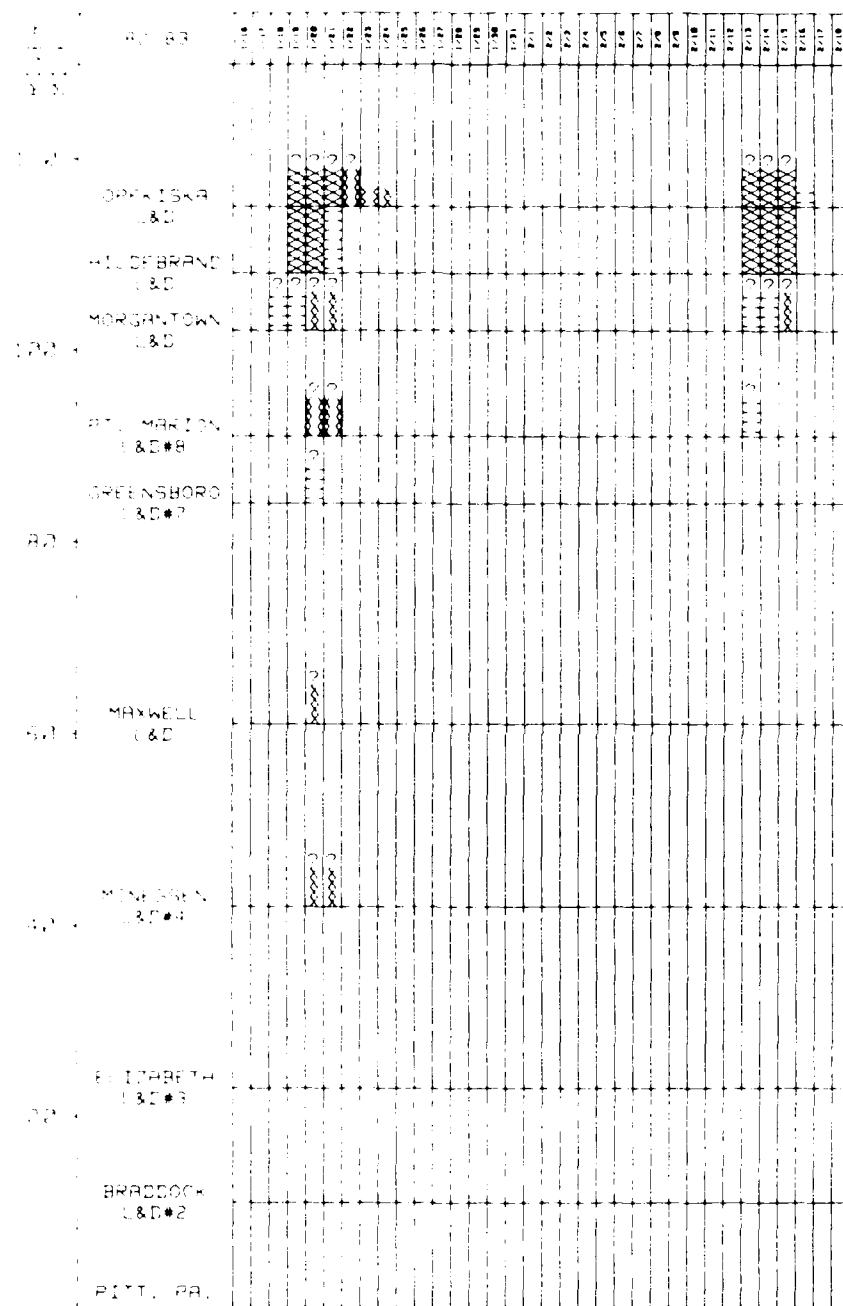


Figure A11.

	FRANKLIN	CLARK	MONTGOMERY	MAGILL	SEWERS	AL. MAR	MONTGOMERY	WILSON	DEKSTER
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									
35									
36									
37									
38									
39									
40									
41									
42									
43									
44									
45									
46									
47									
48									
49									
50									
51									
52									
53									
54									
55									
56									
57									
58									
59									
60									
61									
62									
63									
64									
65									
66									
67									
68									
69									
70									
71									
72									
73									
74									
75									
76									
77									
78									
79									
80									
81									
82									
83									
84									
85									
86									
87									
88									
89									
90									
91									
92									
93									
94									
95									
96									
97									
98									
99									
100									

