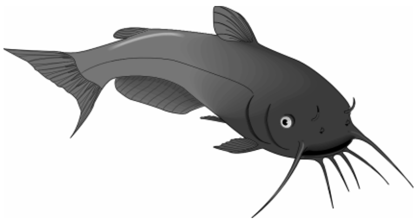
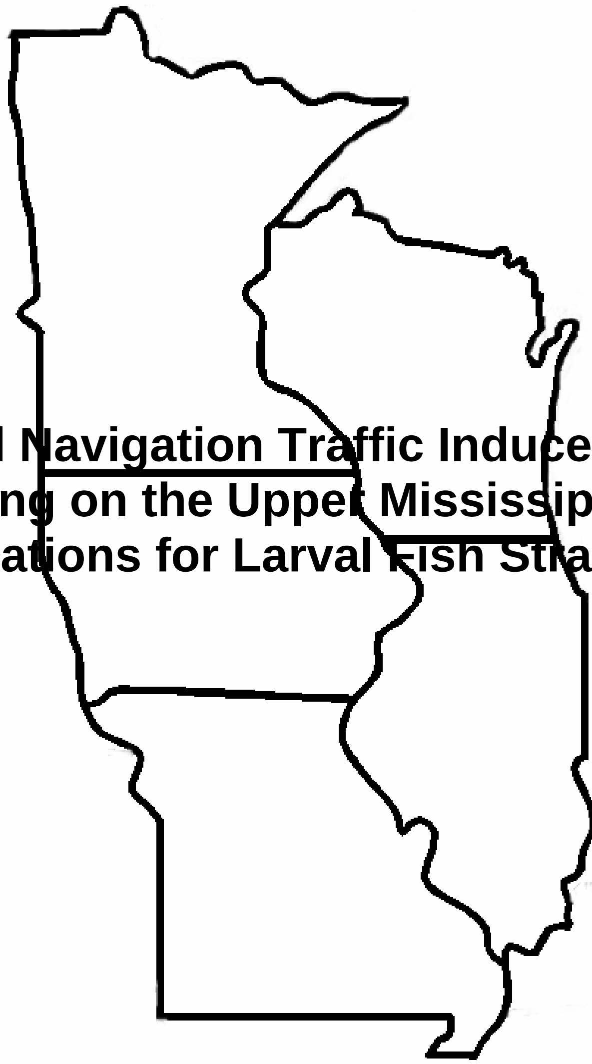
ENV Report 55

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





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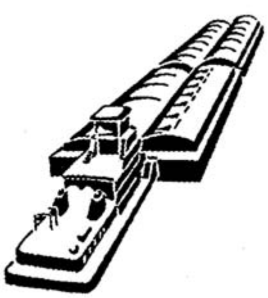

US Army Corps of Engineers®

June 2005

Rock Island District
St. Louis District
St. Paul District

Upper Mississippi River - Illinois Waterway
System Navigation Study

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Commercial Navigation Traffic Induced Shoreline Dewatering on the Upper Mississippi River: Implications for Larval Fish Stranding

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Interim report

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ABSTRACT: Commercial vessel passage may strand young fishes during drawdown and subsequent dewatering of the littoral zone. In order to determine the potential magnitude of impact, the area of shoreline dewatered by the movement of commercial navigation traffic was calculated for a typical year for pools 4, 8, 13 and 26 of the Upper Mississippi River for March through August, the period when larval fish would be expected. During May and June — the peak larval fish density and species diversity months — the width of the dewatering zone ranges from less than 0.03 m (Pool 26, May) to 0.28 m (Pool 8, June) for 50 percent of tow passages and from less than 0.05 m (Pool 26, May) to 0.53 m (Pool 8, June) for 90 percent of tow passages. With the exception of Pool 8, the average width of dewatered shoreline during May and June is less than 0.20 m for 50 percent of tow passages and less than 0.39 m for 90 percent of tow passages. The average width of the area exposed, or dewatered, decreased in a downstream direction as the channel becomes larger. The number of times the shoreline zone is dewatered depends on traffic levels that tend to increase in a downstream direction. Larval fish mortality could occur if larvae remained in the narrow dewatering zone for multiple drawdown events. However, littoral species display behavioral responses to drawdown that would minimize repeated strandings.

