Proceedings of the 1991 Winter Simulation Conference
Barry L. Nelson, W. David Kelton, Gordon M. Clark (eds.)

SIMULATION OF FOX RIVER LOCKS BOAT LIFT

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ABSTRACT

The SLAM computer simulation model of the locks system on the lower Fox River was modified to represent operation of a proposed boat lift at the Rapide Croche lock. This boat lift is needed due to construction of a barrier for preventing migration of sea lamprey into the Fox River and Wolf River basins. The barrier was put in place prior to the 1988 navigation season by sealing the Rapide Croche lock. Since then only three end locks, Menasha, Little Kaukauna, and DePere, have been operated. Prior to the sea lamprey barrier, the entire system of sixteen locks had been operated every summer since 1856. Two alternatives have been proposed for the boat lift at Rapide Croche. The simulation model was used to investigate delay of boat traffic within the system for both alternatives.

1 INTRODUCTION

In recent years governmental agencies at local, state, and federal levels have been involved in decisions concerning various aspects of the Fox River system and in operation of the locks. Primary issues have been costs and benefits of continued operation of the locks system and the threat of invasion of the Fox River and Wolf River basins by the sea lamprey.

The Fox River locks SLAM simulation model was developed to represent boat traffic through the locks system on the lower Fox River between Menasha and DePere. The model was developed based on the entire sixteen-lock system depicted in Table 1. The entire system was operated every summer from 1856 to 1987, prior to sealing of the Rapide Croche lock as a barrier to prevent migration of the sea lamprey. The Fox River locks system, data analysis, and model development, including assumptions and verification, have been described previously (Bandy 1987). The simulation model is based on a SLAM network representation of operation of the locks and boat traffic through the locks (Bandy 1988).

Table 1: Fox River Locks System

Name	Miles above mouth of river at Green Bay	Downriver water elevation (in feet)	Lift in feet (at low water datum)
Lake Winnebago	39.0	745.1	-
Menasha	37.0	735.4	9.7
Appleton 1	31.9	725.7	9.7
Appleton 2	31.6	716.1	9.6
Appleton 3	31.3	706.3	9.8
Appleton 4	30.7	698.7	7.6
Cedars	27.3	688.9	9.8
Little Chute	26.4	675.3	13.6
Combined Locks	25.4	652.8	22.5
Kaukauna 1	23.6	642.5	10.3
Kaukauna 2	23.4	632.9	9.6
Kaukauna 3	23.3	622.7	10.2
Kaukauna 4	23.1	612.5	10.2
Kaukauna 5	22.8	602.2	10.3
Rapide Croche	19.2	592.8	9.4
Little Kaukauna	13.0	586.7	6.1
DePere	7.1	576.8	9.9

The sea lamprey is a marine parasite that came up the St. Lawrence Seaway into the Great Lakes, entering Lake Ontario more than a century ago. The sea lamprey was found in Lake Erie in 1921 and had entered the three remaining Great Lakes by 1938 (Fernbach and Bogar 1988). Initially the sea lamprey was not a threat to the Fox River and Wolf River basins because the poor water quality in the lower Fox River served as a barrier to migration. Fifteen years ago the lower Fox River was considered one of the ten most polluted rivers in the nation. However, in the past several years, industries have spent hundreds of millions of dollars to improve water quality, and the lower Fox River has improved to the point that it can support the sea lamprey. Prior to the 1988 navigation season the Rapide Croche lock between Wrightstown and Kaukauna was sealed by the Department of Natural Resources to prevent upstream migration of the sea lamprey. Since then only three locks have been operated during the summer navigation season, the Menasha lock at the upper end of the system near Lake Winnebago, and the Little Kaukauna and DePere locks at the lower end of the system near Green Bay.

Construction of a boat lift at Rapide Croche was proposed by the East Central Wisconsin Regional Planning Commission as part of their study of the Fox River locks system following the 1987 navigation season (Theine et al. 1988). At that time their proposal was to have a boat lift built and operating for the 1989 boating season. Two alternatives were proposed for the boat lift, with the combination swivel/travel lift being preferred to the "T-type" travel lift.

