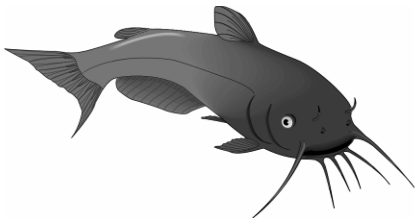
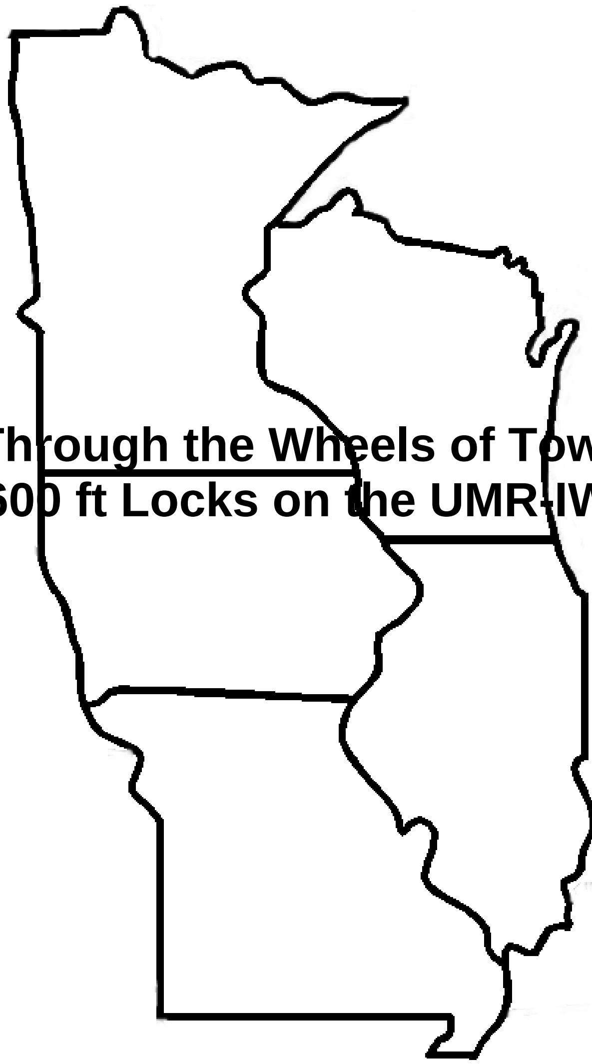
ENV Report 59

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





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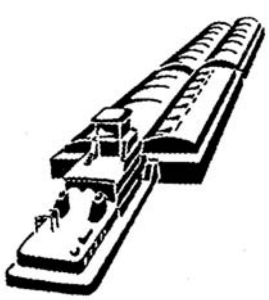

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US Army Corps of Engineers®

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Upper Mississippi River - Illinois Waterway System Navigation Study

ENV Report 59
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Flow Through the Wheels of Towboats in 600 ft Locks on the UMR-IWW

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Interim report

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ABSTRACT: Due to tow length being greater than lock length for most tows on the Upper Mississippi River System, tows must break in half and use two lockages to pass through the lock. A double lockage requires the towboat to use propeller thrust for a considerable amount of time while in the lock chamber. Entrainment of fish into the propeller jet and mortality is a concern of the U. S. Army Corps of Engineers (USACE). To address concerns about fish mortality, one component in the evaluation is the amount of flow through the wheels of the towboats during lock passage. A field study was conducted to evaluate towboat operation during the double lockage. Duration and propeller speed were recorded for tows passing through the lock. The average upbound unloaded tow from the field study passed 49 percent of the water volume of the lock through the wheels. The average downbound loaded tow from the field study passed 228 percent of the water volume of the lock through the wheels. These results are limited to relatively low flow conditions on the river. Data are needed for higher flows as well as for upbound loaded and downbound unloaded tows.

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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 system 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), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The work was conducted under the direction of Mr. Thomas A. Richardson, Director, CHL. This report was written by Dr. Stephen T. Maynord CHL. Permission was granted by the Chief of Engineers to publish this document.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston. COL James R. Rowan was Commander, ERDC.