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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 report 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, 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 Upper Mississippi River and Illinois Waterway to reduce delays to commercial navigation traffic. The study will determine the location and appropriate sequencing of potential navigation improvements in 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 that is the decision document for processing to Congress.

This study was conducted in the Coastal and Hydraulics Laboratory (CHL) and Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The work was conducted under the direction of Mr. Thomas A. Richardson, Director, CHL.

This report was written by Dr. Stephen T. Maynord, CHL, and Dr. Thomas M. Keevin, Environmental Analysis Branch, U.S. Army Engineer District, St. Louis. Dr. Sandra K. Knight (ERDC-CHL-MS) and Dr. Mark Farr (ERDC-EL-MS) reviewed a draft of this paper. This study was funded by the U.S. Army Engineer District, St. Louis, through the Upper Mississippi River-Illinois Waterway System Navigation Study. Permission to publish this document was granted by the Chief of Engineers.

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

1 Introduction

Commercial vessel passage may strand young fishes during drawdown and subsequent dewatering of littoral areas (Holland and Sylvester 1983; Nielsen et al. 1986), but actual field observations of stranding are sparse. In laboratory studies, Holland (1987) evaluated the effects of experimental dewatering on eggs and larvae of walleye (*Stizostedion vitreum*) and northern pike (*Esox lucius*). Eggs and larvae were exposed to air for 2 minute durations at exposure intervals of 1, 3, 6, or 12 hrs (representing 2-24 tows/day) from the time just after fertilization to 10-14 days posthatch. Dewatering (2 min air exposure) did not cause mortality of eggs of walleye or northern pike, but significant mortality of larvae of both species occurred at dewatering frequencies of 1 and 3 hrs, the latter being equivalent to passage of eight tows per day.

During passage of commercial navigation traffic or any large displacement vessel in a navigation channel, drawdown of the water surface occurs between the vessel and the shoreline. The magnitude of drawdown depends on vessel speed, submerged cross-sectional area of the vessel, and channel cross-section. Shallow and restricted channels increase drawdown because flow in restricted channels is accelerated more than flow in unrestricted channels. If a vessel travels close to the riverbank, drawdown will be higher in the region between the vessel and bank than it would have been if the vessel were in the middle of the channel (Bouwmeester et al. 1977).

As commercial navigation vessels (towboats and barges) move forward, they push water; this motion then accelerates beside and beneath the barge. At the same time, it leaves an open space behind, momentarily causing water to flow from all directions to fill the void. The propellers of the vessel also bring water from beneath the vessel. All these conditions cause acceleration of the water in the vicinity of the vessel. As the water accelerates, the pressure decreases. The kinetic energy of the water increases as its potential energy decreases. The decreases in potential energy and pressure manifest themselves in decreased water levels. The associated drop in the vessel is known as *squat*. The reduction in water elevation is referred to as *drawdown* (Bhowmik et al. 1993). A schematic representation of the drawdown phenomenon is shown in Figure 1.