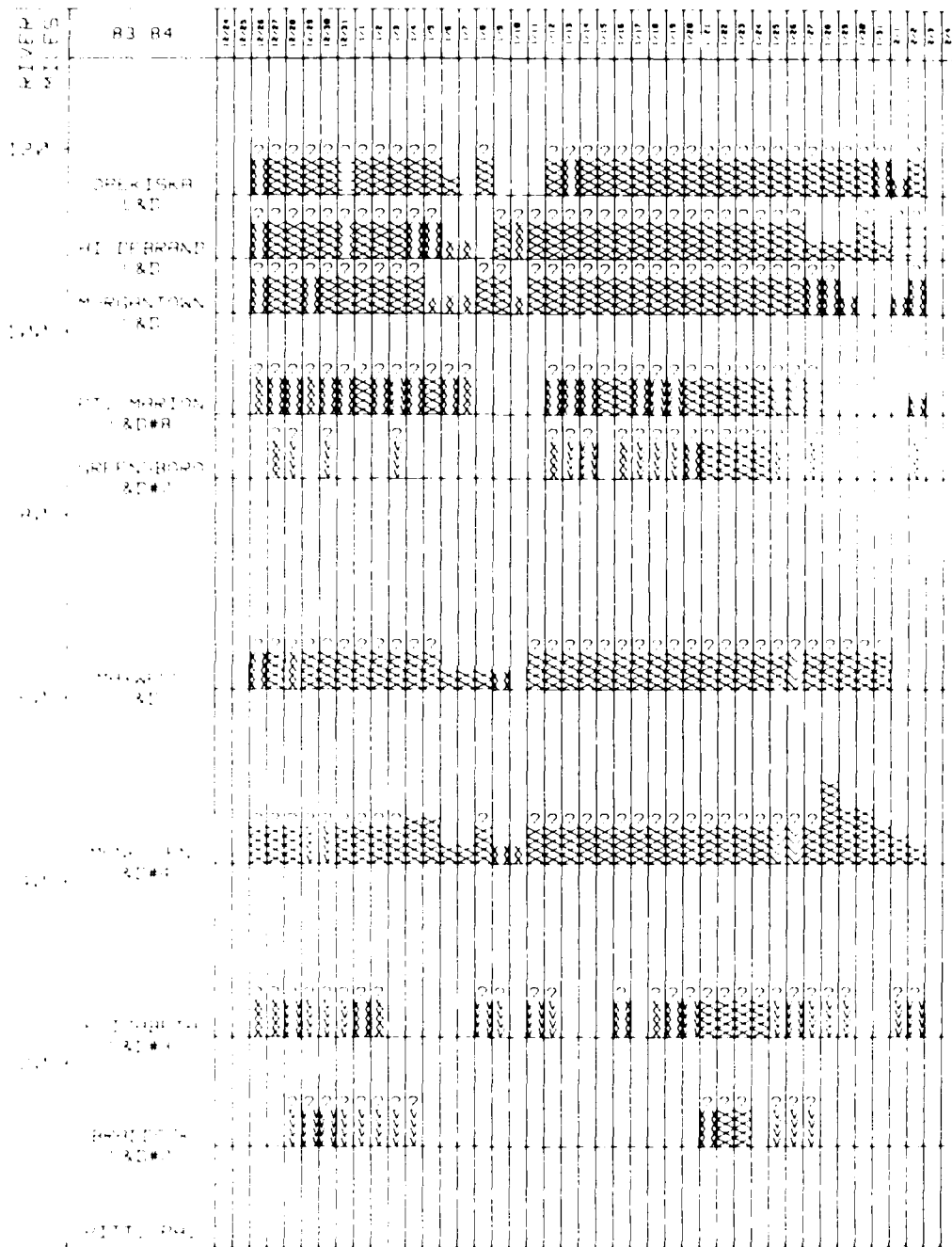


Figure A12.