1 Introduction

The Upper Mississippi River-Illinois Waterway (UMR-IWW) System Navigation (Feasibility) Study (U.S. Army Corps of Engineers 1994) is currently evaluating capital investment planning for the UMR-IWW for the years 2000-2050. The study is evaluating the justification for providing additional lockage capacity on the UMR-IWW. If lockage capacity is increased, frequency of tow passage on the UMR-IWW is expected to increase. Increased commercial navigation traffic subjects organisms using the waterway to an increased frequency of potentially damaging physical forces caused by tow traffic.

To address concerns about fish mortality from tows in lock chambers, the flow through the wheels of the towboats during lock passage was a necessary aspect of the evaluation. It should be noted that many marine vessels have propellers but they are referred to as “wheels” on towboats.

2 Description of Double Lockage Procedure

Most tows on the UMR-IWW consist of 15 or 16 barges plus the towboat and have dimensions of about 343 m (1125 ft) long by 32 m (105 ft) wide. Loaded tows generally have 15 barges in front of the towboat in a 3 wide by 5 long configuration. Unloaded tows have the same configuration of 15 barges in front of the towboat and frequently have one additional empty barge alongside the towboat. With the exception of non-standard size chemical barges, individual barges are 59.5 m long (195 ft) by 10.7 m (35 ft) wide. With the exception of Lock 27, Melvin Price Lock, and Lock 19, all of which have usable lengths of 366 m (1200 ft), locks on the UMR-IWW have a usable length of about 183 m (600 ft). Locking through the 183 m (600 ft) locks requires a double lockage after the tow is broken in half. Figure 1 shows a schematic of the various stages of a double lockage of a typical 15 barge tow.

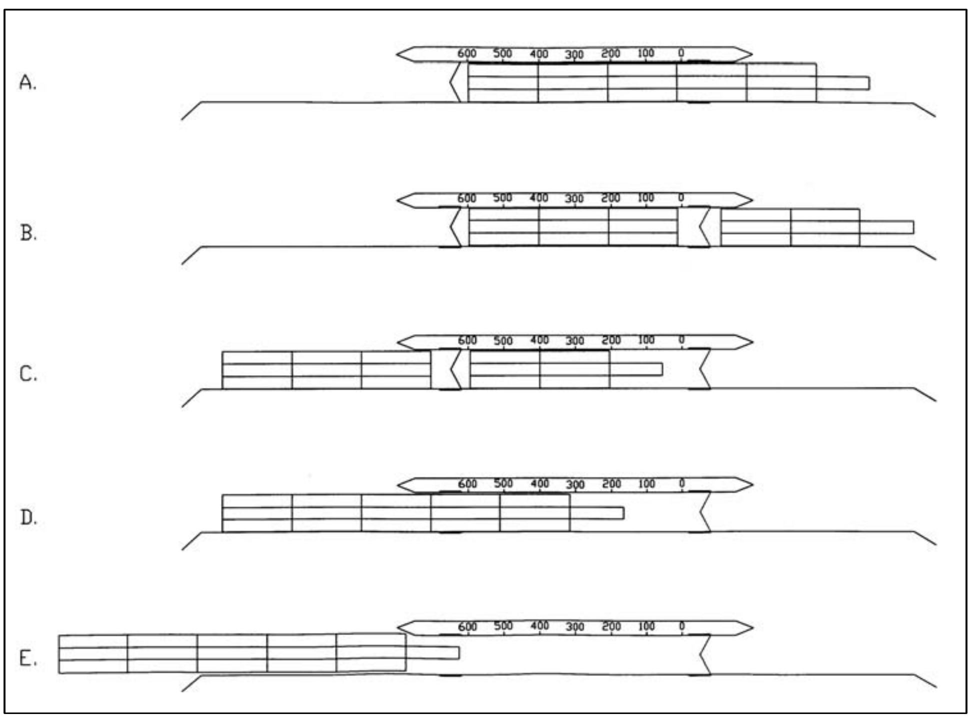

Figure 1. Schematic of double lockage procedure

The figure shows an upbound tow but the stages are the same for a downbound tow. Stages are as follows:

Stage A: The tow pushes into lock at less than walking speed. Only small amounts of thrust are used by the towboat. The towboat is not yet in the lock, so there is no mortality of fish in the lock from the towboat wheels.