The East Central Wisconsin Regional Planning Commission also developed a long-range plan for the Fox River system in 1989 that included recommendations to nominate the lock and dam system to the National Register of Historic Places, to establish national recognition for the historic corridor, and to establish an operational lock and channel system for through navigation by installing a boat lift at Rapide Croche (Theine et al. 1989).

The SLAM simulation model was altered to represent both of the alternatives for the proposed boat lift. It was then used to investigate the impact on boat traffic through the locks systems if the entire system were to be reopened with a boat lift at Rapide Croche. The model provided simulated results for the delay of boat traffic within the system for both alternatives.

2 MODEL DESCRIPTION

The Fox River locks SLAM simulation model represents operation of the locks and the boat traffic through the locks system. The SLAM network representation includes the daily opening, closing, and operation of the locks, and the boats approaching, entering, and leaving the locks. Lockages can involve a single boat or several boats, depending on the boat traffic. Since most of the boating is recreational, it is fairly common to have several boats moving through the locks system as a group. Many aspects of the boat traffic are contained in FORTRAN subroutines, which are called from the SLAM network.

The SLAM network representation of the locks system involves the use of resources, gates, entities, and various network nodes, including ALTER, ASSIGN, AWAIT, CLOSE, CREATE, FREE, GOON, OPEN, and TERMINATE nodes. Activities are used to control the flow of entities (primarily representing boats) through the network and for the times required for entity movements.

Four resources and two gates control the operation of each lock. The resources are for boats entering and leaving the lock going upstream and for boats entering and leaving the lock going downstream. They are defined initially with capacities of 1 and are altered at the start of the simulation to capacities of 0, until each is needed, when its capacity is temporarily restored to 1. At any time during a simulation run, at most one of the four resources for a given lock will have a capacity 1, with the other three having a capacity of 0. Usually all four will have a capacity of 0. The two gates are for whether or not the lock is busy and for whether or not the lock is closed.

For each entity in the SLAM network that represents a boat, there are five attributes: 1) the time the boat enters the locks system, enters the lock, or leaves the lock; 2) the first lock used upon entering the locks system; 3) the destination lock for the boat; 4) the number of passengers in the boat; and 5) the number of boats traveling together as a group. The third attribute is used to differentiate between boats that are making one-way trips through the locks and boats that are making round trips within the locks system. For boats making one-way trips, attribute 3 is the final destination in the locks system for the boat. For boats making round trips, attribute 3 is initially given a negative value representing the last lock used by the boat before it turns around and returns, with the true "final destination" for the boat being the first lock used (attribute 2). For other entities in the SLAM network, the attributes are used as needed for various purposes.

FORTRAN user functions are used for many aspects of the locks system, including closing all of the interior locks on Tuesdays and Wednesdays, interarrival times for boats at each source, whether the boats are making one-way trips or round trips, the frequency and number of boats traveling together as a group, final destinations for the boats, number of passengers in the boats, travel times between locks, time spent at the "final destination" before returning to the lock for boats making round trips, and collecting statistics.

3 REPRESENTATION OF SWIVEL/TRAVEL LIFT AT RAPIDE CROCHE

One of the alternatives proposed for the boat lift at Rapide Croche by the East Central Wisconsin Regional Planning Commission is a combination swivel/travel lift. With the swivel/travel lift a dike, or coffer dam, would be constructed as a new sea lamprey barrier about 300 feet below the Rapide Croche lock, with the swivel lift on top of the coffer dam. The travel lift would provide a means of traveling around the coffer dam and would be relatively short. The Rapide Croche lock itself would again be operated as it was prior to 1988.

Boats traveling in either direction below the lock would use either the swivel lift or the travel lift. It was assumed that the swivel lift would take six minutes per boat, while the travel lift would take nine minutes per boat. However, the swivel lift would not be large enough to handle all boats, especially sail boats. It was assumed that 40% of the boats would have to take the extra three minutes to use the travel lift. The SLAM network representation of the swivel/travel lift at Rapide Croche is shown in Figures 1 and 2. Figure 1 is for boats arriving at Rapide Croche going upstream and Figure 2 is for boats leaving the Rapide Croche lock going downstream.