DATE	BRADDOCK	CLUBBETH	MCNEESSEN	MAXWELL	DEWITT RD	PT. MAR	MCANTON	WLOPPANO	DEKESKA
1-24									
1-25									
1-26		AF10X	10F10X	AF10X		AF10X	AF10X	AF10X	AF10X
1-27		AF10X	10F10X	10F20X	AF10X	AF10X	10F10X	10F10X	10F10X
1-28	AF10X	AF10X	10F10X	AF10X	AF10X	AF10X	10F10X	10F10X	10F10X
1-29	BR10X	AF10X	AF10X	10F10X		AF10X	10F10X	10F10X	10F10X
1-30	BR10X	AF10X	AF10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X
1-31	AF10X	AF10X	10F10X	AF10X		AF10X	10F10X	6520X	10F10X
1-1	BR10X	BR10X	10F10X	10F10X		10F10X	10F10X	10F10X	10F10X
1-2	AF10X	AF10X	10F10X	10F10X		AF10X	10F10X	10F10X	10F10X
1-3	AF10X	AF10X	10F10X	10F10X		AF10X	10F10X	10F10X	10F10X
1-4	AF10X		10F10X	10F10X	AF10X	AF10X	10F10X	AF10X	10F10X
1-5			10F10X	10F10X		10F10X	AF10X	10F10X	10F10X
1-6			10F10X	10F10X		AF10X	AF10X	AF10X	10F10X
1-7			10F10X	10F10X		AF10X	AF10X	AF10X	10F10X
1-8		AF10X	10F10X	10F10X			10F10X		10F10X
1-9	AF10X	AF10X	AF10X	AF10X			10F10X	10F10X	
1-10			AF10X	AF10X			AF10X	AF10X	
1-11		AF10X	10F10X	10F10X			10F10X	10F10X	
1-12	AF10X	AF10X	10F10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X
1-13			10F10X	10F10X	AF10X	AF10X	10F10X	10F10X	AF10X
1-14			10F10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X
1-15			10F10X	10F10X		10F10X	10F10X	10F10X	10F10X
1-16	AF10X	10F10X	10F10X	AF10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-17		10F10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X	10F10X
1-18		AF10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X	10F10X
1-19	AF10X	10F10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X	10F10X
1-20	AF10X	10F10X	10F10X	AF10X	AF10X	10F10X	10F10X	10F10X	10F10X
1-21	AF10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-22	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-23	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-24		10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-25	AF10X	AF10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-26	BR10X	BR10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-27	AF10X	AF10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X	10F10X
1-28		AF10X	10F10X	10F10X		AF10X	10F10X	10F10X	10F10X
1-29		AF10X	10F10X	10F10X		AF10X	10F10X	10F10X	10F10X
1-30			10F10X	10F10X			10F10X	10F10X	10F10X
1-31			10F10X	10F10X			10F10X	10F10X	10F10X
2-1		AF10X	10F10X			AF10X	10F10X	10F10X	10F10X
2-2	AF10X	AF10X	10F10X		AF10X	AF10X	10F10X	10F10X	10F10X
2-3									
2-4									

