FINAL REPORT

WATERWAY SYSTEMS TRAFFIC ANALYSIS

Project IIA-W1, FY 93

Report No. ITRC FR 93-6

Prepared by

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May 1996

Illinois Transportation Research Center
Illinois Department of Transportation

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
ITRC FR 93-6		

4. Title and Subtitle WATERWAY SYSTEMS TRAFFIC ANALYSIS	5. Report Date May 1996 6. Performing Organization Code
7. Author(s) C. Jotin Khisty and Sherly George	8. Performing Organization Report No.
9. Performing Organization Name and Address Illinois Institute of Technology Dept. of Civil and Architectural Engineering 3201 South Dearborn Street Chicago, IL 60616-3793	10. Work Unit (TRAIS) 11. Contract or Grant No. IIA-W1, FY 93
12. Sponsoring Agency Name and Address Illinois Transportation Research Center 200 University Park Drive Edwardsville, IL 62025	13. Type of Report and Period Covered Final Report July 1993 to August 1994 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The purpose of the Chicago River and Lock system analysis was (i) to describe and analyze the traffic conditions existing on the waterway system, including traffic conflicts; (ii) to project the probable future traffic volume growth; (iii) to determine the capacity of the system by applying a queuing model; (iv) to characterize existing and future traffic conflicts; and (v) to identify potential solutions to reduce conflicts in the future. Several methods were used to accomplish these objectives: detailed traffic data were collected from lockage reports at the Chicago Lock; forecasts based on historical trends were projected; several tour-boat companies, barge operators, recreational boaters, and representatives of government agencies who were directly involved with the Chicago River and Lock were interviewed; several days were spent directly observing the lock operations and river traffic; accident data and conflict information were analyzed; a level of service concept coupled with a capacity study was developed; and finally, a queuing analysis of the lock operation was performed to estimate average delays to users of the lock. Based on these analyses, the following recommendations were made: (i) restrict new tour-boat companies; (ii) emphasize and enforce "no wake" zones; (iii) emphasize and enforce certification of boaters; (iv) increase law enforcement patrols in the study area and enforce tough anti-alcohol/drug boating laws; (v) make available to all users the rules for lock usage; and (vi) display proper signs for user information.

17. Key Words	18. Distribution Statement
Capacity study; Chicago River and Lock; vessel conflicts; queuing model; vessel operation	No Restrictions. This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	66	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

Waterway Systems Traffic Analysis

Prepared by: C. Jotin Khisty, Ph.D., P.E., Professor and Sherly George, Graduate Research Asst.

The vessel-carrying capacity of the Chicago River, Illinois, to Lake Michigan is controlled by a lock. Vessels passing through the lock currently experience long delays during the summer months. The Chicago River, with its major portion passing through the commercial and industrially developed central business district of Chicago, has witnessed a steady growth in water-borne traffic in recent years, and this growth is anticipated to continue in the foreseeable future. More than 50% of the total traffic using the river consists of recreational vessels. As both commercial and recreational use increases, users compete for space, which eventually results in long queues on either side of the lock, causing long delays to all the vessels using the systems. The increasing conflicts between vessels and the evident safety concerns of users are additional factors which need investigation and analysis. The purpose of this analysis was: (1) to describe and analyze the traffic conditions existing on the waterway system, including traffic conflicts; (2) to project the probable future traffic volume growth and vessel mix; (3) to determine the capacity of the system by applying a queuing model; (4) to characterize traffic conflicts likely to occur in the future; and (5) to identify potential solutions to reduce conflicts in the future.

Several methods were used to accomplish these objectives, and they are: detailed traffic data were collected from lockage reports at the Chicago Lock; forecasts based on historical trends were projected; several personnel from barge companies, grain and produce companies, recreational marine cruise-line companies and officials of the federal and state departments were interviewed, who are directly involved with the river system, as also a large number of recreational boaters; accident records from the U.S. Coast Guard were analyzed; several weekends and weekdays were spent observing the movements of vessels through the river and lock; a level-of-service concept was developed for application to the lock system; and a capacity analysis was done to study the performance of the lock, using a queuing model to estimate average delays to users of the lock. The results of the study indicated that conflicts created on the Chicago River are mainly caused by the concentration of vessels at certain locations of the river. The major causes of conflicts are: the reckless operation of vessels, speeding, and a lack of operating knowledge among users. Conflicts

in vessel traffic are mainly caused due to increases in the number of vessels using the lock during certain periods of time, particularly in the summer months. The results derived from the queuing model applied to the lock operation indicated that although the traffic flow through the lock has not quite reached capacity, there are short periods of time during the day, particularly during the summer peak season, when it does reach capacity. However, considering the steady annual increase in overall traffic flow projected in the future, the possibility exists of the traffic of the lock reaching, and even exceeding, capacity at more frequent intervals in the years to come.

Based on the analysis of data, the results of the interviews held with various groups of individuals connected with the river and the lock, the analysis of the queuing model applied to the lock, and the observations of the study investigators, the following solutions were recommended:

(a) restricting new commercial tour boat companies on the Chicago River,

(b) demarcating no-wake zones at appropriate places,

(c) licensing of recreational boat operators,

(d) enforcing navigational rules, particularly the "boating while intoxicated law" and "laws against negligent operation",

(e) prescribing an order of precedence of different categories of vessels using the lock, with the objective of achieving optimum lock utilization; establishing adequate understanding and coordination between lock operators and vessel operators would enable enforcement of lock operating rules,

(f) making available the rules of the Chicago River and Lock to all operators of vessels, e.g., safety rules, rules regarding no-wake zones, order of precedence, operating procedures, and

(g) displaying adequate and proper signing at crucial locations along the river and lock.

SECTION 1.

1.1 INTRODUCTION

1.1.1 Problem Statement: Waterborne transportation is often the most economical and energy efficient mode of moving commodities and products. Federal, state, local agencies and the people of Chicago have started realizing the importance of the Chicago River as an unique resource for transportation and industries. The Chicago River, once primarily a dumping site, has become the focus of several restoration projects. The river, with its major portion passing through the commercially and industrially developed Central Area, has witnessed a steady growth in waterborne traffic in recent years and this growth is anticipated to continue in the foreseeable future. The limited capacity of the river is restricted by the existence of the Chicago Lock, which separates the river from Lake Michigan. More than fifty percent of the total waterborne traffic is constituted of recreational vessels. As both commercial and recreational use increases, the users will compete for space, which will eventually result in long queues on either side of the lock, causing delays to all vessels using the system.

Currently vessels passing through the lock experience long delays during summer months mainly due to the presence of recreational vessels. Increasing conflicts between vessels and safety concerns among the users are other issues to be dealt with. There is, therefore, an immediate need to analyze the current traffic pattern on the Chicago River and Lock system to identify the existing traffic conflicts as well as projected future traffic conflicts. Along with this, it is also necessary to determine the capacity of the system and forecast the future traffic growth for the economical, efficient and safe management of the system.

1.1.2 Purpose of the Study: The main purpose of this study is to evaluate the existing conditions of the Chicago River and Lock System by: 1. collecting present and historic traffic data (mix, size, capacity) and accident/incident data(vessels involved, direction, severity, location), and 2. identifying the traffic conflicts. The focus of the study is on projecting the future traffic volume of the system, and identifying factors which influence the capacity, such as, the level-of-service, the vehicle mix and directional movement, locking time and speed distribution, all of which are essential for a lock operation analysis. This analysis entails developing a queuing model of the lock operation to effectively find the delay caused to vessels using the lock on a typical summer weekend day, when the recreational and passenger vessels reach their peak volumes.

1.1.3 Objectives: The objectives of this project are as follows:

1. To determine the present traffic volume and mix of waterborne traffic on the Chicago River and Lock System.
2. To estimate the future traffic volume and mix.
3. To determine the system capacity.
4. To determine both present and future traffic conflicts for the economical, efficient and safe management, and operation of the system, and
5. To identify potential solutions to reduce traffic conflicts in the near future as well as in the long term.

SECTION 2.

2.1 BACKGROUND

The Illinois Waterway, a vital segment of the United States Inland Waterway System, traverses the state from Lake Michigan west and then southwest to its junction with the Mississippi River at Grafton. The current navigation system consists of 368 miles of commercially navigable waterways and is one of the nation's busiest routes for commercial barge traffic. The largest among the Illinois waterways, the Illinois River, is formed by the confluence of the Kankakee and Des Plaines Rivers about midway between Chicago and Lasalle and it flows for a distance of 273 miles. Tributaries of the Illinois River include the Fox, Desplaines, Chicago, Calumet, Kankakee and Sangamon Rivers.

2.1.1 Chicago River: The Chicago River flows for a distance of 14.4 miles from its mouth at the Lake Michigan basin. The main branch runs up to Wolf point, and then separates into the north and south branches. Virtually all segments of the Chicago River are commercially navigable, the exception being the north branch after Addison Street. The mouth of the Chicago River at Lake Michigan is the focal point of industrial and commercial development. The reversal of the Chicago River, about a hundred years ago, helped dramatically to improve the quality of the lake water, and today the Chicago Lakefront area is recognized throughout the world as the Chicagoland's most attractive resource. Even though the Chicago River was abused and neglected for decades, there has been a growing awareness among the governmental agencies and the citizens, in recent years, about the Chicago River as an economic development resource and as an aesthetic and recreational amenity. Consequently, a number of developmental projects are underway with the Chicago River as the main focus and the predominant among them is the Greenways and Waterways project. Some important developments are listed below:

- Chicago River Walk: To establish a continuous riverside walkway throughout the downtown river corridor.

• Gateway Park and Monroe Harbor Marina: A series of lake front parks eventually connected to the emerging River Walk.

• " Bubbley Creek " Wetland and Union Stockyard gate: Wetland park providing habitats for birds and fish life, at the South fork of the Chicago River.

2.1.2 Study Area: The waterway features of the study area are:

Segment 1. Chicago River, Main branch: Lake Michigan to Wolf point

This section passes through the Central Business District and is lined predominantly by downtown high rise office buildings. The Chicago River Channel, which extends from Chicago Lock to the Lake Shore Drive Bridges is approximately 1650 feet in length, 400 feet in width and is 21 feet deep. The river is 200-300 feet wide and 21-25 feet deep. All bridges crossing this segment are movable and this river section is navigable by oceangoing vessels.

Segment 2. North branch: Wolf point (Main branch) to Addison Street (5 miles).

This segment is approximately 200 feet wide and the depth varies from 21 feet at North Avenue and from 7 to 14 feet from North Avenue to Addison Street. The banks are lined with industrial and commercial development.

Segment 3. South branch: Wolf point (Main branch) to Damen Avenue (4.5 miles).

The south branch is largely a man-made channel, 21-24 feet deep and 200-250 feet wide . It passes predominantly through commercially and industrially developed areas and is navigable by ocean-going vessels.

2.1.3 Vessel Types: The State of Illinois has one of the largest commercial navigation systems of all the inland states. The commercial shipments through the river include petroleum products, coal and farm products. The waterborne commercial traffic on the Chicago River includes river barges and tow boats. Barges that use the Chicago River are mainly of two sizes: 295ft x 55-59ft (Tank Barges), using the Main and South Branches only, and 195ft x35ft (Covered Hoppers), using the Main, South & North Branches.