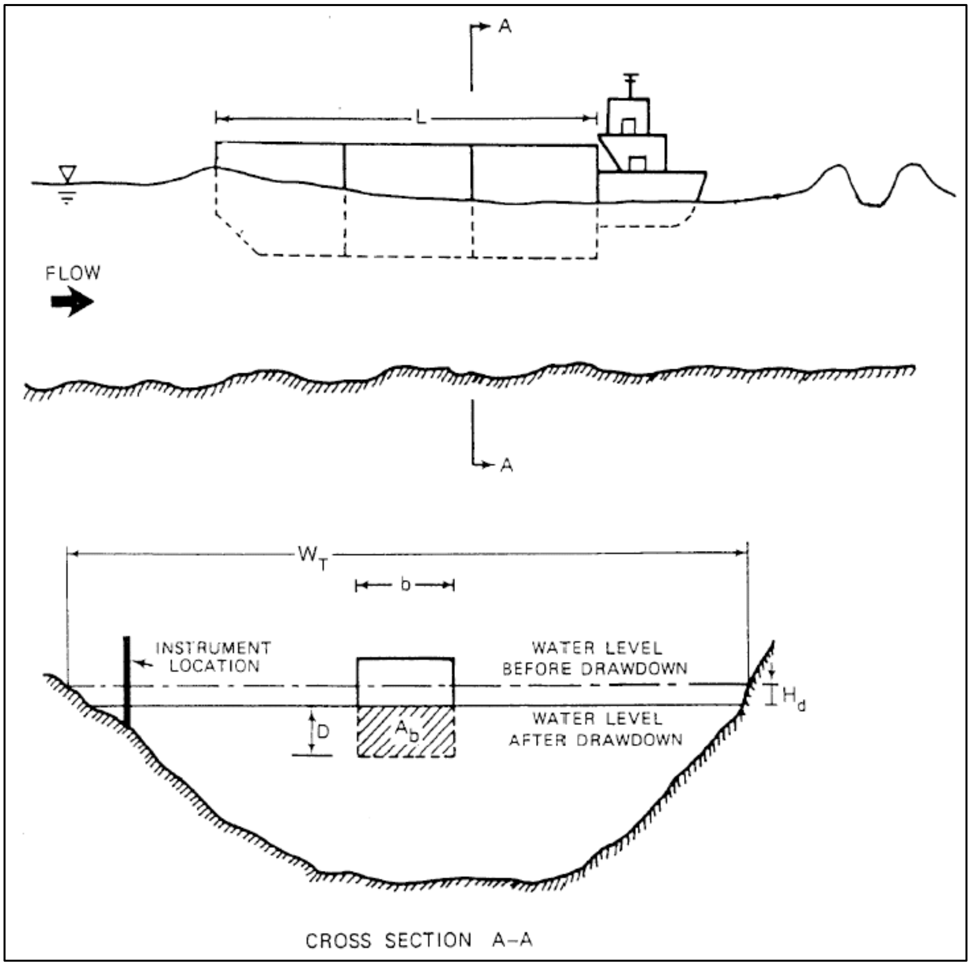

Figure 1. A schematic representation of the drawdown phenomenon, where D is the draft and W_T is the channel width. Beam, length, and submerged cross-sectional area of the vessel are represented by b, L, and A_b (Bhowmik et al. 1993)

Bhowmik et al. (1981) measured vertical drawdown for 27 tow passage events during 1980-1981 on the Mississippi and Illinois rivers. Drawdown elevations averaged 0.08 m (range 0.03-0.21 m) on the Illinois River for 19 events and 0.06 m (range 0.02-0.1 m) on the Mississippi River for 8 events. The drawdown resulting from vessel passage is followed by a rise in water level back to ambient levels. Typical rates of drawdown (vertical fall of water level per unit time) for channel sizes, tow sizes, and tow speeds found on the UMR are about 0.25-0.50 cm/sec. Higher speed tows closer to the shoreline produce values of around 0.75 cm/sec.

The objectives of this study were to quantify the shoreline width and total area exposed by drawdown created by commercial navigation traffic in pools 4, 8, 13 and 26 of the UMR during vessel passage and to evaluate the potential for larval fish stranding as a result of periodic dewatering based on existing literature.

2 Material and Methods

Calculation of Near Shore Bank Slope: Detailed near shore bank slope data were not available for the UMR. Depth at the center of 10 m wide cells that extend across the channel, measured at 0.5 mile cross section intervals along the UMR was available for a range of flows (Figure 2). Annual exceedance flows of 5, 50, and 95 percent were selected to represent a "typical" high, medium, and low flow for each month of the year in each pool. In order to define the probability of each flow for a given month, a duration analysis was used to define the percent of time that the high, medium, and low flow conditions occurred. The high flow (5 percent exceedance) was assumed to be representative of the upper 20 percent of the annual duration curve, and the low flow (95 percent exceedance) was assumed to be representative of the lower 20 percent of the annual duration curve. The balance of the year (60 percent) was represented by the 50 percent duration or median flow value. Data shown in Table 1 provide the monthly historical percentages of low, medium, and high flows on the UMR above the Missouri River confluence. A composite or representative depth representing each shoreline at each cross section for each month was determined using the percentages in Table 1 and the cell depths (depth at center of cell) for low, medium, and high flows. For example, a shoreline having low flow depth of 0.25 m, medium flow depth of 0.90 m, and high flow depth of 1.30 m would have a composite depth in the month of May of (0.032)(0.25) + (0.462)(0.90) + (0.507)(1.30) = 1.08 m. The area dewatered or exposed during drawdown occurs only in the last 10 m wide cell on each side of the channel. In this last cell, the depth at the cell edge at the shoreline was 0. At the center of the last 10 m wide cell, the depth was known; therefore, the average slope was equal to (depth at center) / (½ cell width). For the example cell above using the composite depth, the near bank average slope was 1.08/5.0 = 0.216, or expressed otherwise as 1V:4.6H.