Stage B: The tow is broken into halves, with nine barges in the front half (called "first cut") and six or seven barges plus the towboat in the back half (called "second cut"). The first cut is secured with mooring lines in the lock, and the second cut backs out so that the lower miter gates can be closed. The second cut is also secured with mooring lines to the lower or downstream lock approach wall. The lock is then filled. At no time during stage B are the towboat wheels in the lock, so there is mortality in the lock from the wheels.

Stage C: The upper miter gates are opened and a cable is used to pull the first cut upstream of the upper miter gates. The first cut is secured with mooring lines to the upper or upstream lock approach wall with the stern of the first cut just upstream of the upper miter gates. The upper miter gates are closed, the lock is emptied, and the lower miter gates are opened. The second cut pushes into the lock at less than walking speed. In the majority of cases, by the time the towboat wheels pass the miter gates and thus enter the lock, the tow is coasting or beginning to exert a small amount of reverse thrust to stop the tow. This is the first time the wheels of the towboat have the potential to cause mortality of fish in the lock. Both the thrust and the duration of wheel rotation are low in this stage of the lockage. The second cut is then secured in the lock with mooring lines, and the lock is filled.

Stage D: The upper miter gates are opened and the second cut moves at a creeping pace toward the first cut. Deck hands are standing at the stern of the first cut and/or the bow of the second cut ready to lash the two cuts back together. After the two cuts are touching but not lashed, the towboat exerts enough thrust to keep the two cuts tightly together and stationary while the deck hands lash the two cuts back together. The mooring lines on the first cut keep the tow from moving upstream. During the lashing of the tow back together, the thrust on the wheels is not large, but the duration can be 30 minutes or more depending on various factors including experience of the crew and the types of devices available to tension the lashings on the barges. The amount of thrust during the relashing depends on the draft of the tow and the flow in the river, particularly for upbound tows. The bow of the upbound tow is subjected to river flow-induced forces which will increase as draft and river flow increase. To keep the mooring lines tight on the first cut, the towboat will have to increase thrust as draft and flow increase.

Stage E: The tow exits the lock. As in Stage D, the amount of thrust will depend on upstream and downstream conditions and the draft of the tow. Speed of exit will often exceed walking speed in order for the tow to deal with adverse conditions such as outdraft for upbound tows. While downbound exits are generally expected to require less thrust than upbound exiting tows going into the flow, Lock 25 (evaluated in this study) required tows to exert a large amount of thrust during downbound exit. The duration of the exit is generally 4 minutes or less.

Summarizing tow effects on mortality of fish in locks, only stages C, D, and E have potential for mortality, with stages D and E being the stages having the greatest thrust and/or duration.

3 Lock and Dam Field Study

A field evaluation of tow operating characteristics through Lock and Dam 25 was conducted from 14-16 April 2003. During this same period, biologists from the US Army Engineer District, St Louis were conducting sampling of the lock after each tow passage to identify fish mortality. The objective of the field evaluation of tow operating characteristics was to determine the amount of water that passes through the wheels of the towboat during passage through the lock. During the field evaluation, each towboat captain was contacted by radio to explain the study and the needed data for the towboat and the passage through the lock. Table 1 shows the towboat characteristics for the eight tows monitored during the field study.

Table 1
Tow Characteristics in Lock 25 Field Study

Towboat	Owner	Date	Time	Direction	Loads/Empties
Greg Minton	Marquette	4/14/03	1941	up	0/16
Mary K Eckstein	Marquette	4/15/03	0817	up	0/16
Roberta Tabor	ARTCO	4/15/03	1115	down	15/0
James Ermer	ACBL	4/15/03	1446	down	15/0
Cooperative Vanguard	ARTCO	4/15/03	1800	down	15/0
Afton	ACBL	4/16/03	0745	down	14/1
Arnold Sobel	ACBL	4/16/03	1030	down	15/0
Show Me State	Marquette	4/16/03	1400	down	15/0

The operating characteristics of each tow while transiting the lock are shown in Table 2. For the purposes of this study, stage E ends when the stern of the towboat passes over the miter gate sill.