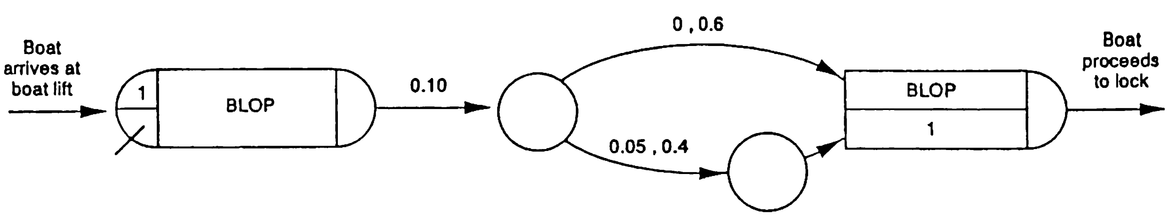

Figure 1. Boats Arriving At Rapide Croche Swivel/Travel Lift Going Upstream

Boats arriving at Rapide Croche going upstream encounter the boat lift prior to the lock, as indicated in Figure 1. Resource BLOP is used to represent operation of the boat lift. It is assumed that only one boat would be using the boat lift at a time, rather than allowing simultaneous usage of the swivel lift and the travel lift. Thus resource BLOP has a capacity of 1. An AWAIT node is used for the boats as they arrive at the boat lift and wait, if necessary, for use of one unit of the BLOP resource. When the BLOP resource is available, the boat uses the boat lift to bypass the coffer dam, which takes 6 minutes (0.10 hours) if the swivel lift is used and 9 minutes (0.10 plus 0.05 hours) if the travel lift is used. The probability is 0.6 that the swivel lift would be used and 0.4 that the travel lift would be used. In either case a FREE node is then used to free one unit of resource BLOP, and the boat proceeds to the Rapide Croche lock.

Boats going downstream proceed through the Rapide Croche lock before they encounter the boat lift, as indicated in Figure 2. The procedure for going through the boat lift is identical to that for boats that are going upstream. Thus the structure and interpretation of Figure 2 is identical to that of Figure 1. BLOP is the resource used in Figure 2, just as in Figure 1, since the same boat lift would handle boats in both directions. Also it is assumed that the boat lift would handle boats on a first come, first serve basis.

4 REPRESENTATION OF "T-TYPE" TRAVEL LIFT AT RAPIDE CROCHE

The other alternative proposed for the boat lift at Rapide Croche is a "T-type" travel lift ramp that completely bypasses the lock. The lock would remained sealed as a sea lamprey barrier, with the lift located on the island south of the lock. Extensive modifications would be required, including major modifications to the retaining walls both upstream and downstream of the lock. The "T" configuration would be needed so that the lift can turn 180 degrees to transport sailboats. The lock itself is over 150 feet long, and construction would require several hundred feet of asphalt and/or concrete, along with dredging at both upstream and downstream entrances.

Boats traveling in either direction would use the "T-type" travel lift to bypass the lock. It was assumed that the lift would take fifteen minutes per boat, regardless of the size or direction of travel of the boat. Furthermore, it was assumed that it would take six minutes to move the empty lift from one end of the

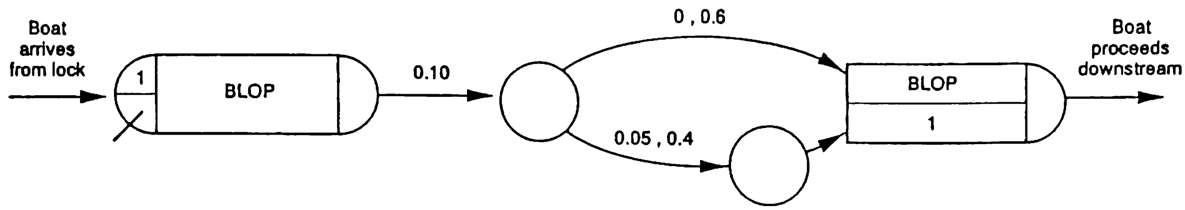

Figure 2. Boats Leaving Rapide Croche Swivel/Travel Lift Going Downstream

ramp to the other, when required to do so by the pattern of boat traffic. The SLAM network representation of the "T-type" travel lift at Rapide Croche is shown in Figure 3 for boats going upstream and in Figure 4 for boats going downstream.