The commercial passenger vessels consist of a variety of sightseeing and charter cruise vessels, operating along the Chicago River and Lake Michigan. The vessel sizes vary from 55 to 65 ft in length and 16 to 28 ft in width. Pleasure boats or recreational vessels on the river include power boats, sail boats(with and without auxiliary power) and other non motorized recreational crafts. The length of these vessels range from under 16 ft. to 50 ft.

2.2 LITERATURE REVIEW

Service facilities, in general, can suffer from many problems, and one of these is the queuing problem. Queuing problems are likely to arise when a service facility, such as a lock, is limited to provide service to all its users when they need it. Naturally, when users of the facility arrive faster than they can be serviced, lines or queues will develop. On a waterway with locks, the locks are the most important single cause of delay. Thus the literature reviewed in this study concentrates mainly on delays to vessels passing through locks. In this context, a number of queuing models and simulation models were reviewed.

Models are simplified representations of reality, and are likely to be complex if they involve several different kinds of random events. In queuing models there are at least three essential features to be considered. First, arrival intervals of vessels may be independent of one another, or the arrival of one vessel may influence the probability of the next vessel's arrival.

Second, the service time in the lock may differ, each time the lock is used, depending on the probability distribution applicable to the system. And thirdly, the "queue discipline", or the way the queue forms and moves, needs to be critically examined. There may be, for example, one or more lines or channels to be considered.

One of the earliest lock delay models was proposed by De Salvo & Lave (1). This model is essentially a simple single server queuing model, with Poisson distributed arrivals and exponentially distributed service times (i.e., M/M/1 queues). According to this model, knowing the service rate of the lock and the annual number of tows to be served, one can estimate the waiting time required for any tow at a single-lock system.

Wilson (2) extends this model by treating the service process as general distributions (M/G/1 queues). According to him, the assumption of exponentially distributed service times does not correspond well with the real system. This model calculates the mean delay experienced by a tow in a single chamber lock. The model results were compared with the simulation model results and were found to agree well.

Simulation is the most reasonable approach for a comprehensive analysis of large complex waterway systems. One such model was developed by Carrol and Bronzini (3). This model is based on the Monte Carlo simulation procedure. It simulates waterway operation in detail and provides outputs on tow traffic delays, processing times average and standard deviation of delay, queue lengths and lock utilization ratios. A recent simulation model was developed by Dai and Schonfield (4).

Based on the above discussion, it seemed important to develop a model that matched the physical conditions existing at the Chicago Lock. A queuing model or a simulation model could be used to analyze the delay experienced by each vessel. A simulation model is more accurate but is also time consuming. Since the development of a delay model was not the primary purpose of this study, it was decided that a queuing model would serve the purpose of estimating the average delay experienced by each vessel. It may be mentioned that simplistic models by themselves may not adequately consider the time, day, season, or weather sensitivity of commercial or recreational vessel arrivals at the lock.

2.3 IDENTIFICATION AND COLLECTION OF DATA

2.3.1 Data Needs: The primary purpose of collecting vessel traffic data on the Chicago River and Lock System was to gather sufficient information to analyze the existing traffic condition both in the river and lock. Detailed traffic data pertaining to the movement of each vessel through the lock was necessary for the analysis of the lock operation, whereby, the average delay experienced by each vessel could be estimated. The average delay time is a measure expressing the capacity and level-of-service of the waterway system.

2.3.2 Available Data: The data pertaining to the waterborne traffic through the Chicago River are the daily lockage reports maintained at the Chicago Lock. For each vessel, these reports typically show the vessel type, vessel number, arrival date, arrival time, start of lockage and end of lockage times. These data are usually send to the Navigation Data Center, US Army Corps of Engineers. They process the data and publish monthly and yearly reports.

2.3.3 Data Collection Efforts: The following data were collected from the Navigation Data Center, Virginia.

1. Yearly traffic data (1986 - 1993)

- It includes vessel mix (commercial, recreational, and other vessels i.e.,passenger and federal vessels, direction of movement, loading condition of barges (loaded or unloaded) and tonnage.

2. Monthly traffic data for the year 1991.

- Categorized as in (1) above.

3. Detailed daily report for the month of July, 1993.

-It comprises of the daily report prepared at the lock site detailing each vessel, its arrival time at the lock, start of lockage, end of lockage, direction of movement and barge details (loaded / unloaded and tonnage).

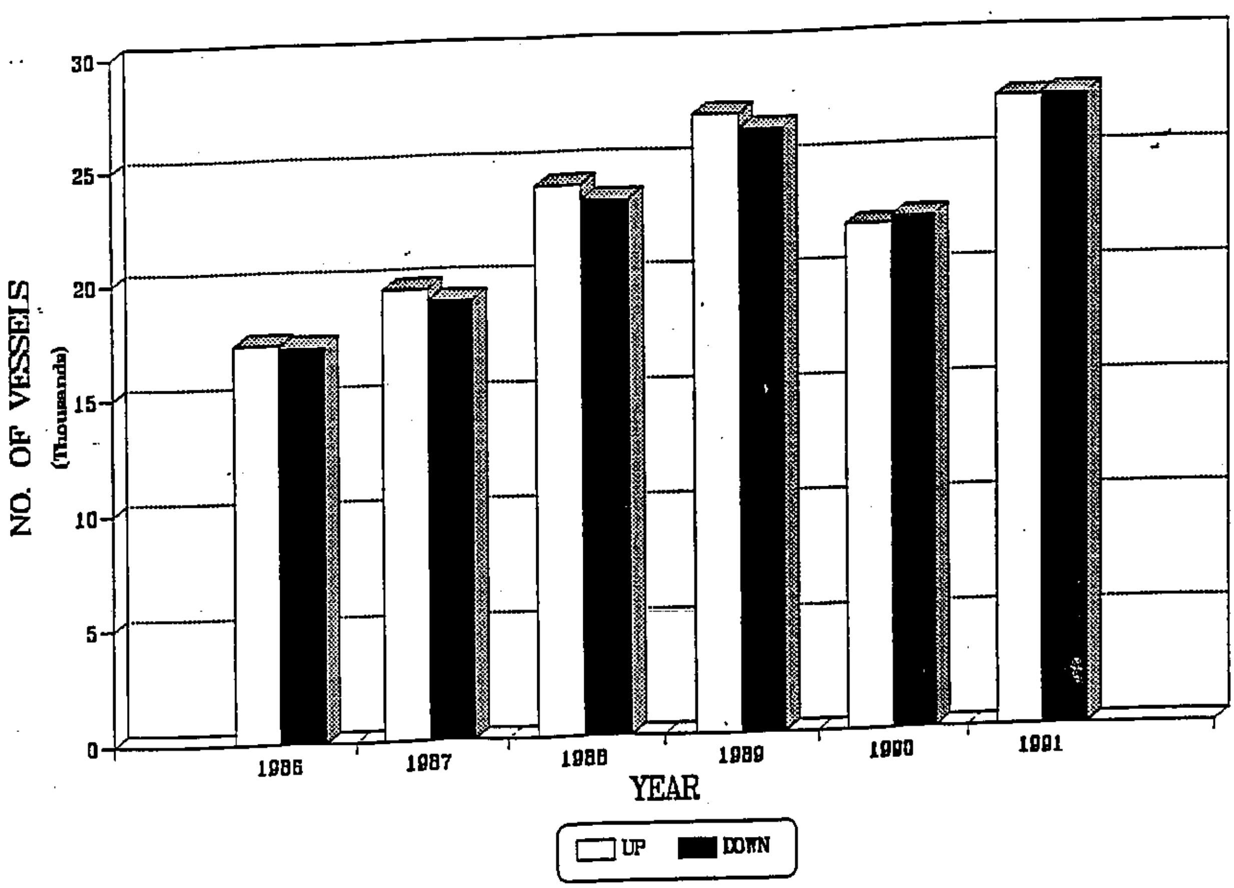
SECTION 3.

3.1 EXISTING VESSEL TRAFFIC

The waterborne traffic through the Chicago River has witnessed a steady growth in recent years. The total traffic for the year 1993 was 45835 (both directions). Figure 1. explains the yearly variation in total traffic for the past eight years. The directional movement, river to lake (up) and lake to river (down) are also depicted. While the year 1993 witnessed record floods on the Upper Mississippi River, the Illinois River was not significantly affected.

3.1.1 Commercial Barge Traffic: Major commercial shipment through the river include petroleum products, coal, farm products, chemicals and construction materials. The different types of barges using the Chicago River are dry cargo barges (usually 195 ft. length and 35 ft. width) and liquid barges (200- 295 ft. length and 55-59 ft. width). The commercial traffic through the Chicago Lock is significantly lower than the shipments through the O'Brien Lock,

Figure. 1.
TOTAL NUMBER OF VESSELS PER YEAR



which is about nine miles south of the Chicago Lock on the Calumet River. The inner dimensions of the O'Brien Lock is 1000 ft. in length, 110 ft. in width and 18.5 ft. in average depth over the sills. The bigger size of the lock chamber is the main reason for more traffic through the O'Brien Lock.

The total commercial traffic for the year 1993 was 625694 tons for the Chicago Lock. However, the total number of commercial barges only account for about 0.5 percent of the total transits through the lock. The monthly variation in commercial traffic is presented in Figure 2. The monthly pattern of commercial traffic shows that April through October are the busier months of the year.

3.1.2 Passenger Traffic: Passenger traffic through the river consists mainly of commercial passenger tour boats, which operate at fixed schedule during the summer months. There are at least twelve tour boat companies operating sightseeing and charter cruise vessels along the river as well as on the lake. The routes the passenger vessels take along the river are similar, that is, the north branch up to Goose Island and along the south branch up to River City Marina. The passenger vessels sizes vary from 50-100 ft. in length and 16- 28 ft. in width.

The 1993 data indicate that the total traffic through the lock was 15059 which accounted for about 28% of the total vessel transits through the waterway. The peak season starts at the month of June and continues up to August. The monthly variation of the traffic is presented in Figure 3. The hourly variations on a typical summer weekend day are shown in Figures 4 and 5.