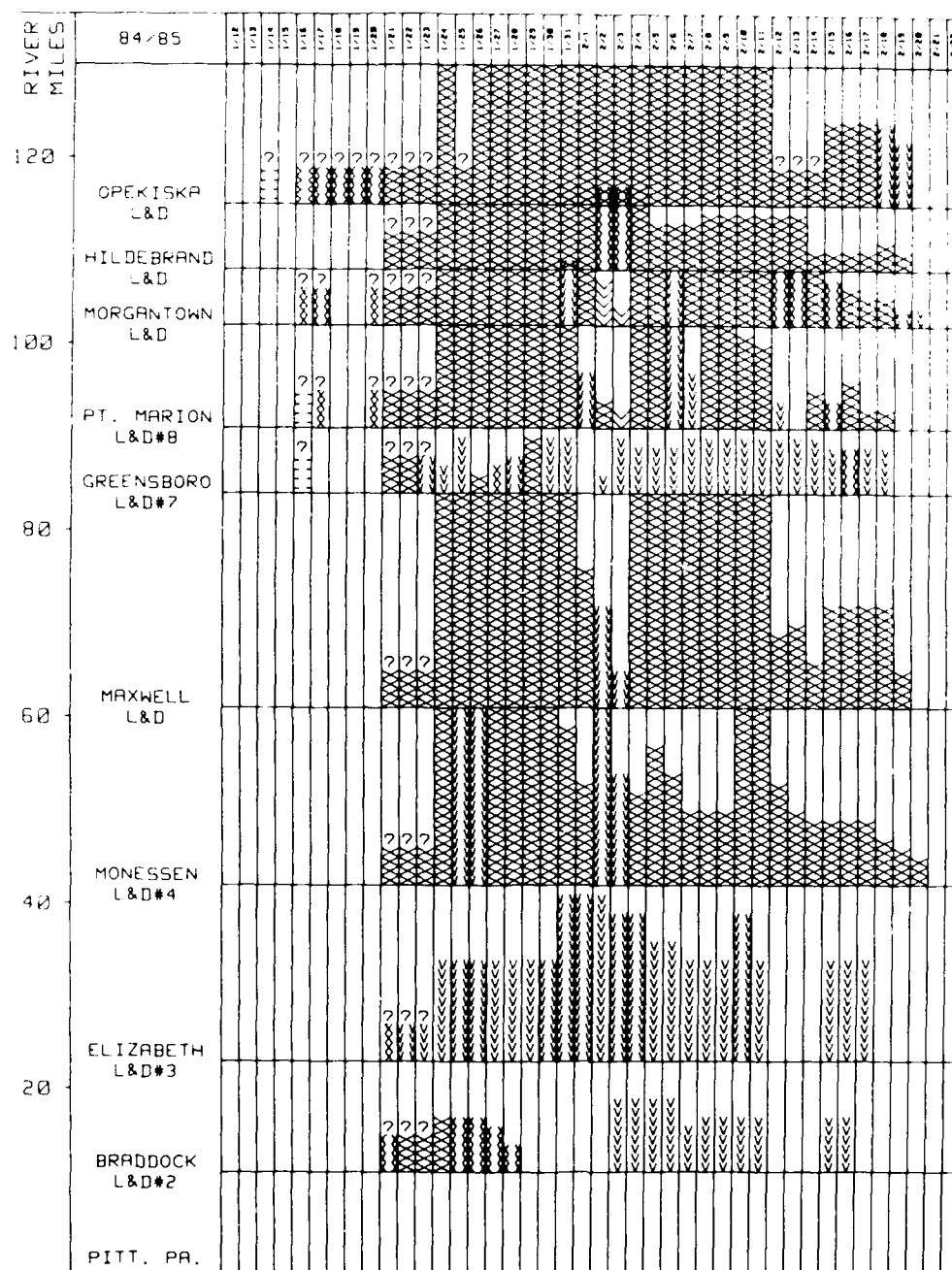


Figure A13.

DATE	BRADDOCK	ELIZABETH	HONESSLA	MARCELL	BRANDBORO	PI. MAR	MSANTOLIN	ALDERRAND	CHICKICKA
1-12									
1-13									
1-14									SSICK
1-15									
1-16					1010X	1010X	1010X		7010X
1-17						1010X	1010X		8010X
1-18									9010X
1-19									7010X
1-20						1010X	1010X		8010X
1-21	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-22	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-23	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-24	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-25	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-26	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-27	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-28	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-29	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-30	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
1-31	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-1	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-2	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-3	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-4	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-5	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-6	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-7	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-8	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-9	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-10	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-11	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-12	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-13	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-14	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-15	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-16	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-17	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-18	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-19	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-20	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-21	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X
2-22	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X	1010X