The SLAM network representation for the "T-type" travel lift is quite similar to the SLAM network representation for the locks (Bandy 1988), but is much simplified in that only one boat can use the lift, while several boats can go through the locks in a single lockage. Thus for the "T-type" travel lift only two resources are required, one for boats going upstream and one for boats going downstream, as opposed to the four resources required for each lock.

Figure 3 is for boats using the "T-type" travel lift at Rapide Croche going upstream. An AWAIT node is used for the boats as they arrive at the lift and wait, if necessary, for use of one unit of the RCUE resource, which has a capacity of either 0 or 1. When the RCUE resource is available, the attribute representing

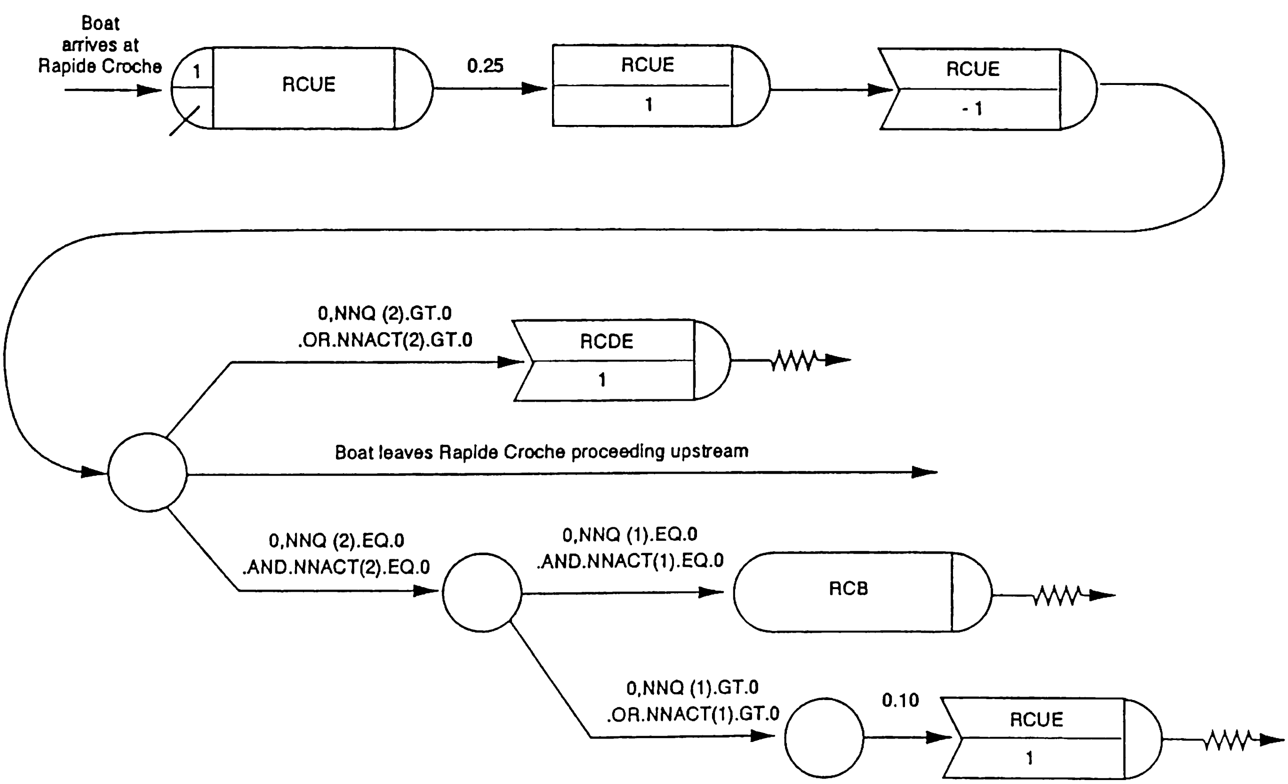

Figure 3. Boats Using Rapide Croche "T-type" Travel Lift Going Upstream

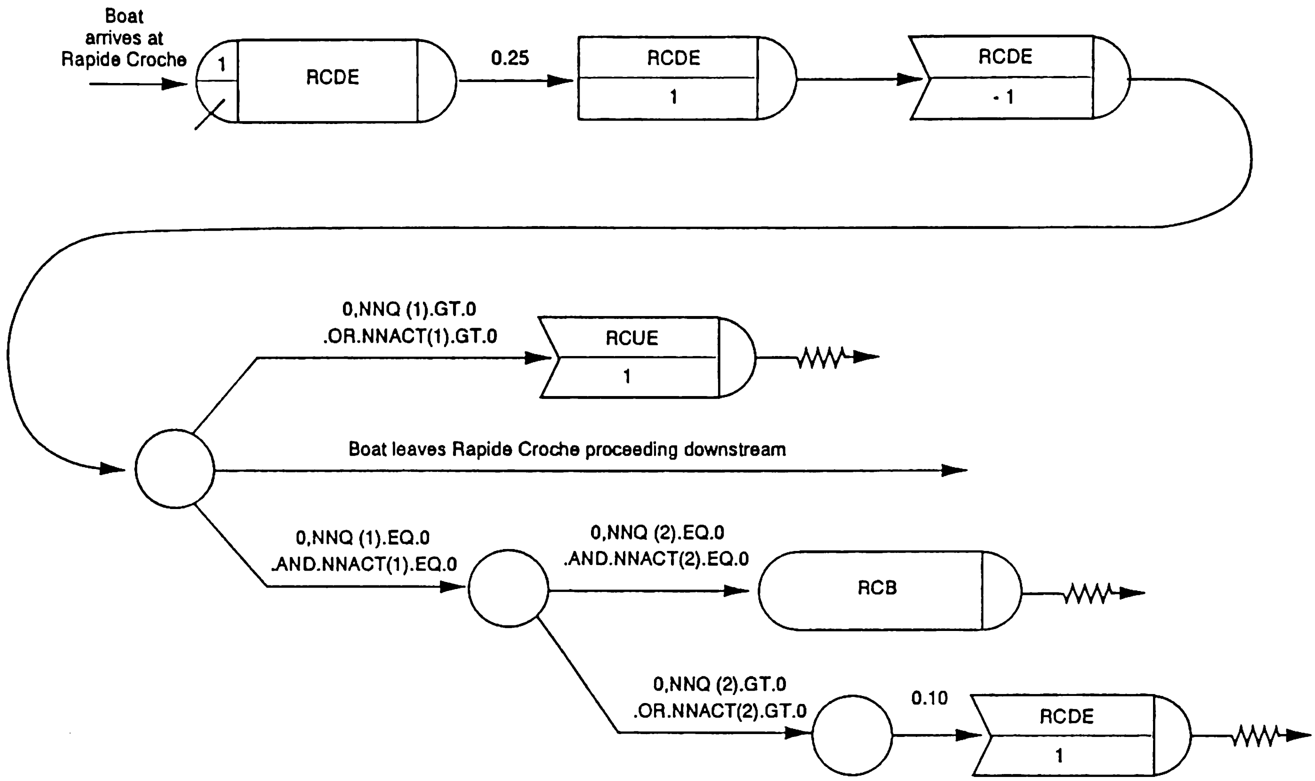

Figure 4. Boats Using Rapide Croche "T-type" Travel Lift Going Downstream

the boat uses it for 15 minutes (0.25 hours), which represents the boat being transported past the Rapide Croche lock on the "T-type" travel lift. A FREE node is then used to free one unit of resource RCUE immediately, and an ALTER node is used to modify the capacity of resource RCUE from 1 to 0. As the boat leaves Rapide Croche proceeding upstream, an additional entity is produced to decide what to do next with the operation of the lift. If a boat is waiting to enter the lift going downstream (NNQ(2).GT.0) or a boat is approaching the lift going downstream (NNACT(2).GT.0), resource RCDE's capacity is altered from 0 to 1 to enable the lift to be used in the downstream direction and the entity is terminated. Otherwise (NNQ(2).EQ.0.AND.NNACT(2).EQ.0) a check is made for boats traveling upstream. If a boat is waiting to waiting for the lift going upstream (NNQ(1).GT.0) or if a boat is approaching the lift going upstream (NNACT(1).GT.0), the capacity for resource RCUE is altered from 0 to 1 after a delay of 6 minutes (0.10 hours), and the entity is terminated. Otherwise (NNQ(1).EQ.0.AND.NNACT(1).EQ.0) an OPEN node is used to open gate RCB, to indicate that the lift is no longer busy, and the entity is terminated.