3.1.3 Recreational Traffic: Recreational traffic, consisting of power boats, sail boats, row boats and canoes, constitute the major portion of the total transits through the lock. The

Figure. 2. MONTHLY VARIATION IN TRAFFIC (1991) (BARGES AND OTHER)

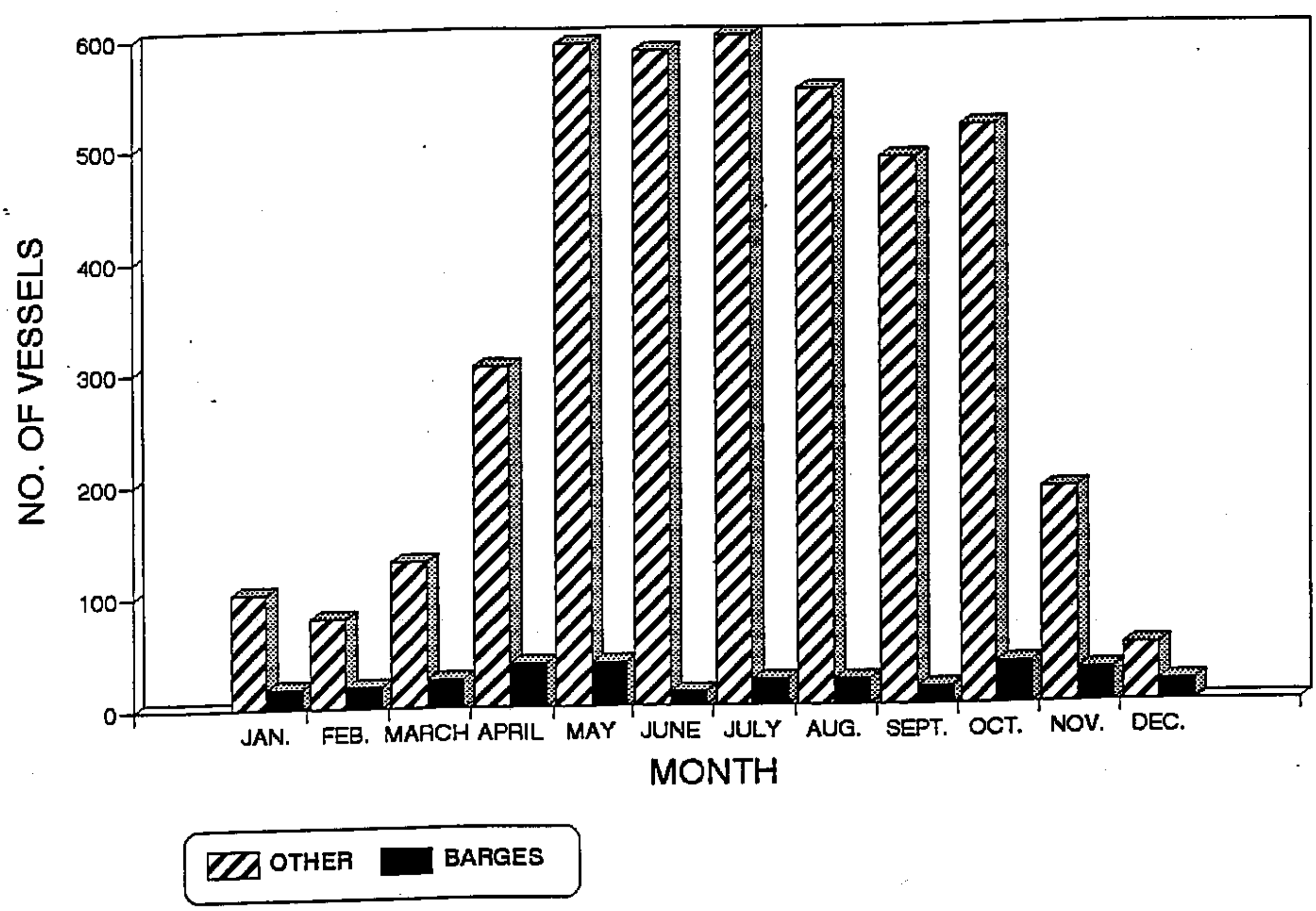


Figure. 3. MONTHLY VARIATION IN TRAFFIC (1991) (RECREATIONAL AND PASSENGER)

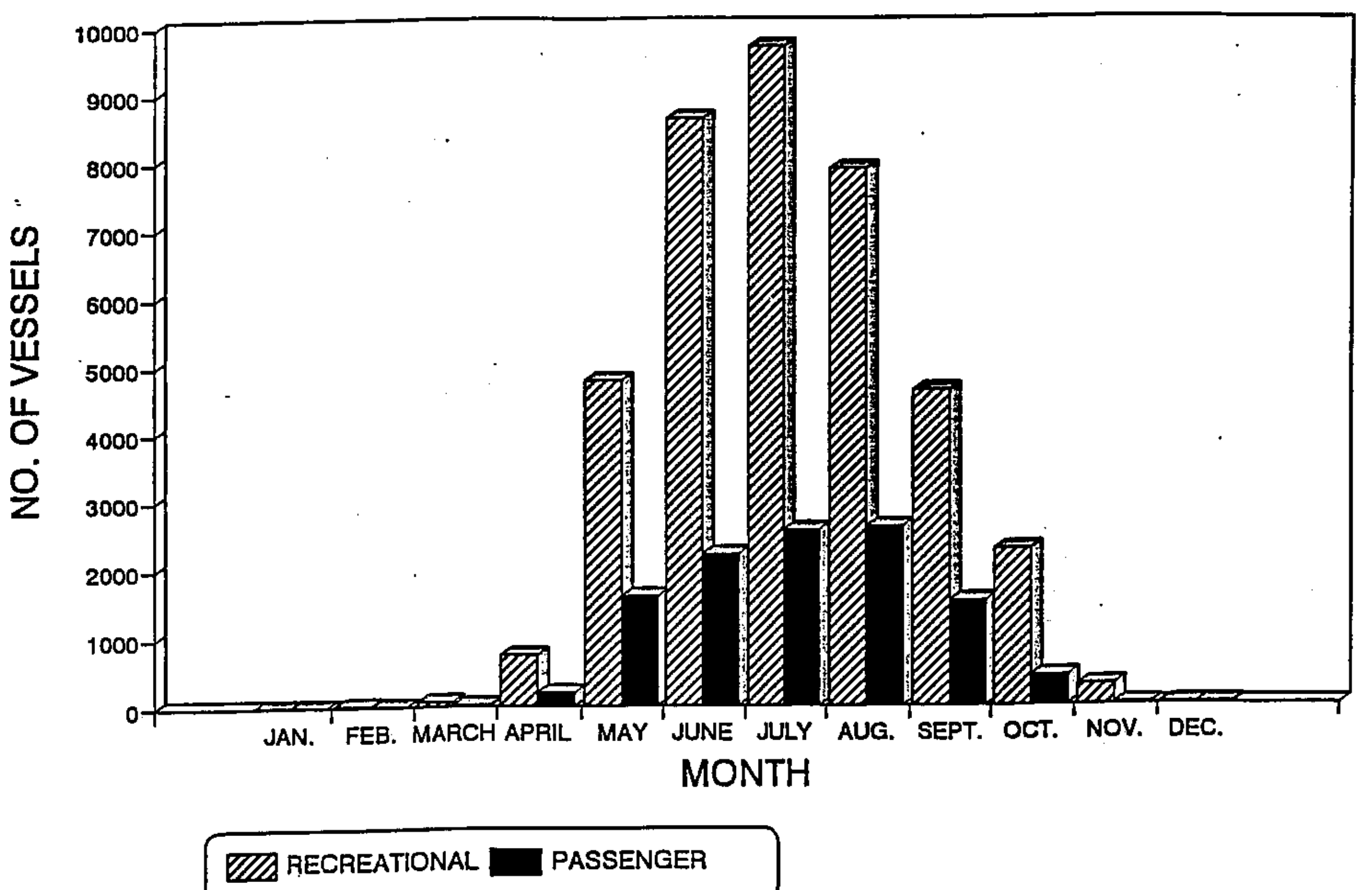


Figure. 4. HOURLY VARIATION IN TRAFFIC ON A TYPICAL WEEKEND DAY (JUNE, 1991)