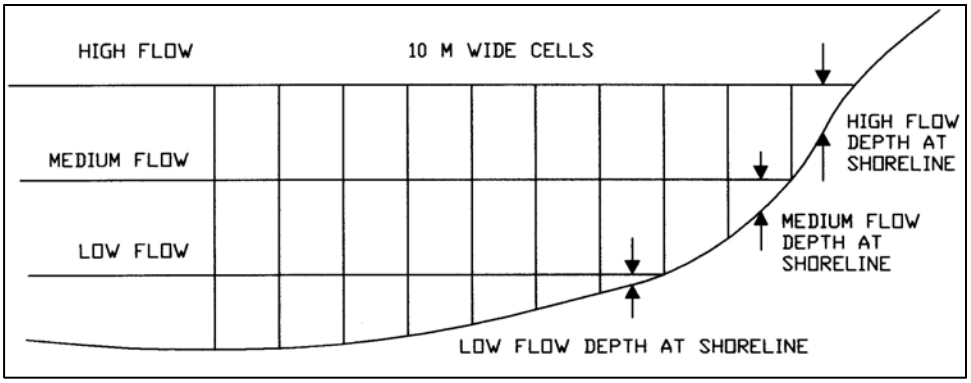

Figure 2. Low, medium and high flow depth at shoreline

Table 1
Percent of low, medium, and high flows on the Mississippi River above the Missouri River confluence, by month. Data based on evaluation of monthly records at 14 gages on the Upper Mississippi River, some of these gages having been in place for over 120 years.

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

Calculation of Shoreline Area Exposed: Each Trend Pool (4, 8, 13, and 26) of the UMR was evaluated for area exposed during vessel drawdown. Left, center, and right sailing lines were determined for each cross-section and represent 5, 90, and 5 percent probability of occurrence. Based on up- and downbound tow direction, 3 different speeds, 3 different tow sizes, 3 different drafts, and both open wheel and Kort nozzle propellers, 108 different tow configurations were evaluated on the UMR. Bartell et al. (2003) determined the probability of the 108 different tow configurations in each pool of the UMR. Vessel drawdown was calculated using the NAVEFF model (Maynord 1996, 1999) for 108 tow types, 3 water stages, and 3 sailing lines. Using the probability of the 108 tow types along with the probability of the 3 stages and 3 sailing lines, a fleet of 5,000 tows was randomly selected. A frequency table of drawdown was determined based on the 5,000 tow events. Use of 5,000 events was selected after trying various numbers of events (500, 1,000, 2,000, 5,000, 10,000) in the frequency table. A minimum of 5,000 events was required to provide a frequency table that did not vary significantly with the number of events selected. The frequency table was saved for each cell in the pool in the format shown in Table 2.

Table 2
Typical frequency table of water level drawdown from passage of commercial tows, Upper Mississippi River

Probability of exceedance[1]	Drawdown, m
1.0 [2]	0.003
0.9	0.014
0.8	0.022
0.7	0.028
0.6	0.037
0.5	0.043
0.4	0.055
0.3	0.066
0.2	0.072
0.1	0.091
0.0 [3]	0.178

[1] Probability that a single tow will produce drawdown exceeding the value shown.
[2] Minimum drawdown in 5,000 events
[3] Maximum drawdown in 5,000 events