Figure 4 is for boats using the "T-type" travel lift at Rapide Croche going downstream. The procedure for going through the boat lift is identical to the procedure for boats that are going upstream. Thus the structure and interpretation of Figure 4 is identical to that of Figure 3. It should be noted that the resources, RCDE and RCUE, are reversed and also the numbers for the queues and activities are reversed.

5 DELAY OF BOATS DUE TO PROPOSED BOAT LIFT AT RAPIDE CROCHE

The simulation model was used to investigate the impact on boat traffic if the entire system were to be reopened with a boat lift at Rapide Croche. The model provided simulated results for the delay of boat traffic within the system for both alternatives that have been proposed for the boat lift. This was done by making runs with the original model without a boat lift and with the revised model for each of the alternatives for the proposed boat lift. Comparisons of results from the revised model with results from the original model provided estimated delays of boats due to the boat lift at Rapide Croche for each of the proposed alternatives. The results are given in Table 2 for the swivel/travel lift below the Rapide Croche lock and in Table 3 for the "T-type" travel lift bypassing the Rapide Croche lock.

Table 2: Delay (Hours) For Swivel/Travel Lift

	Number of Boats Starting Together					
	1	2	3	4	5	Total
Total Number	499	130	45	20	15	709
Total Delay	331	36	17	9	7	400
Average Delay	0.66	0.28	0.37	0.45	0.46	0.56
Added Groups	0	22	8	2	4	36
One-Way Trips - Downstream						
Number	163	62	21	16	15	277
Delay	39	16	2	4	7	68
Average Delay	0.24	0.26	0.11	0.25	0.46	0.25
Added Groups	0	12	3	2	4	21
One-Way Trips - Upstream						
Number	227	64	24	4	0	319
Delay	103	18	14	5	0	140
Average Delay	0.45	0.28	0.59	1.28	-	0.44
Added Groups	0	8	5	0	0	13
Round Trips						
Number	109	4	0	0	0	113
Delay	189	2	0	0	0	191
Average Delay	1.73	0.58	-	-	-	1.69
Added Groups	0	2	0	0	0	2

Comparisons were made for the total time for all boats in the system and for only those boats that traversed Rapide Croche. It was found, as would be expected, that the primary delays due to the boat lift were for boats that traversed Rapide Croche. There was a slight secondary effect on some boats that did not traverse Rapide Croche, due to changes in timing for lockages at the other locks resulting from delays of the boats traversing Rapide Croche. For boats that did not traverse Rapide Croche, some were delayed and some actually spent less time in the locks system, depending on their timing relative to the boats that were delayed at Rapide Croche by the boat lift. In total, however, the secondary effects were negligible.

For boats traversing Rapide Croche the delay in boat traffic resulting from the boat lift was calculated based on total system times for each individual boat. Each boat was identified in each of the three runs of the simulation model and total system times were compared with and without the boat lift, for each of the alternatives proposed for the boat lift.

Results in Tables 2 and 3 are broken down by the number of boats that start out traveling together (from 1 for boats traveling alone up to 5). Results are given at the top of each of the tables for all boats traversing the Rapide Croche lock and are then broken down into three groups, one-way trips downstream, one-way trips upstream, and boats making round trips. Results are given for the total number of boats, the total delay (in hours) for the boats, the average delay per boat, and the number of additional groups of boats traveling together as a result of the boat lift.