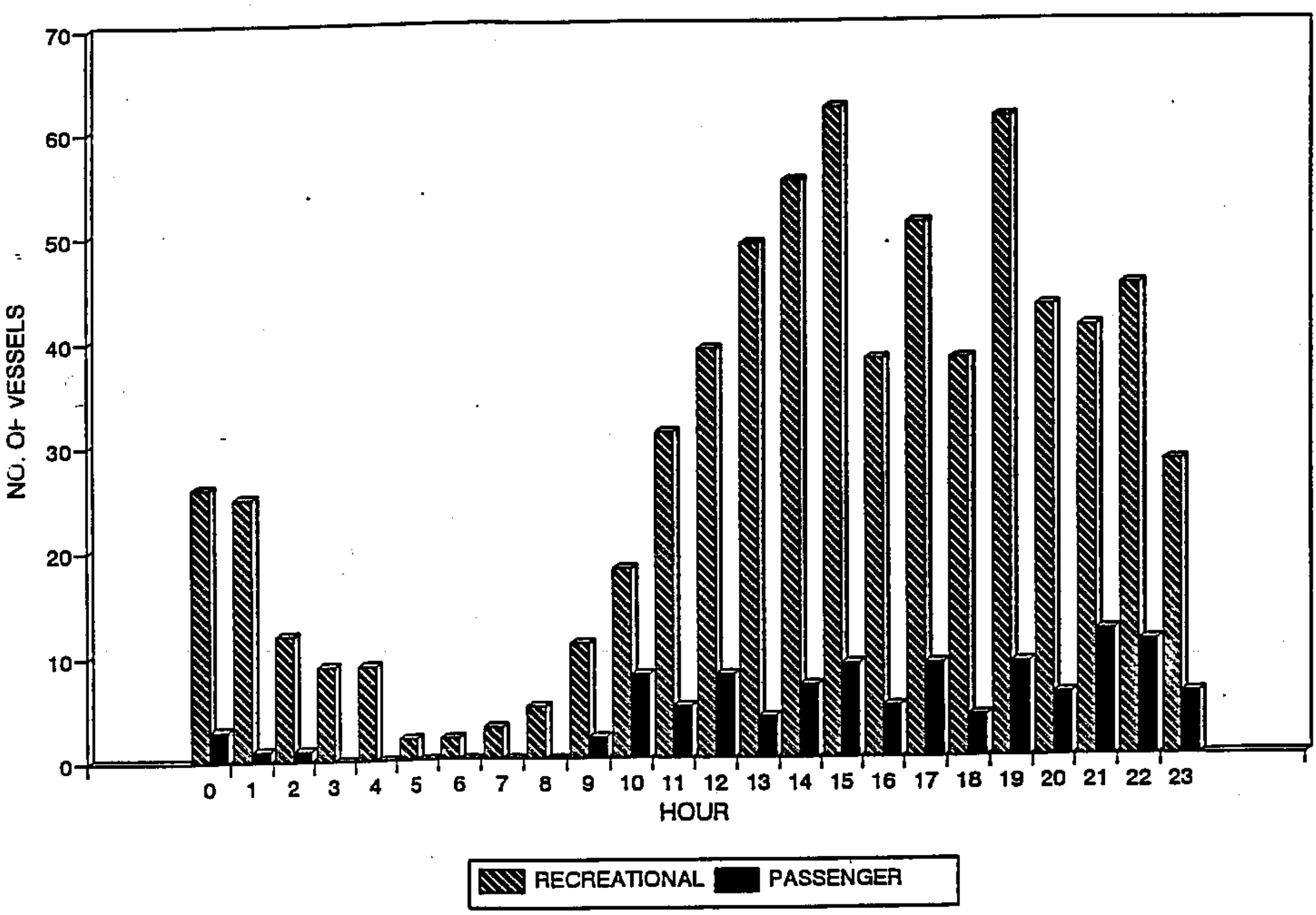
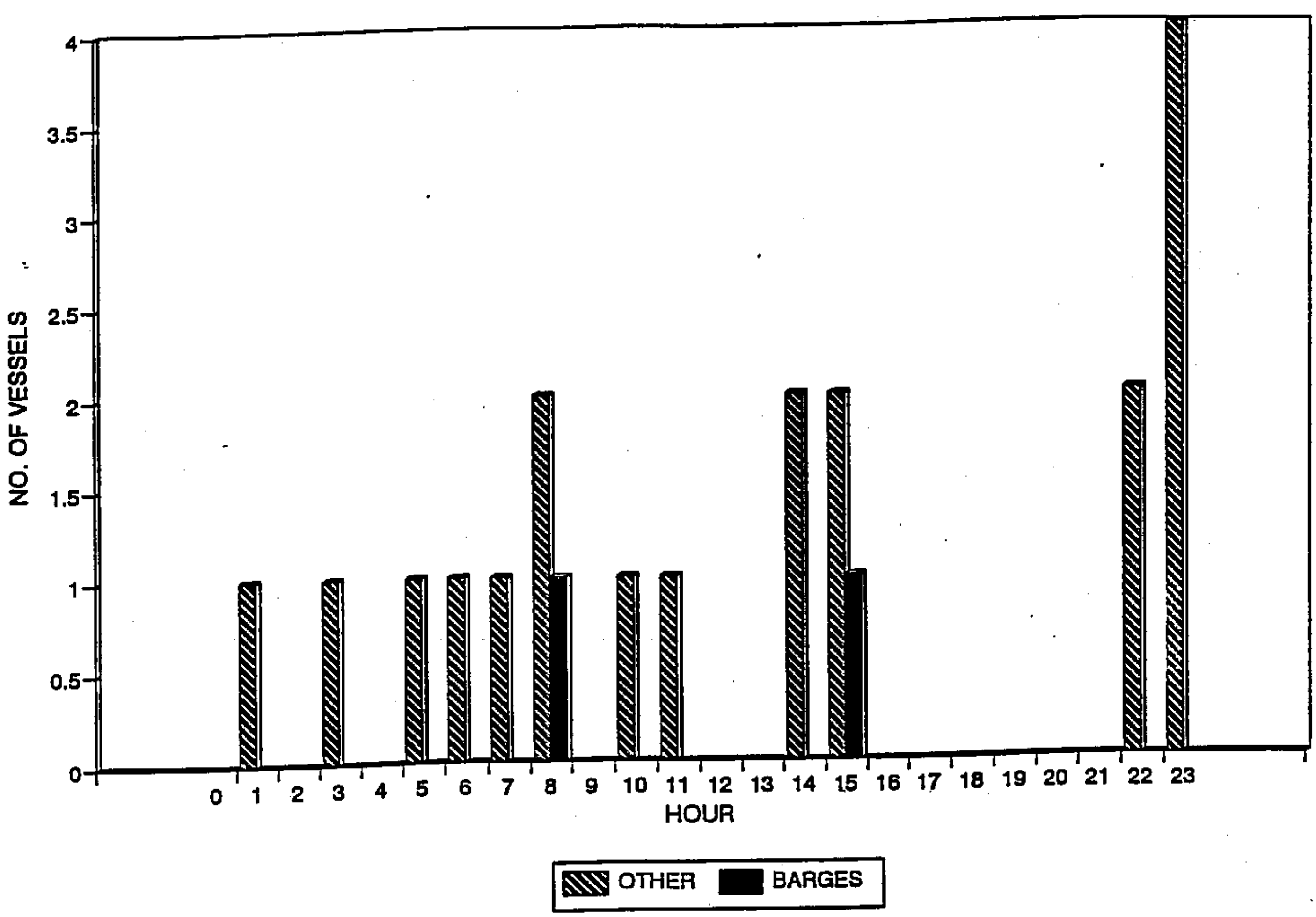


Figure. 5. HOURLY VARIATION IN TRAFFIC ON A TYPICAL WEEKEND DAY (JUNE, 1991)



recorded traffic for the year 1993 was 30536, which accounted for about 71% of the total transits. The traffic season begins in the month of May and reaches peak during June and July. Figure 3 depicts the monthly variation in traffic. Daily traffic is heavy during weekends. The hourly variation of traffic is shown in Figures 4 and 5.

Most of the recreational vessels that use the river return to the lake during the evening period and they moor in harbors out in the lake. They use the river marinas and yacht yards only on days when high winds prevail and also during the winter season. There are only three marinas along the river: Marina City, River City and River Bend Marina.

3.2 FUTURE VOLUME PROJECTIONS

Forecasting the future traffic on the river is based on projections extrapolated from current and historic data. Also, future growth factors for different types of vessels need to be arrived at before predicting future traffic. On analyzing the traffic data for the past nine years (ignoring the unusual drop in 1990) it became evident that there is a general increase in yearly traffic. The projected vessel traffic volumes are presented in Figures 6 through 9. The actual trend in traffic for the period 1986 to 1993 is depicted in these figures. A high growth projection and a low growth projection are also presented.

3.2.1 Commercial Traffic Growth: The commercial barge traffic volume can be expressed either by the number of vessels per year or by the total tonnage per year. The latter is the most common measure of lock capacity. The peculiarity of the Chicago Lock is that barge traffic constitutes the lowest segment amongst the total traffic. The level-of-service of the lock, which is an important factor governing the future planning needs, can only be measured by taking into account the number of vessels rather than tonnage. Thus a more appropriate measure of representing the commercial traffic is the number of barges. However, we have made an attempt to predict the future commercial traffic both in number of vessels and total tonnage.

The predicted barge and commercial traffic (in total number of vessels) are shown in Figure 6. The high growth projection represents a 5% annual growth factor, based on an average annual growth rate of traffic for the period 1986 to 1993. On the other hand, the low growth projection represents a growth rate of 3.7%. This percentage reflects the actual growth rate of traffic during the period 1976 to 1983. Barge traffic is shown separately in Figures 6 and 7.

After analyzing the current and historic data of commercial barges, it was found that the average tonnage growth rate is about 10%. This percentage is used to predict the high growth projection. In comparison, the historical tonnage growth rate (1950- 1988) for the O'Brien Lock was 2.2%. The low growth projection uses this value as the annual growth rate. Figure 7 shows the commercial traffic projection in tonnage.

3.2.2 Passenger Traffic Growth: Neglecting the drop in year 1990, there is a general trend towards an increase in passenger traffic through the lock. The various river based developmental projects reinforce the expectations for future growth. The passenger traffic data for the period 1986 to 1993 gives an annual growth rate of 1.6%. This percentage is adopted for the low growth projection. The high projection uses a growth factor of 3.7%, which represents the actual growth rate for the period 1976 to 1983. Figure 8 shows the projected growth for passenger vessels.

Figure. 6. FUTURE TRAFFIC GROWTH COMMERCIAL VESSELS (TOTAL NUMBERS)

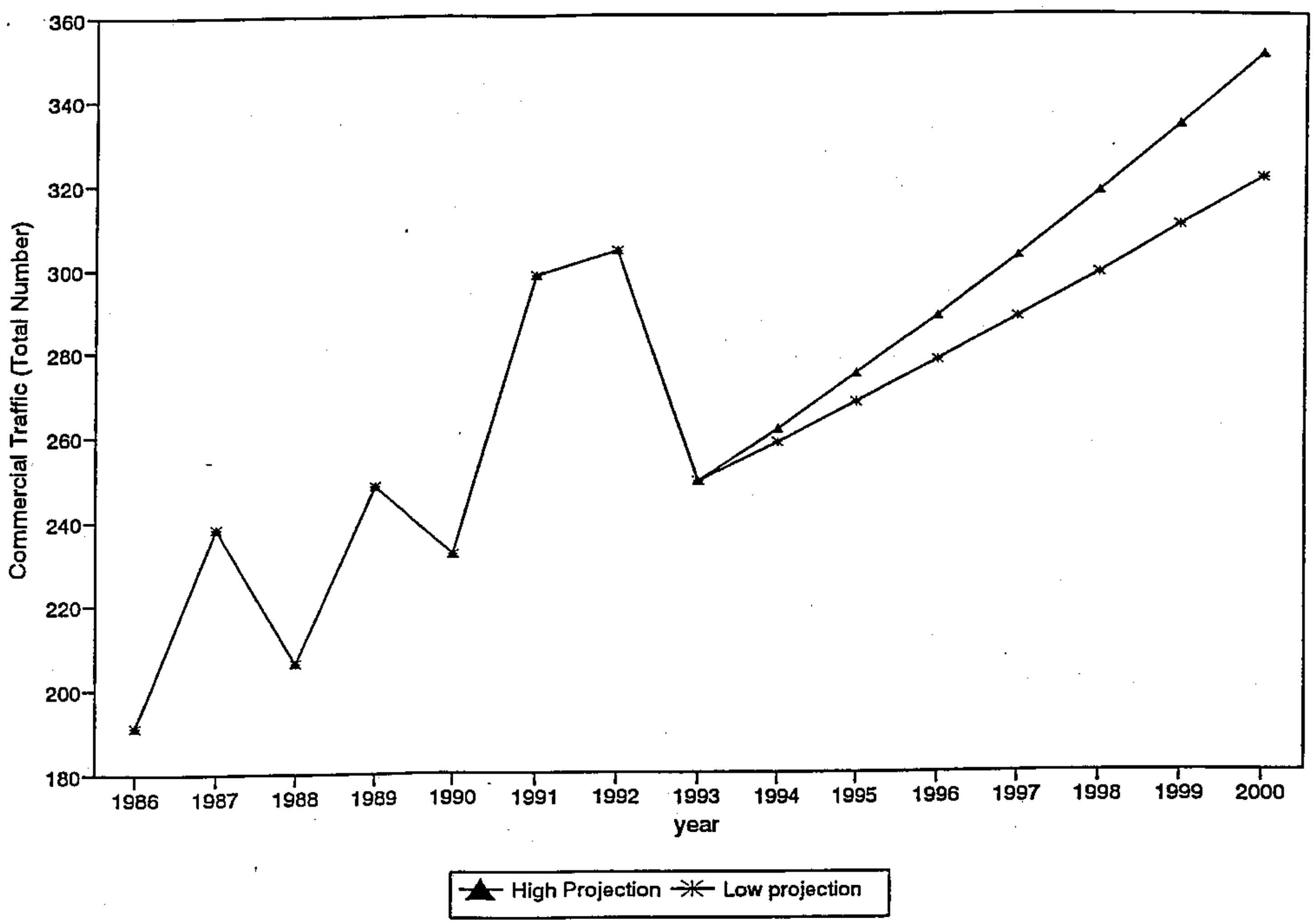


Figure 7. FUTURE TRAFFIC GROWTH COMMERCIAL VESSELS (TOTAL TONNAGE)