Table 2
Tow Operating Characteristics during Passage through Lock

Towboat	Stage C		Stage D		Stage E	
	Time, sec	**RPM***	**Time, sec**	**RPM***	**Time, sec**	**RPM***
Greg Minton	90 30	S=95 P=95	30 960 90	S=P=95 S=80 S=75	60 30	S=P=80 S=80
Mary K. Eckstein	60	P=81	30 600 30	P=80 S=79 P=80	60	P=130& S=86
Roberta Tabor	60	S=87	45 60 30 15 60 60 480	86/82 P=86 P=86 S=82 P=86 86/82 P=86	180 105 30	86/82 150/150 208/208
James Ermer	240	P=89	60 630	89/89 S=89	375 30	89/89 130/130
Cooperative Vanguard	35	P=90	75 75 15 15 15 35 630	90/90 100/100 P=100 100/100 P=100 100/100 88/79	45 60 195 30 ** 30 180 60 15	P=85 85/85 119/114 85/85 ** 150/150 119/114 S=114 172/172
Afton			195 45 900 45	P=100 100/100 100/100 S=100	60 75 150	125/125 150/150 225/225
Arnold Sobel			105 1005 15 30	P=85 P=85 P=63 P=72	390	85/82
Show Me State	30	85/100	30 30 20 615	P=84 P=84 84/98 P=84	15 180 15	84/84 120/120 S=84

P= port
S=starboard
****** The designated times and wheel speeds for Cooperative Vanguard, Stage E, were different from all other tows. About 25-50 ft prior to passing over the lower sill, the Cooperative Vanguard reversed engines and started maneuvering to get the bow of the tow off the lower guide wall. All other tows passed over the sill before starting this maneuvering.

4 Discharge and Volume Through Propeller Jets

The discharge through a single propeller jet Q_p for a maneuvering tow or slow moving tow is given in Maynord (1999) as:

$$Q_p = 0.89\, n\, D^3 \sqrt{\frac{K_t}{z}} \tag{1}$$

where n = wheel speed in revolutions/sec, D is the wheel or propeller diameter, K_t = thrust coefficient at zero speed of advance, and z = 1 for Kort nozzles and 2 for open wheels. All of the towboats passing Lock 25 in the field study had 5 bladed wheels. Table 3 shows other wheel characteristics that were obtained from the towboat companies except for the thrust coefficient K_t.

Table 3
Wheel Characteristics

Towboat	Wheel Diameter, m	Pitch, m	Open/Kort	Power, hp	K_t
Greg Minton	2.74	2.85	Kort	6000	0.52
Mary K Eckstein	3.00	2.92	Kort	7200	0.48
Roberta Tabor	2.76	2.85	Kort	6000	0.52
James Ermer	2.79	2.67	Kort	6200	0.47
Cooperative Vanguard	2.59	2.36	Open	3800	0.39
Afton	2.54	2.29	Open	4200	0.385
Arnold Sobel	2.90	2.93	Kort	6000	0.51
Show Me State	2.74	2.85	Kort	6140	0.52

Table 3 also shows the thrust coefficient used for each towboat that depends on several factors not available for the field study tows including nozzle design and blade area ratio. The ratio of wheel pitch to diameter is a key parameter and was used in determining K_t. The open water test results in Van Manen (no date given) for Kort nozzle and open wheels were used to determine K_t, given in Table 3, based on a B4-55 propeller. Equation 1 was used with wheel speed and duration (Table 2) and wheel characteristics (Table 3) to determine the volume through the wheels for stages C, D, and E as shown in Table 4.