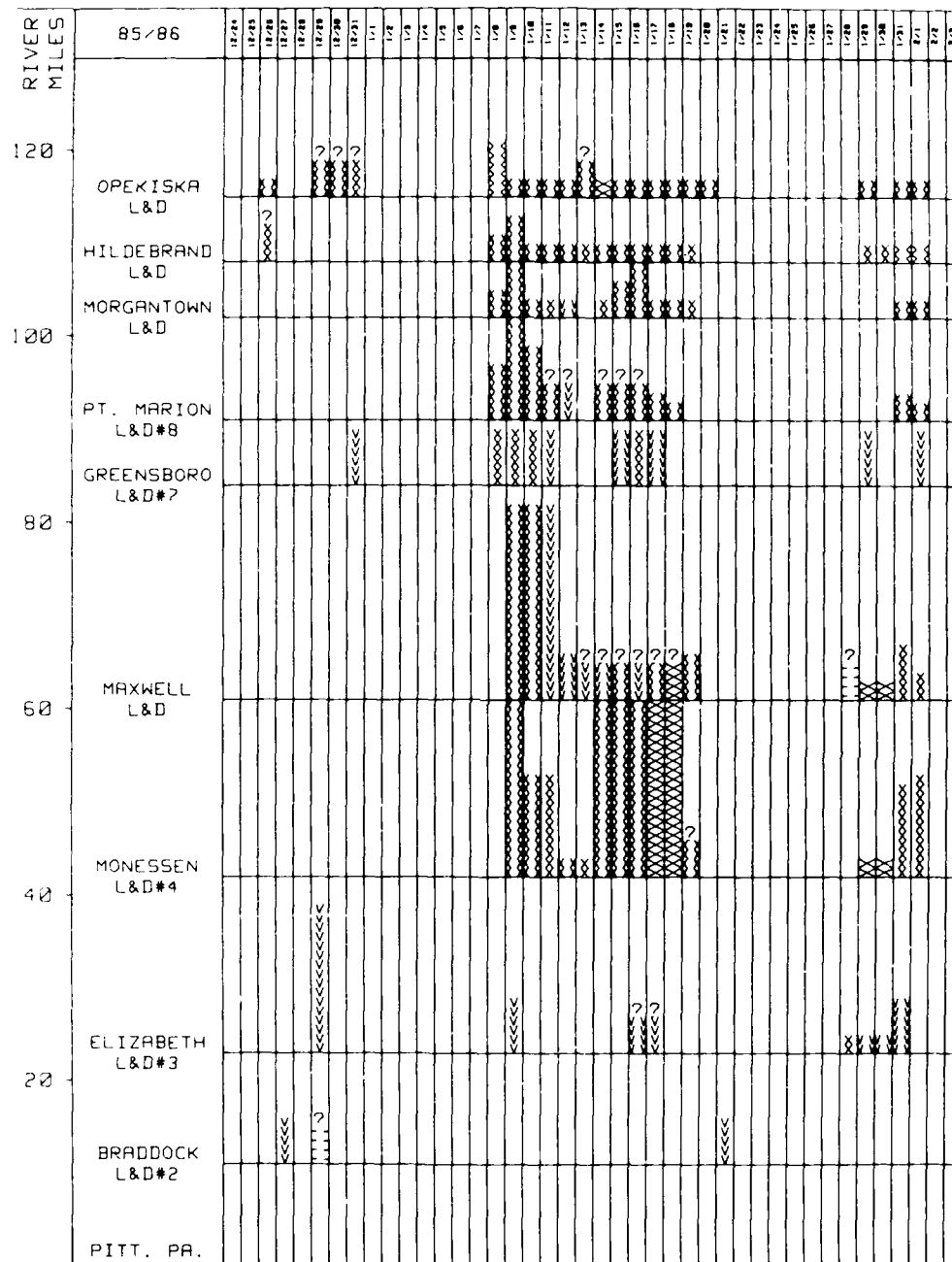


Figure A14.

DATE	BRADDOCK	ELLORETH	MONROE	MAYNELL	GRANBORD	PT. MAR	MSANTOWN	WLOBRAND	OPKISKA
12/24									
12/25									
12/26								SF1CX	9F1H1
12/27	3P1A								
12/28									
12/29	1P1A	OP1B1S							9F1CX
12/30									9F1CX
12/31					1P1B5				1F1CX
1/1									
1/2									
1/3									
1/4									
1/5									
1/6									
1/7									
1/8					1P1C5	7P1C5	7P1C2	8F1C2	9S1C5
1/9	1P1B5	9A1B1B	9A1B2D	9A1C5	9F1C1D	9F1C5	9F1C4	9A1C1	
1/10		9A1C1D	9A1B2D	9A1C5	9F1C2D	7P1C1	8F1C1	9A1C1	
1/11		9A1B1D	9A1B2D	1P1C5	9F1C2X	5F1C1	8F1C1	9A1C1	
1/12		9A2B1	9A1B4		3P1B1X	7P1C1	6F1C1	9A1B1	
1/13		4A2B1	3P1B1X				1F1C1	8A1B1X	
1/14		9A1B1B	9A1B1X		6F1B1X	2P1B1	9F1C1	10P1C1	
1/15		9A1B1B	9A1B1X	7P1C5	8F1B1X	7P1C3	9F1C1	9F1B1	
1/16	9A1B1X	9A2B1B	5P1B1X	5A1C5	9F1C1X	9F1C5	9F1C1	9F2C1	
1/17	3P1B1X	10A1C1B	9P1B1X	9A1C5	9F1C2	9F1C1	9F1C1	9F2C1	
1/18		10P1C1B	10P1B1X		9F1C1	8F1C1	8F1C1	9F2C1	
1/19		9P1C1X	9P1B1X			5F1C1	5F1C1	6F1H1	
1/20								6F1H1	
1/21	1P31A								
1/22									
1/23									
1/24									
1/25									
1/26									
1/27									
1/28	1P1B1		1S1B1X						
1/29	9A1B1	10P1C1	10P1B1	1P1H5			4F1C1	8F1C1	
1/30	9A1B1	10P1L1	10P1B1				5F1C1		
1/31	9A1B5	1P1L9	1P1C5		6F1C2	7P1C1	7S1C1	8F1C1	
2/1		1P1L10	5P1L2	3P1H5	7P1C1	8F1C1	7S1C1	8F1C1	
2/2									
2/3									