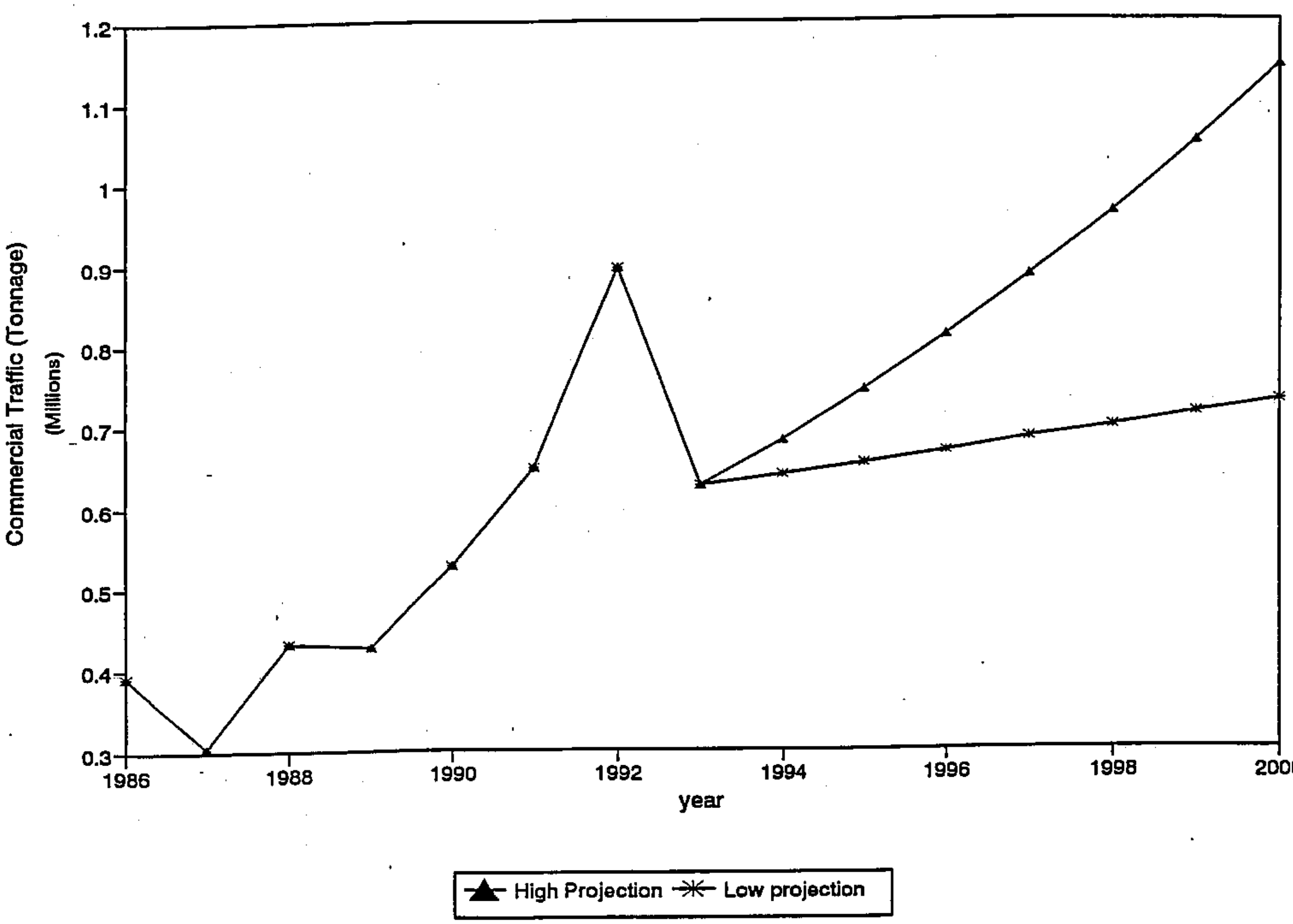


Figure 8. FUTURE TRAFFIC GROWTH
PASSENGER VESSELS (TOTAL NUMBER)

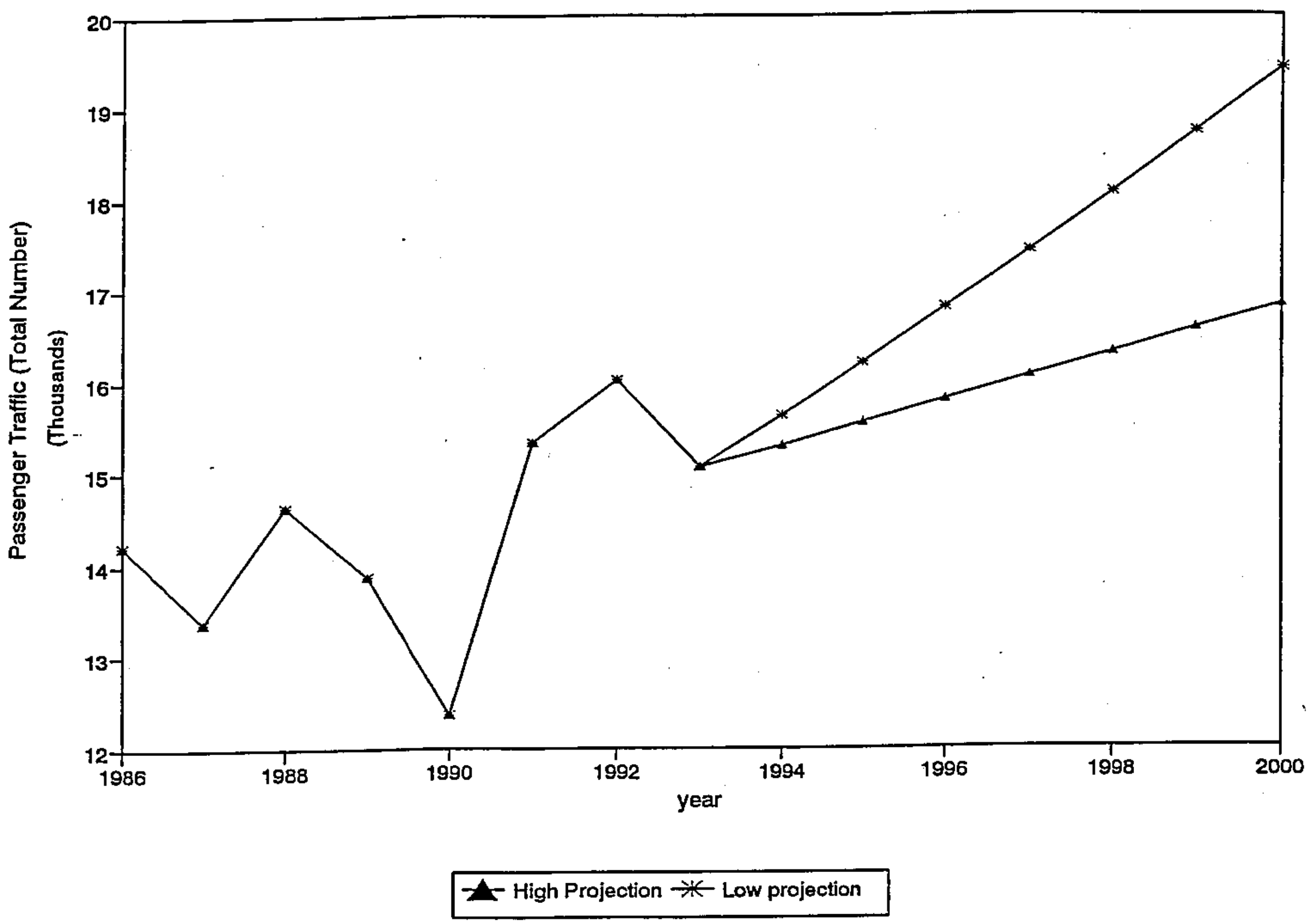
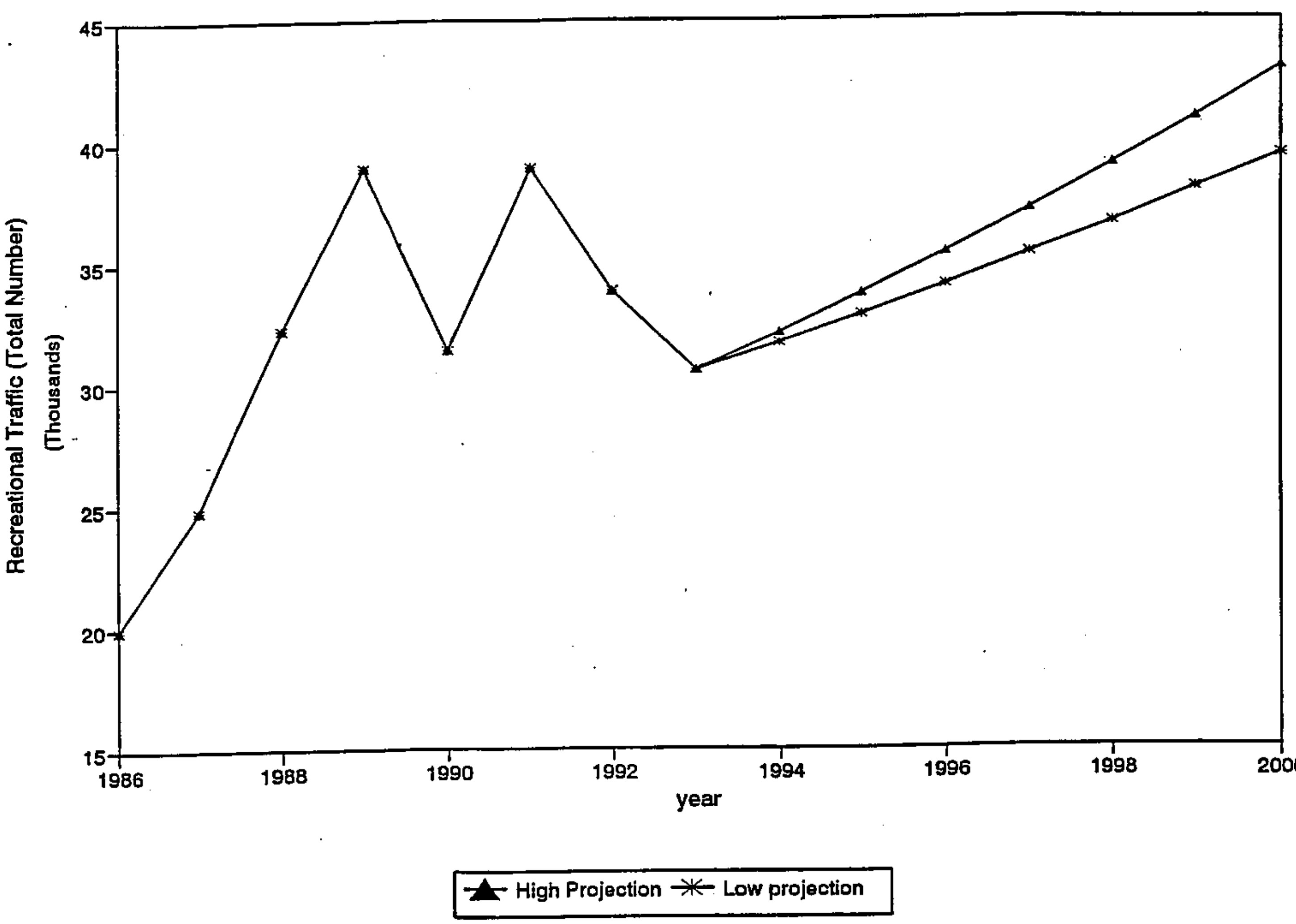


Figure 9. FUTURE TRAFFIC GROWTH RECREATIONAL VESSELS (TOTAL NUMBER)



3.2.3 Recreational Traffic Growth: There is strong indication for future growth in recreational traffic. The high growth projection uses a growth rate of 5%, which was the annual growth rate for the period 1986 to 1993. The low growth projection uses 3.7% as the growth rate. The projected traffic levels are depicted in Figure 9.