Table 4
Volume through Propellers during Passage through Lock

Towboat	Volume Through Propellers, m^3 (ft^3)		
	Stage C	Stage D	Stage E
Greg Minton	2519 (88895)	19722 (695947)	2652 (93572)
Mary K Eckstein	1346 (47490)	14438 (509486)	3589 (126638)
Roberta Tabor	1170 (41272)	16368 (577571)	16630 (586821)
James Ermer	4741 (167310)	14817 (522845)	15682 (553393)
Cooperative Vanguard	359 (12671)	16724 (590165)	7360 (259703); 7195 (253910)
Afton	No data	22734 (802213)	11207 (395457)
Arnold Sobel	No data	25083 (885113)	16763 (591528)
Show Me State	1226 (43277)	13334 (470513)	10381 (366336)

Results in Table 4 show that Stages D and E are the dominant stages concerning volume through wheels of towboats. Stage C shows considerable variability and averages 1894 m^3 per tow passage. Stage D shows less variability and averages 17903 m^3. Stage E shows a difference between the two upbound unloaded tows which averaged 3121 m^3 and the six downbound loaded tows which averaged 14203 m^3.

For Lock 25, the total lock volume at the lower pool elevation of 419 with a lock floor elevation of 405 is (600/3.28)*(110/3.28)*((419-405)/3.28) = 26185 m^3. The total lock volume at the upper pool elevation of 434 is (600/3.28)*(110/3.28)*((434-405)/3.28) = 54240 m^3. With a six-barge loaded second cut in the chamber, the water volume in the chamber at lower pool is 26185 – (390*105*9+140*38*8.5)/(3.28^3) = 14459 m^3. With a 6 barge loaded 2nd cut in the chamber, the water volume in the chamber at upper pool is 54240 – (390*105*9+140*38*8.5)/(3.28^3) = 42514 m^3. With a 6 barge unloaded 2nd cut in the chamber, the water volume in the chamber at lower pool is 26185 – (390*105*2+140*38*8.5)/(3.28^3) = 22582 m^3. With a six-barge unloaded second cut in the chamber, the water volume in the chamber at upper pool is 54240 – (390*105*2+140*38*8.5)/(3.28^3) = 50638 m^3.

During Stage C for an upbound unloaded tow that occurs at lower pool, the average tow in the field study is passing 9 percent of the water volume through the wheels. During Stage C for a downbound loaded tow that occurs at upper pool, the average tow in the field study is passing 4 percent of the water volume through the wheels. During Stage D for an upbound unloaded tow that occurs at upper pool, the average tow in the field study is passing 34 percent of the water volume through the wheels. During Stage D for a downbound loaded tow that occurs at lower pool, the average tow in the field study is passing 126 percent of the water volume through the wheels. During Stage E for upbound unloaded tows that occur at the upper pool elevation, the average tow from the field study is passing 6 percent of the water volume through the wheels. During Stage E for downbound loaded tows that occur at the lower pool elevation, the average tow from the field study is passing 98 percent of the water volume through the wheels.

Combining all three stages, the average upbound unloaded tow from the field study passed 49 percent of the water volume through the wheels. The average downbound loaded tow from the field study passed 228 percent of the water volume through the wheels.

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14. ABSTRACT

Due to tow length being greater than lock length for most tows on the Upper Mississippi River System, tows must break in half and use two lockages to pass through the lock. A double lockage requires the towboat to use propeller thrust for a considerable amount of time while in the lock chamber. Entrainment of fish into the propeller jet and mortality is a concern of the U. S. Army Corps of Engineers (USACE). To address concerns about fish mortality, one component in the evaluation is the amount of flow through the wheels of the towboats during lock passage. A field study was conducted to evaluate towboat operation during the double lockage. Duration and propeller speed were recorded for tows passing through the lock. The average upbound unloaded tow from the field study passed 49 percent of the water volume of the lock through the wheels. The average downbound loaded tow from the field study passed 228 percent of the water volume of the lock through the wheels. These results are limited to relatively low flow conditions on the river. Data are needed for higher flows as well as for upbound loaded and downbound unloaded tows.

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