Table 3: Delay (Hours) For "T-type" Travel Lift

	Number of Boats Starting Together					
	1	2	3	4	5	Total
Total Number	499	130	45	20	15	709
Total Delay	314	50	16	14	9	403
Average Delay	0.63	0.39	0.35	0.72	0.57	0.57
Added Groups	0	54	19	10	10	93
One-Way Trips - Downstream						
Number	163	62	21	16	15	277
Delay	73	25	4	8	9	121
Average Delay	0.45	0.42	0.18	0.52	0.57	0.44
Added Groups	0	26	8	9	10	53
One-Way Trips - Upstream						
Number	227	64	24	4	0	319
Delay	113	21	12	6	0	150
Average Delay	0.50	0.33	0.50	1.50	-	0.47
Added Groups	0	26	11	1	0	38
Round Trips						
Number	109	4	0	0	0	113
Delay	128	3	0	0	0	131
Average Delay	1.17	0.77	-	-	-	1.16
Added Groups	0	2	0	0	0	2

Some explanation is probably appropriate for the last item in Tables 2 and 3, the number of additional groups resulting from the boat lift. In the locks system, ordinarily boats that start out traveling together as a group would stay together because the locks can handle many boats with a single lockage. However, a boat lift can handle only one boat at a time. Thus the boats leave the boat lift separated. It was assumed in the simulation model that the boats would not wait for each other, but would proceed to the next lock. Of course it is possible that the lead boat would be delayed at a lock and one or more of the other boats would catch up with it to reform the group, either wholly or partially. This happened quite often in the model runs, especially for the swivel/travel lift, whose lift time is much smaller than for the "T-type" travel lift bypassing the Rapide Croche lock, and where the boats must go through the Rapide Croche lock in addition to either the swivel or the travel lift.

As an example of the number of additional groups resulting from the boat lift, take a case where four boats enter the locks system as a group, but the first boat leaves the locks system by itself, the second and third boats leave together, and the last boat leaves by itself, which results in two additional groups. Of course, in actuality, if a boat lift is installed at Rapide Croche, it is highly likely that the boats would wait for each other to reform the groups, given the social nature of recreational boating. Thus the average delays shown in Tables 2 and 3 would be even larger for boats traveling together.

Table 2 indicates that a swivel/travel lift would result in an average delay of 0.56 hours (about 34 minutes) for those boats that traverse Rapide Croche, with 36 additional groups of boats being formed in the simulation model. The average delay was greatest for boats traveling alone. This was due primarily to the fact that the vast majority of boats making round trips travel alone, which results in using the boat lift twice, with a much longer resultant delay. For boats making one-way trips, generally the more boats traveling together the longer the average delay. Of course, this is not true in all cases because of the small number of boats in some of the categories.

Table 3 indicates that a "T-type" travel lift bypassing the Rapide Croche lock would result in an average delay of 0.57 hours (about 35 minutes) for those boats that travel through Rapide Croche, with 93 additional groups of boats being formed in the simulation model. This average delay is almost identical to that for the swivel/travel lift; however, in actuality it would be much greater than for the swivel/travel lift because more additional groups are formed and more waiting would occur in reality to get the groups back together. The average delay was greatest for groups of four boats traveling together, with boats traveling alone having the second longest average delay. For boats making one-way trips, again generally the more boats traveling together the longer the average delay.

Comparing the results in Tables 2 and 3, it appears that the average delay in the system would not be much different for the two alternatives proposed for the boat lift at Rapide Croche, although the potential delays for individual boats, when there is a lot of congestion at Rapide Croche, would be much greater for the "T-type" travel lift bypassing the Rapide Croche lock than for the combination swivel/travel lift below the Rapide Croche lock.

6 FURTHER WORK

Under normal circumstances there should be several uses for the simulation model, including investigation of the effect of operating hours for the locks, volume of boat traffic in the locks system, and development along the Fox River. However, the threat of invasion of the Fox River and Wolf River basins by the sea lamprey has resulted in sealing of the Rapide Croche lock as part of a lamprey barrier. As a result only three of the locks, Menasha, Little Kaukauna, and DePere, have been operated during the last few summers. Many decisions still need to be made concerning future operation of the Fox River Locks system, including construction of a boat lift at Rapide Croche. Until some of these decisions have been made, there will be limited use for the simulation.

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