SECTION 4.

4.1 TRAFFIC CONFLICTS

4.1.1 Framework: The Chicago River is not the perfect place for the smooth and carefree movement of vessels. This is because of the non-uniform cross sections of the river. Furthermore, most types of vessels prefer a fixed route. For instance, a passenger tour boat's route along the river is from the Main stem on to the North branch up to Goose Island and from the South branch up to Congress Avenue. Although recreational vessels constitute the bulk of the total traffic, their presence in the river is limited to certain areas which are mainly due to lack of tie ups and landings, fewer recreational sites, and aesthetics. Barge traffic has increased in years and almost an equal number, if not more, of commercial barges passing through the lock use the South/North branch as their main route. The concentration of these vessels over these areas creates conflicts between them. So there is a dire need for analyzing the present and possible future conflicts in the river and lock area.

The best way of collecting information regarding conflicts between vessels was by interviewing people representing various agencies who were directly involved with waterway traffic. With this objective in mind, several individuals were interviewed representing barge companies, grain transport companies, recreational marinas, cruise line companies, the U.S. Army Corps of Engineers, the U.S. Department of Conservation, and the U.S. Forest Service. A number of boaters were also interviewed to get first-hand information and opinions of their points-of-view.

4.1.2 Interviews with Users of the River & Lock System

Barge operators: They pointed out that conflicts that exist in the River between commercial barges and recreational vessels are mainly due to reckless operation of motorboats. There was deep concern regarding motorboat operators not following the general rules of navigation, including speeding. A barge operator, who provides tugs to move the barges of other companies to various terminals along the Chicago River, attested to the serious problem of recreational boaters operating their vessels recklessly (some operating their boats without lights after dark), posing a hazard to everybody else on the River. The captain of a large barge company also cited recreational boaters as the main offenders. These boaters were not aware of their responsibilities, not realizing the limitations of the movement of a barge in comparison to a recreational boat. At the Lock, barge operators sometimes observed that lock operators let smaller vessels rush to the Lock before a barge was tied up securely to the side wall. At other times, passenger tour boats were given priority over barges at the Lock.

Licensing of all boat operators and educating them about navigation rules emerged as the best solution for mitigating the conflicts and speeding problems experienced by barge operators. Vigorous policing and patrolling of the River system, together with enforcing the navigational rules on all operators, was highly recommended as a solution to the problems described above, as well as for mitigating the problem of those operators under the influence of drugs and alcohol.

Recreational Marina Operators: The marina operators stressed the need for the residents of Greater Chicago and tourists to this area to "rediscover" the beauty of the Chicago River and it's attractions, and this could be achieved by providing additional access to the River at more locations. While the marina operators confirmed that conflicts did exist between barges and recreational boaters, they felt that only a small proportion of boaters created a bad image for all boaters. They endorsed the recommendation of barge operators that proper education of boaters, together with strict enforcement of drunk-operating laws would reduce, if not eliminate, current problems. Concern was also voiced about passenger tour boats cutting into the traffic stream in a hurry, with the object of completing their cycle-operating time as quickly as possible. This problem creates confusion for everybody, and tends to give recreational boaters a lower preference for right-of-way at the Lock.

Overall, the rapidly increasing number of tour boat companies along the main stem of the River has reduced the effective navigable waterway to a great extent. To add to this problem, it was observed that recreational boaters generally do not know how to operate their boats defensively when they are approaching large vessels, or when they are docking in the marinas. Part of this problem is excessive speeding, and no-wake zones are also affected for the same reason.

From the recreational boater's point of view, it was reported that some recreational boaters experience frustration at the lock because they are denied entry to the lock-chamber while waiting for the arrival and entry of tour boats. Unnecessary waiting time naturally makes lock-cycle times longer. One possible solution proposed is that if a tour boat is not seen within the established markers, the recreational boaters should be allowed to enter the lock-chamber, and if the lock-chamber is fully occupied, tour boats should wait their turn for the next lock-cycle. The Army Corps of Engineers have expressed that such problems are resolved through meetings conducted with representatives of recreational boaters, passenger tour boat companies, and the lock personnel.

Strong support was expressed for licensing recreational boat operators, considering the hazardous consequences of a large number of teen-agers (even 12-year-olds and younger), operating boats at speeds well above the limit prescribed. Marina operators strongly recommended the need for educating all boaters about safety, and for the city marine police to tighten their surveillance of the system.

Grain Companies: These companies handle grain, salt, steel, coal, etc., Because of a change in the current laws allowing river barges (with an American Bureau of Shipping Certificate) to go out in the Lake up to Milwaukee, there has been an increase in barge traffic in the system. This is a positive indication of the growth of commercial barge traffic through the Lock.

Commercial Passenger Cruise Lines: Representatives of cruise line companies generally felt that the careless operation of recreational boaters is a threat for everybody else on the river and through the lock. They felt that the best solution to this problem is for every recreational boater to obtain a U.S. Safe Boat Auxiliary Certificate, issued by the U.S. Coast Guard, and this certification would be the only other alternative to regular licensing.

U.S. Army Corps of Engineers: The Officer-in-Charge of the Chicago Lock was interviewed several times. He said that the Lock personnel were instructed to allow commercial tour boats to enter the Lock prior to the recreational boaters only if they are spotted on the river or the lake, within two to three minutes travel time from the lock chamber. The marker on the River side is the Lake Shore Drive Bridge. On the lake side, the marker is a circular area with a radius equal to the distance to the south guide wall.

Conflicts between vessels on the river, the lake, and the lock are primarily a consequence of recreational boaters operating their vessels while intoxicated; lack of navigational skills and knowledge, lack of proper safety devices, radios, and lines for tying up their boats while in the lock chamber are also cause for serious problems. The bottom line is that recreational boaters must be licensed. The attitude of commercial tour boat operators is demanding, in the sense that they want the lock service the moment they reach the Lock.

State and Federal Governments: The Chicago River Demonstration Project is the foremost among several projects that are underway to enhance the Chicago River's resources. The main objectives of this project are: to assess the environmental and recreational resources of the river system, propose recommendations to delineate existing values, and to find out future recreational resource capabilities. The agencies involved in this project are the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, and the USDA Forest Service. As part of this project, the North Central Forest Experimental Station conducted a survey on people's perceptions about the use of the Chicago River. The results of this survey revealed that more than 50% of the respondents find water quality, odor, and garbage dumping as major problems with the use of the River. Other problems include: floating debris on the river, lack of adequate policing and inadequate signing, and vessels without lights using the river after dark.

One of the activities of the Illinois Department of Natural Resources, Chicago Division, includes enforcing Illinois State laws, boating laws, recreational laws, and investigating boat accidents. Its operating area consists of the Illinois portion of Lake Michigan and the waterways of Cook County. The department's concerns were mainly with the conflicts between vessels, partly because of the increasing number of vessels using a small body of water. Adding to the problem was the lack of navigational rules among users of the river. In the lock area, the problems stemmed from recreational boaters trying to squeeze their way into the lock without following the order of precedence. There are also no-wake violations along the river. It was generally felt that education and enforcement are the key points for reducing conflicts, and that a mandatory operator education law would significantly reduce the problems cited.

Recreational Boaters: More than twenty recreational boater were interviewed. A large majority were not satisfied with their experience with the lock personnel, who apparently gave first preference to commercial boats over recreational boats. Other complaints were as follows: (1) Passenger tour boats did not yield to recreational boats, and honked the latter to speed up. (2) Some tour boats operated their vessels at high speeds and frightened recreational boaters. (3) operators of larger recreational boats complained about the behavior of the operators of smaller recreational boats. Most of the latter do not follow established rules at the lock, by rushing into the lock chamber without caring to give the right-of-way to other boats waiting ahead in the queue. (4) The overall experience at the lock is frustrating mainly because permission is not granted to enter the lock, just because a commercial tour boat is seen far beyond the Lake Shore Drive bridge, or way out on the Lake. (5) More policing and patrolling is needed near the Lock in the summer evenings, particularly during the weekends. (6) Sailboat operators complained about the long waiting time for bridges to open. (7) Some boaters felt that the river was not kept clean.

4.1.3 Summary of Conflict Study

1. Conflicts on the River: Based on the interviews conducted, it was found that conflicts created on the Chicago River are mainly caused by the concentration of vessels in certain areas and also by the careless operation of the recreational boaters. The narrow section of the River is a major factor contributing to the conflicts experienced.

Conflicts that were identified on the Chicago river are mainly caused by :

1. Recreational boaters operating recklessly speeding and creating wakes at no-wake-zones.

2. Recreational boaters not respecting the right-of-way for other vessels or vice versa.

3. Recreational boaters not being aware of limitations of barge captains while piloting (e.g. unable to stop quickly).

4. Operating vessels under the influence of drugs and/or alcohol.

5. Lack of knowledge about navigation rules, such as operating a recreational vessel near a large commercial vessel, docking properly, making sharp turns and taking proper actions at junctions where traffic moves in all directions.

6. Improper or inadequate display of signs (e.g. no-wake zones)

2. Conflicts at the Lock: Several weekends and weekdays during the year were spent at the lock, when the traffic was very high to study the conflicts that occur at the lock. The possible causes of conflicts that were identified, based on interviews conducted with a large number of people representing diverse users, personnel and officers of different organizations and departments, coupled with observations at and near the lock are as follows:

1. Smaller boats tie up to the lock wall before larger boats get their chance.

2. Passenger tour boats enter the lock chamber before all vessels leave.

3. Ignorance of boaters who do not know how to dock and tie up their boats to the lock wall properly.

4. Speeding of vessels as they enter and leave the lock chamber.

5. Start of lockage before all vessels tie up securely.

4.1.4 Accident Analysis: Generally, situations which entail severe conflicts among vessels result in accidents. Thus, it was essential to study the boating accidents that occurred

TABLE 1. ACCIDENT STATISTICS OF THE CHICAGO RIVER (COMMERCIAL VESSELS)

No.	YEAR	LOCATION	VESSEL	COURSE
1	1988-89	No Accidents Reported		
1	1990	Chicago Harbor	STAR OF CHICAGO	Unknown
2	1991	Railroad Bridge Mile 320.3	CAP'N HACKWORTH	South bound
3	1991	Clark St. Bridge	CHICAGO'S FIRST LADY	South bound
4	1991	Mile 322.2 South Branch	NORTHLAND/ ELLEN C.	North/ South
5	1993	Cicero Ave Bridge	WALTER HAGESTAD	North bound
6	1993	Cermak Ave Bridge	KATIE ANN/ BARAKA	North bound

SOURCE : US Coast Guard

on the river. Data pertaining to accidents involving commercial vessels were collected from the US Coast Guard, Marine office. The accident statistics from 1988 through 1993 are detailed in Table 1. There was one accident reported in 1990, three in 1991 and two in 1993. With such a low number of accidents reported every year, it is not possible to draw any conclusions about the general nature and cause of accidents.