The length of shoreline impacted was estimated by evaluating navigation charts for shoreline distance versus river miles. River mile distance along the pool provides the independent variable that is known from the river mile limits of each pool. For example, Pool 13 extends from River Mile 522.5 to 556.7, a distance of 34.2 miles. Shoreline distance is the unknown dependent variable that was measured on the navigation charts. The measurements showed that the shoreline distance was as low as 1.1 times the river mile distance and up to 1.6 times the river mile distance. The river mile multiplier was designated as α and a value of 1.5 was used to account for irregularities along the shoreline to define the total length of shoreline impacted. Cross-sections along the UMR are spaced at 0.5 mile intervals and each section is assumed to represent a reach 0.25 mile upstream and 0.25 mile downstream. The cross-section interval is designated as reach length (RL). The miles of shoreline impacted within a given pool becomes (RL) (# of cross-sections in a pool) (2 shorelines, left and right) (α). Areas were calculated for each bank of each cross section for a given percentage of exceedance of drawdown.

Drawdown on the opposite bank of a given cross section is calculated separately because the drawdown almost always differs on the two banks. Pool 4 calculations do not include Lake Pepin, which had very little drawdown at the shoreline due to the large cross section and large distance from the towboat. Shoreline area exposed is determined as:

- Shoreline area exposed = (α)(RL)(1610 m/mile)(drawdown)(bank slope) - (equation 1)

- Using the example bank slope of 1V:4.6H and a 50 percent probability of exceedance for the cell shown in Table 2 results in an area exposed on one bank over the 0.5 mile reach of (1.5)(0.5)(1610 m/mile)(0.043)(4.6) = 239 sq m.

3 Results

Using equation 1 on page 3, shoreline area exposed was determined for the left and right bank for each cross-section. Total shoreline area exposed was determined for each trend pool on the UMR as shown in Table 3 for 50 and 10 percent exceedance probability for March through August, the period when larval fish would be expected in the Mississippi River. The 10 percent exceedance probability means that only 10 percent of the tows will produce an effect that exceeds the stated value, and 90 percent of the tows will produce an effect that is less than the stated value. The number of times the shoreline zone is dewatered is not used in the area analysis and depends on traffic levels that tend to increase in a downstream direction. The width of the area exposed, or dewatered, was averaged over the length of the pool and decreased in a downstream direction as the channel becomes larger (Table 3). For example, in June, 90 percent of tow passages produced drawdown values of 0.53, 0.27, and 0.07 m for pools 8, 13, and 26, respectively. During May and June, the peak larval fish density and diversity months, the width of the dewatering zone ranges from less than 0.03 m (Pool 26, May) to 0.28 m (Pool 8, June) for 50 percent of tow passages and from less than 0.05 m (Pool 26, May) to 0.53 m (Pool 8, June) for 90 percent of tow passages. With the exception of Pool 8, the average width of dewatered shoreline during May and June is less than 0.20 m, for 50 percent of tow passages and less than 0.39 m for 90 percent of tow passages (Table 3). Average dewatered width is plotted in Figures 3 and 4 for probability of exceedance of 0.5 and 0.1, respectively.

For all Trend Pools, April had the lowest area of shoreline exposed followed by May (Table 3). August had the largest area of shoreline dewatered followed by July. The magnitude of shoreline width dewatered at each cross-section in a pool varies significantly around the average shoreline width shown in Table 3. For example, in Pool 8 in May for Pe = 0.1, the average dewatered width equals 0.491 m but dewatered width at all cross sections in pool 8 varies from 0.03 m to 5.3 m, strongly depending on (1) proximity of the sailing line to the shoreline and (2) the slope of the bank.

Table 3
Shoreline area and average width of shoreline exposed during water level drawdown from commercial tows, Upper Mississippi River, March - August, 50 and 10 percent probability of exceedance