The source of recreational accident statistics is the Illinois Department of Conservation, Department of Law Enforcement, where the accidents are reported by different law enforcement agencies. Only those accidents are filed by the Department of Conservation, that involve a property damage of more than $500. The accident statistics for the Chicago River dating from 1988 through 1993 are given in Table 2.

Table 3 shows the marine unit activity report of the Chicago Marine Police Unit for the period 1993. Ten accidents were recorded during 1993, but the seriousness or nature of those accidents are not known. At this point, it is also worth referring to the marine accident reports for the State of Illinois. Table 4 depicts the boating accidents reports for the year 1993. Even though the total number of accidents reported was down 13 from the 1992 total of 147, the number of fatalities was up by 4 for a total of 32 lives lost in recreational boating accidents. The facts surrounding the 1993 accidents indicates that out of the 32 fatalities, 29 of them might have survived had they been wearing safety devices. Alcohol abuse was found to be another significant factor causing these accidents. One out of every 4 fatalities indicated excessive consumption of alcohol. Other factors contributing accidents are standing up in small or overloaded boats, failing to follow the boating rules, careless / reckless operation, and canoes out in unsafe conditions.

TABLE 2. ACCIDENT STATISTICS OF THE CHICAGO RIVER (RECREATIONAL VESSELS), 1988 -1993

1988 - No accidents reported
1989 - No accidents reported
1990:

Total Number of accidents reported - 5

Type of accident;

Capsizing	- 1
Flooding	- 1
Collision with vessel	- 1
Hit by boat/propel	- 1
Other	- 1
Total----------	5

Operators opinion/ cause of accident;

Alcohol use	- 2 (40 %)
Excessive speed	- 4 (80 %)
No proper lookout	- 1 (20 %)
Fault of other person	- 2 (40 %)

1991:

Total Number of accidents - 5

Type of accident;

Collision with fixed object	- 2
Falls overboard	- 2
Other	- 1
Total ----------------	5

Operators opinion / cause of accident;

Excessive speed	- 1 (20 %)
No proper lookout	- 1 (20 %)
Hazardous waters	- 2 (40 %)
Fault of other person	- 1 (20 %)

(TABLE 2 Continued)

1992:

Total number of accidents - 3

Type of accident;

- Collision with vessel - 2
- Other - 1
  - Total --------- 3

Operators opinion / cause of accident;

- No proper lookout - 2 (40%)
- Fault of equipment - 1 (20 %)
- Unknown - 1 (20 %)

1993 - No accidents reported

SOURCE: US Department of Conservation

TABLE 3. MARINE ACTIVITY REPORT PERIOD 1993 (CHICAGO MARINE POLICE)

ARREST ACTIVITY:	TOTALS
1. ARRESTS PART I/II	12
2. ARRESTS 8 - 4.010	02
3. NARCOTIC ARRESTS	--
4. D.U.I	06
5. PERSONAL CITATIONS	187
6. HANG-ON CITATIONS	11
7. CURFEWS	--
8. SCHOOL ABSENTEES	--
9. SCUBA DIVING	54
10. WEAPONS SEARCH/REC.	03
11. BODIES RECOVERED	04
12. AUTO SEARCH/REC.	11
13. SEARCH DOWN VICTIMS	12
14. WARNING ISSUED	60
15. BOATS ASSISTED	03
16. BOAT ACCIDENTS	10
17. BOATS ADRIFT	48
18. BOAT FIRES	03
19. BOATS PUMPED OUT	30
20. BOATS TOWED	268
21. BOAT SEARCH O/D	16
22. SAFETY INSPECTIONS	398
23. MISC. ASSIGNMENTS	323
24. DETAILS	97
25. ESCORTS	23
26. FLARE SIGHTINGS	15
27. NAVIGATIONAL HAZARDS	34
28. PERSONS RESCUED	15

SOURCE: Chicago Marine Police Unit

TABLE 4

STATE OF ILLINOIS

BOATING ACCIDENT REPORT

From January 1, 1993 to December 31, 1993

Total Accidents	- 134
Injuries	- 94
Alcohol Confirmed	- 23
# of Drownings	- 29
# of Deaths From Injuries	- 3
TOTAL FATALITIES	- 32

PROPERTY DAMAGE (total of all vessels involved)

Total $ Amount	$212,616.00
Average $ Amount	$1,915.46

Number of Registered Boats - Approximately: 373,740

TIME & PLACE

MONTH

January	- 02	April	- 04	July	- 39	October	- 05
February	- 01	May	- 15	August	- 28	November	- 02
March	- 02	June	- 24	September	- 10	December	- 02
						TOTAL	134

DAY

Monday	- 17	Wednesday	- 14	Friday	- 07	Sunday	- 43
Tuesday	- 08	Thursday	- 08	Saturday	- 37	TOTAL	134

COUNTY

Adams	- 04	Jefferson	- 01	Ogle	- 02
Brown	- 01	JoDaviess	- 02	Pope	- 01
Cass	- 01	Johnson	- 01	Putnam	- 01
Christian	- 01	Kane	- 04	Randolph	- 01
Clark	- 01	Kankakee	- 01	Richland	- 01
Clinton	- 03	Knox	- 01	Rock Island	- 02
Cook	- 19	Lake	- 15	Sangamon	- 05
Dewitt	- 06	LaSalle	- 06	Shelby	- 04
DuPage	- 01	Livingston	- 02	St. Clair	- 02
Effingham	- 01	Macon	- 05	Tazewell	- 03
Franklin	- 03	Macoupin	- 02	Vermilion	- 01
Fulton	- 01	Marion	- 01	Whiteside	- 01
Grundy	- 02	Marshall	- 01	Will	- 04
Henderson	- 01	Mason	- 04	Williamson	- 03
Henry	- 01	McHenry	- 04	Winnebago	- 03
Jackson	- 02	Monroe	- 01	Woodford	- 01
				TOTAL	134

TIME

Midnight - 6:00 a.m.	- 11
6:01 a.m. - 12 Noon	- 16
12:01 p.m. - 6:00 p.m.	- 66
6:01 p.m. - 11:59 p.m.	- 39
Unknown	- 2
TOTAL	134

FORMAL INSTRUCTION

None	- 78
U. S. Coast Guard Aux	- 13
U. S. Power Squadron	- 10
American Red Cross	- 01
State	- 12
Other	- 16
Unknown	- 33
TOTAL	163

WATER CONDITION

Calm	- 62
Choppy	- 39
Rough	- 10
Very Rough	- 07
Strong Current	- 15
Unknown	- 01
TOTAL	134

WEATHER CONDITION

Clear	- 100
Cloudy	- 28
Fog	- 00
Rain	- 02
Hazy	- 03
Snow	- 00
Other	- 01
TOTAL	134

BOAT INFORMATION

Open Motorboat	- 85
Cabin Motorboat	- 20
Auxiliary Sail	- 06
Sail (only)	- 03
Rowboat	- 04
Canoe	- 08
Jet ski	- 18
Other	- 11
Unknown	- 08
TOTAL	163

FIRE EXTINGUISHER USED

Yes	- 21
No	- 110
Unknown	- 08
TOTAL	139

WIND

None	- 21
Light	- 69
Moderate	- 27
Strong	- 11
Stormy	- 02
Unknown	- 04
TOTAL	134

VISIBILITY

Good	- 113
Fair	- 13
Poor	- 05
Unknown	- 03
TOTAL	134

WEATHER ENCOUNTERED

Was as forecasted	-107
Not as forecasted	- 01
No forecast obtained	- 18
Unknown	- 08
TOTAL	134

OPERATION AT TIME OF ACCIDENT

Cruising	- 89
Approaching Dock	- 06
Water Skiing	- 07
Towing	- 06
Drifting	- 17
At Anchor	- 05
Tied to Dock	- 06
Fishing	- 08
Diving/Swimming	- 00
Hunting	- 01
Racing	- 00
Being Towed	- 02
Fueling	- 01
Other	- 15
Unknown	- 00
TOTAL	163

OPERATOR'S OPINION/CAUSE OF ACCIDENT

Alcohol - Use	- 25
Weather Conditions	- 14
Excessive Speed	- 27
No Proper Lookout	- 27
Overloading	- 04
Improper Loading	- 11
Hazardous Waters	- 34
Fault of Other Person	- 35
Drug Use	- 01
Fault of Hull	- 05
Fault of Machinery	- 09
Fault of Equipment	- 07
Other	- 62
Unknown	- 04
TOTAL	265

TYPE OF ACCIDENT

Grounding	- 05	Collision with Float Obj.	- 10
Capsizing	- 23	Falls Overboard	- 13
Flooding	- 02	Falls in Boat	- 01
Sinking	- 08	Burns	- 02
Fire or Explosion (fuel)	- 03	Hit by Boat/Propeller	- 06
Fire or Expl. (other)	- 01	Other	- 09
Collision with Vessel	- 32	Unknown	- 00
Collision with Fixed Obj.	- 19	TOTAL	134

BODY OF WATER

Apple Canyon Lake	- 02	Lake Mildred	- 01
Calumet Sag Channel	- 05	Lake of Egypt	- 02
Canton Lake	- 01	Lake Pistakee	- 01
Carlyle Lake	- 03	Lake Sara	- 01
Chain O'Lakes	- 02	Lake Shelbyville	- 04
Chautaqua Lake	- 01	Lake Springfield	- 05
Clinton Lake	- 06	Lake Summerset	- 01
Crab Orchard Lake	- 02	Lake Thunderbird	- 01
East Fork Lake	- 01	Lake Zurich	- 01
Farm Pond	- 03	Mill Creek Lake	- 01
Fox Lake	- 03	Mississippi River	- 07
Fox River	- 10	New West Frankfort Lake	- 01
Gillespie Lake	- 01	Otter Lake	- 01
Grass Lake	- 02	Patterson Bay	- 01
Illinois River	- 14	Petite Lake	- 01
Kankakee River	- 03	Reese Creek	- 01
Kaskaskia River	- 03	Rend Lake	- 02
Lake Arlan	- 01	Rock Quarry	- 01
Lake Centralia	- 01	Rock River	- 06
Lake Decatur	- 03	Sangamon River	- 02
Lake Holiday	- 01	Sanchris Lake	- 01
Lake Kincaid	- 02	Silver Lake	- 01
Lake Michigan	- 17	Small Pond	- 01
		Vermilion River	- 03
		TOTAL	134

AGE	Less than 20 hours	20 to 100 hours	100 to 500 hours	Over 500 hours	Unknown	Total
13 - 17	02	04	01	00	00	07
18 - 19	01	01	01	00	00	03
20 - 29	11	07	11	03	01	33
30 - 39	04	09	14	16	05	48
40 - 49	04	06	15	12	04	41
50 - 59	02	02	06	05	00	15
60 - 69	02	00	01	01	02	06
70 - Over	00	01	00	01	02	04
Unknown	00	00	02	00	04	06
TOTAL	26	30	51	38	18	163

17 or Younger 7 With Instructions 5 Without Instructions 2

4.1.5 Conclusions: The comparatively low figure of accidents reported every year shows that the nature of accidents in Chicago River is not very alarming. Moreover it is difficult to draw any conclusion about the leading cause of these accidents. However, it can be undoubtedly stated that the major contributing factors are excessive speed, failure to follow operating rules, careless/reckless operation and excessive alcohol use. Failure to wear safety devices was found to be the leading cause of 32 fatalities reported in the state of Illinois for the year 1993.