Trend Pool	Pool River Miles	Miles of Shore in Pool	Area of shoreline exposed in pool during drawdown by passage of a single tow, sq m Average width of dewatering, m											
			March		April		May		June		July		August	
			P_e=0.5[1]	P_e=0.1	P_e=0.5	P_e=0.1	P_e=0.5	P_e=0.1	P_e=0.5	P_e=0.1	P_e=0.5	P_e=0.1	P_e=0.5	P_e=0.1
4[2]	753.0-764.5 and 785.5-796.5	70.5[3]	no navigation		16870 0.149	37910 0.334	19577 0.172	9303 0.346	23350 0.206	44162 0.389	21609 0.190	47989 0.423	31951 0.282	75196 0.663
8	679.5-702.0	69.0	36746 0.331	68803 0.619	24012 0.216	51052 0.460	26586 0.239	54592 0.491	30925 0.278	58321 0.525	30499 0.275	61272 0.552	34298 0.309	74569 0.671
13	523.0-556.5	102.0	22366 0.136	51452 0.313	21732 0.132	40024 0.244	23431 0.143	43747 0.266	25962 0.158	44918 0.274	26792 0.163	51602 0.314	43514 0.265	84031 0.512
26[4]	218.0-241.0	71.0	2950 0.026	6558 0.058	2330 0.021	4610 0.041	2644 0.023	5132 0.045	3266 0.029	6289 0.055	3916 0.035	7439 0.066	10753 0.095	20415 0.180
26	203.0-217.5	45.0	2394 0.033	5224 0.072	1740 0.024	3394 0.047	2046 0.028	3671 0.051	2517 0.035	4746 0.066	3038 0.042	5402 0.075	5858 0.081	10999 0.152

[1] percentage of tows exceeding this value of area exposed
[2] Pool 4 values do not include Lake Pepin which has very little drawdown at the shoreline
[3] miles of shore in pool includes 50% increase to account for shoreline irregularities
[4] portion of Pool 26 above Illinois Waterway confluence

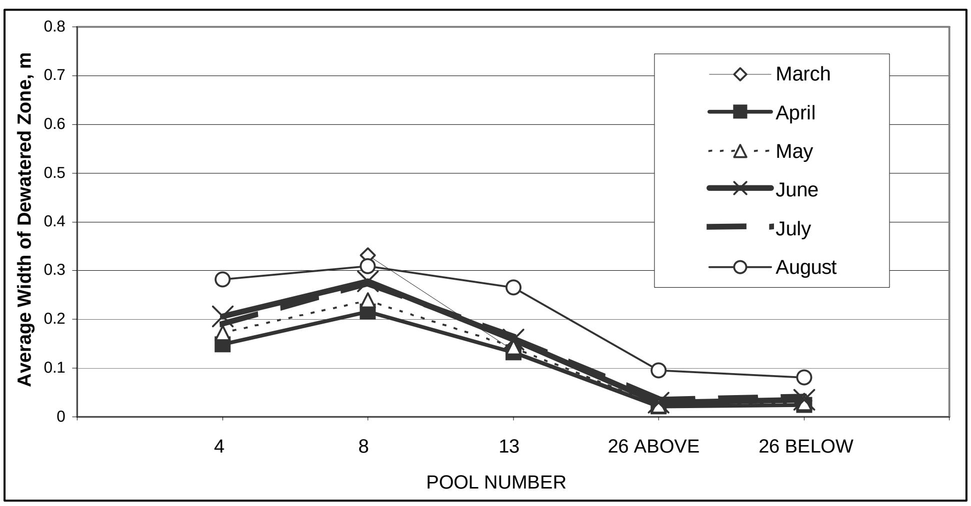

Figure 3. Average Width of Dewatered Zone for Upper Mississippi River trend pools, probability of exceedance by a single tow = 0.5 (width averaged over length of pool)

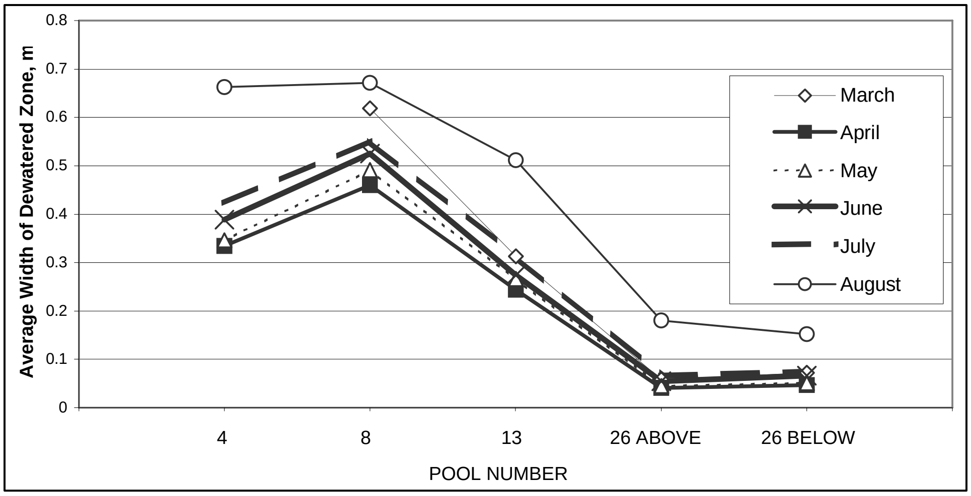

Figure 4. Average Width of Dewatered Zone for Upper Mississippi River trend pools, probability of exceedance by a single tow = 0.1 (width averaged over length of pool)

4 Discussion

Larval fish are found in the Upper Mississippi from April through August (Bartell and Rouse-Campbell 2000). Peak larval fish density occurs in May and June (Gutreuter et al. 1999; Holland and Sylvester 1983; Holland-Bartels et al. 1995). During their two-year study in Pool 26 and the lower Illinois River, Gutreuter et al. (1999) found that larval fish had a distinct temporal component to their arrival in the main channel drift. Buffalo (*Ictiobus spp*) and common carp (*Cyprinus carpio*) larvae dominated the larval assemblage through late May, to be replaced by shad larvae as the dominant taxon. Freshwater drum (*Aplodinotus grunniens*) larvae were the last major taxon present in larval samples during both years. Peak larval diversity appears at about the end of May to early June. These results are consistent with other larval fish studies in the Upper Mississippi and Illinois rivers, which also indicate that clupeid and freshwater drum larvae form a major component of main channel larval fish assemblages throughout the length of the Upper Mississippi River (Holland and Sylvester 1983; Holland-Bartels et al. 1995).

A comparison of peak larval diversity and density with the area of shoreline dewatered (Table 3) by the passage of a commercial tow indicates that during May, there was a 90 percent probability that 3.9 or fewer hectares of shoreline would be dewatered by a passing towboat in Pool 4, 5.5 or fewer hectares in Pool 8, 4.4 or fewer hectares in Pool 13, and 0.9 or fewer hectares in Pool 26. During the month of June, there was a 90 percent probability that 4.4 or fewer hectares of shoreline would be dewatered in Pool 4, 5.8 or fewer hectares in Pool 8, 4.5 or fewer hectares in Pool 13, and 1.1 or fewer hectares in Pool 26. Drawdown would increase for decreasing channel size, for similar vessel sizes, and speeds. Consequently, on the Upper Mississippi River (UMR), drawdown in Pool 26 would be less than drawdown in Pool 8. While the magnitude is generally largest at the vessel, drawdown can still be observed at the shoreline for typical channel widths, vessel sizes, and vessel speeds along the UMR. When standing on the shoreline, drawdown would be most apparent when the nearshore bank slope is relatively flat because a large portion of the bank will be dewatered during passage of the vessel. For example, for a relatively steep bank slope of 1V:2H and a drawdown of 0.1 m, a horizontal distance of 0.2 m from the original waterline would be exposed or dewatered. For the same drawdown and a 1V:20H slope, the dewatered distance would be 2.0 m and would be more apparent to the observer than drawdown occurring on the steeper slope. The width of the dewatered zone is less in the spring than in the summer months due to higher spring flows that produce a larger cross section and result in less drawdown.

Holland (1987) found that significant mortality of larval walleye and northern pike occurred at dewatering frequencies of eight tows per day. However, Holland (1987) used a flow-through aquarium system that prevented fish from moving out of the dewatered zone as water receded. Under natural conditions, it is not known if the same individual fish would remain within the dewatering zone for repeated exposures. The dewatered zone itself is very narrow, possibly limiting repeated stranding. During May and June, the peak larval fish density and diversity months, the width of the dewatering zone ranges from less than 0.05 m (Pool 26, May) to 0.53 m (Pool 8, June) for 90 percent of tow passages. With the exception of Pool 8, the average width of dewatered shoreline during May and June is less than 0.39 m for 90 percent of tow passages (Table 3). The drawdown zone as determined in this study and field studies (Bhowmik et al. 1981) is narrow, and larval fish may not remain within the zone for repeated exposure to air.

Holland's (1987) stranding mortality study prevented fish from moving out of the dewatered zone, precluding any behavioral response by the larval fish to the receding water. Adams et al (1999) found that the likelihood of stranding was definitely related to the behavioral response of fishes to drawdown. Species that typically occur in littoral and backwater areas either swam with the current or passively drifted, whereas the young of main-channel fishes, such as sturgeons and paddlefish, exhibit positive rheotaxis and were more likely to become stranded. Adams et al. (1999) suggested that main-channel species — such as shovelnose sturgeon and paddlefish larvae that in their study were highly vulnerable to stranding — are usually found in the main channel (Wallus et al. 1990), and not in the littoral zone where they would be susceptible to stranding.

Those species commonly found in the littoral zone were less susceptible to stranding, possessing behavioral swimming adaptations. These adaptations possibly evolved in response to natural wind-induced drawdowns that are common in the littoral zone of large river systems. For example, a 16.1-kilometer per hour (10 mph) wind blowing across a 0.8 km river channel will generate a 6.4 cm wave; wind blowing along a 3.2 km length of the channel will generate a 12.8 cm wave. A 32.3-kilometer per hour (20 mph) wind blowing across the channel will generate a 12.8 cm wave; wind blowing along the channel will generate a 25.9 cm wave (Coastal Engineering Research Center 1984). Short period wind waves having periods of roughly 1 sec are different from long period drawdown having a period of roughly 100 secs. However, both represent a disruption of conditions in the near shore zone. Comparison of wind wave magnitude to drawdown should be based on the water level drop during the wind waves to be comparable to the drop defined by the tow drawdown. The drop during wind waves is roughly 1/2 the heights given above. Drawdown, the vertical fall in water level, on the UMR from large tows ($Pe = 0.1$) range from 20 cm in Pool 4 to 5 cm in Pool 26. The values of 1/2 wave heights are comparable to drawdown on the UMR.

Holland (1987) established a mortality threshold of eight tows per day for walleye and northern pike larvae. However, the potential for multiple exposures of larval fish is unlikely because there are both physical and behavioral constraints that may actually limit multiple dewatering exposures. This study demonstrated that the average width of dewatered shoreline on the UMR during peak larval fish abundance (May and June) is very narrow, less than 0.39 m of shoreline for 90 percent of all tow passages, except for Pool 8 which had an average shoreline exposure width of 0.53 m. The typical rate of drawdown (vertical fall of water level per unit time) is also small, between 0.25-0.5 cm/sec. Larval fish may not remain within the narrow drawdown zone for repeated exposures to air. In addition, the physical location of main channel species and the behavioral response of littoral species to dewatering may also limit multiple exposures.

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14. ABSTRACT
Commercial vessel passage may strand young fishes during drawdown and subsequent dewatering of the littoral zone. In order to determine the potential magnitude of impact, the area of shoreline dewatered by the movement of commercial navigation traffic was calculated for a typical year for pools 4, 8, 13 and 26 of the Upper Mississippi River for March through August, the period when larval fish would be expected. During May and June — the peak larval fish density and species diversity months — the width of the dewatering zone ranges from less than 0.03 m (Pool 26, May) to 0.28 m (Pool 8, June) for 50 percent of tow passages and from less than 0.05 m (Pool 26, May) to 0.53 m (Pool 8, June) for 90 percent of tow passages. With the exception of Pool 8, the average width of dewatered shoreline during May and June is less than 0.20 m for 50 percent of tow passages and less than 0.39 m for 90 percent of tow passages. The average width of the area exposed, or dewatered, decreased in a downstream direction as the channel becomes larger. The number of times the shoreline zone is dewatered depends on traffic levels that tend to increase in a downstream direction. Larval fish mortality could occur if larvae remained in the narrow dewatering zone for multiple drawdown events. However, littoral species display behavioral responses to drawdown that would minimize repeated strandings.

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