4.2 CAPACITY ANALYSIS

4.2.1 Capacity: The capacity of a lock system is a relative term. One could compare it to the capacity of a signalized approach of a street intersention. However, unlike the capacity of a highway section, which is relatively stable, the analysis of the capacity of a lock or a signalized intersection is to calculated by introducing the concept of time along with geometric characteristics of the facility and the composition of traffic (5).

The capacity of a lock system is a relative term. It can be defined mainly in four different ways as follows.

1. The traditional definition of the capacity of a lock is the maximum tonnage that can pass through a lock chamber under the most ideal circumstances. This definition for the maximum theoretical capacity doesn't have real significance, because all barges will not be fully loaded and commercial tows are not the only vessels passing through the lock. Thus the number of vessels rather than tons locked per unit time would appear to be a more appropriate measure of lock output and capacity.

2. The capacity of a lock is the number of vessels that can be accommodated in the lock

chamber. It is a function of the lock chamber dimensions, vessel types and vessel dimensions. For a given lock, the capacity varies with the types of vessels and their distributions.

3. The capacity flow through the lock is the maximum flow rate at which the vessels can pass through the lock during a given time period under prevailing waterway, traffic, and locking conditions.

4. The capacity of a lock is the number of lockages that can be performed in a given time period. This definition could be particularly useful for a lock that has a high usage of recreational boats.

Traffic conditions include volume of traffic and distribution of vessels by type and size. Waterway conditions include dimensions of the queuing area and lock chamber and number of possible lanes. The amount of time required for transiting the lock is another important factor guiding the capacity flow. The capacity can be expressed as number of vessels per day or per year. This flow rate is defined for each direction of flow. The capacity of a waterway lock is related to the Level-of-Service (LOS) of the facility.

4.2.2 Level-of- Service (LOS): The Level-of-Service is a measure of the service quality that is perceived by the users of the system. The concept of LOS addresses a wide variety of operating conditions such as capacity, speed, travel time, freedom to maneuver, traffic interruptions in terms of time delay, comfort, convenience and safety. The LOS of a lock makes use of time delay caused to each vessel as the primary measure of effectiveness. The delay is a measure of operator discomfort, frustration, fuel consumption and lost travel time.

The quality of service can be measured in terms of six groups of L.O.S, 'A' through 'F'. The stopped delay time is the duration from the time of arrival of a vessel at the queuing area to the time it starts entering the lock. The stopped delay is a function of the lock service time 'T'. The service time 'T' is the sum of time taken for the vessels to enter the lock, time of lockage and the time taken to leave the lock. A brief description of the different levels of service are given below.

Level-of-Service 'A': At this level the average headway between vessels is greater than the service time 'T' of the lock. The stopped delay could be as low as 0 and this is the most favorable situation as far as the user is concerned. But at this level the lock utilization is very low and so is the efficiency of the system.

Level-of-Service 'B': The operating condition for this level is that the average headway between vessels is greater than the service time of the lock. The vessels are faced with a maximum delay of T. The presence of a commercial barge does not affect the existing LOS at all.

Level-of-Service 'C': At this level, the average headway between vessels is almost equal to the service time 'T' of the lock. The maximum stopped delay could be 1.25T. The recreational vessels do not have to wait longer than one cycle. The presence of a barge might deteriorate the situation for a shorter period of time.

Level-of-Service 'D': The operating condition for this level is that the average headway between vessels is less than the service time of the lock, but the number of vessels waiting are less than the capacity of the lock chamber. The maximum stopped delay could be 1.75T. The presence of a barge will deteriorate the situation for a shorter period of time.

Level-of-Service 'E' : This level indicates the capacity flow rate of the lock. At this level, the number of vessels waiting at the queuing area will be just equal to the capacity of the lock chamber. The presence of a barge will create a situation where a recreational vessels might have to wait more than one cycle of operation of the lock. The maximum delay can be 2T.

Level-of-Service 'F' : This represents an unstable situation of the lock where the number of vessels waiting at the queuing area are more than the capacity of the lock chamber. This could also happen as a result of a stall occurred at the lock. The recreational vessels will have to wait longer than one cycle of lock operation.

The detailed observation done at the lock about its operation and the analysis of the daily reports prepared at the lock reveals that the average service time of the lock varies from 11 to 13 minutes. Based on this service time, a level - of - service criteria table is prepared and is shown in Table 5.

4.2.3 Lock Operation Analysis: The Chicago Lock is located immediately east of the city's business district, separating the Chicago River from Lake Michigan. The lock consists of a single chamber with inside dimensions 600 ft. long, 80 ft. wide and 23 ft. deep. It is open to navigation 24 hours/day, 12 months/year with occasional down time for maintenance. The US Army Corps of Engineers has contracted out the operation of the Lock to a private company.

The lock master is in charge of the immediate control and management of the lock and the lock area including the lock approach channel. East bound and west bound vessels wait at the queuing area for their turn, and the permission to enter and leave the lock chamber is given through signals. When the lock is ready for entrance, the traffic light shows green and the vessels enter the lock according to their order of precedence. The general rule of precedence at the lock is that vessels belonging to the United States have the first preference over all other vessels. Licensed commercial passenger vessels have precedence over commercial cargo tows and in turn the latter have precedence over recreational crafts.

The speed of approaching vessels in the queuing area is 2 mph and the speed of departing vessels is 5 mph. As soon as all the vessels inside the lock chamber are securely tied against the lock wall, the lock gates are closed and the water level is raised or lowered, as necessary. This operation takes about three to four minutes to complete. The mooring lines are cast off when the gates are fully opened and a horn signal is given for the vessels to leave the lock chamber. The total time taken for completing the lockage is largely dependent on the time taken for the vessels to enter and leave the chamber.

4.2.4 Queuing Analysis: A queuing, or waiting-line, phenomenon is an every-day occurrence. Examples include motor vehicles waiting in line to be served at a busy gasoline station, airplanes awaiting clearance for take-off or landing at an airport, and vehicles waiting at an intersection for the green signal. The operation of vessels waiting for service through a lock is similar in many respects to flow through a signalized street intersection. No matter how complex, queuing systems are characterized by three components: an "arrival" pattern, a service facility, and a queue discipline. When all three components are constant, the system can be analyzed by deterministic methods. Probabilistic methods are used when one or more components are not constant (5).

The arrival pattern describes the way in which the vehicles or vessels to be served enter the service facility or lock. The service facility is characterized by the number and arrangement of servers and by the service pattern. For example, a facility can be a single-server or a multi-server facility. The Chicago Lock is a single-server facility. The service pattern measures either the rate at which customers are processed (e.g., vessels/hour), or the time required to serve individual vehicles/vessels or a platoon of vehicles/vessels in a queue. The queue discipline refers to the rules by which the next customer, or vessel to be served is chosen. Some common rules include the following: a first-in, first-out rule (FIFO), as in the case of the lock, where the first vessel in line is served first; and, a last-in, first-out rule (LIFO), where, for example, a machine operator might stack finished parts beside a machine, so that the last part is on top of the stack and will be selected first. The service rule may allow either a single queue or multiple queues. Also, the vehicles/vessels may be treated equally or they may be treated according to some priority rule.

The solution to a queuing problem entails the assessment of a systems performance, which in turn can be described by a set of performance measures or levels-of-service, as described before. A queue is formed when the demand for service exceeds the capacity of the facility for a period of time (or when the arrival rate of vessels is more than the service time rate). As explained before, a major factor governing the level-of-service of waterway facilities is the delay incurred by vessels waiting at a lock entrance for service. Queuing models are developed for quantifying time delays.

4.2.5 Queuing Model: The input requirements for queuing analysis include arrival time of vessels at the lock, service time, and the queue discipline. Interdependence between locks are not considered in this model, as its effect needs to be considered only when a number of locks are located in series and vessels have to pass through them.

Arrival Pattern: The arrival pattern of vessels at the lock is assumed to be Poisson distributed. Considering the effect of interdependence as negligible, this assumption seems to be a good one (2). If the arrival pattern of vessels form a Poisson distribution, the inter-arrival times follow an exponential distribution. Inter-arrival time is the time difference between the arrival of the (i+1)th vessel and the (i)th vessel at the queuing area of the lock.

Service time distribution: It is not possible to assume the service time distribution as exponential distribution as in the case of inter-arrival times. This is because the service pattern of almost all vessels are quite similar, which does not satisfy the requirement for an exponential distribution (6). Thus, for the service times, a general distribution is assumed in which the vessels are assumed to have independent service times, but no restriction is imposed on the service time distribution.

Assumptions: The following assumptions are made for the analysis of lock operation.

1. Vessels arrive at the lock randomly,

2. The arrival of one vessel is independent of the arrival the previous vessel,

3. The vessels are categorized into three groups, viz. commercial barges, Commercial passenger and government vessels and recreational vessels.

4. The lock operation analysis is done for one directional movement of traffic and it is assumed that the total traffic in-bound and out-bound movement are the same.

5. The queue discipline is first-in-first-out.

Commercial barges operate 24 hours/day, 12 months/year, and arrive at the lock on a random basis. On the other hand, commercial passenger vessels have schedules of dock departures which should theoretically result in non-random arrival at the lock, but which, in practice arrive random. Hence, all of the combinations of vessels arriving at the Lock could therefore be construed as random arrivals, and the outcome has little or no effect on the model's ability to predict total or mean delay.

Single-server model with Poisson Arrival and any Service -time distribution (M/G/1 model): Suppose that a queuing system has a single server with Poisson arrival pattern represented with a fixed mean arrival rate, δ . The service pattern is represented by the mean service rate, μ and variance, σ^2. The M/G/1 model is described as follows.

Let t_i - Time between the arrival of the ith and (i+1)th vessel

x_i - Service time of the ith vessel

t_a - mean inter arrival time

t_s - mean service time

δ - arrival rate ($=1/t_a$)

μ - service rate ($=1/x_s$)

σ^2 - service time variance

k - number of servers

$\bar{\tau}$ $=\delta/\mu*K$ - traffic intensity

W - mean delay (time in queue)

$= \delta/\mu^2 (\mu^{2}*\sigma^2+1)/(2*(1-\tau))$

Mean Inter arrival Time: Inter-arrival time is defined as the time difference between the arrival of the (i+1)th vessel and the (i)th vessel at the queuing area of the lock. The inter - arrival time is determined from the daily reports prepared at the lock, detailing each vessel using the lock. The weekend traffic data for the month of July 1993 was collected and used for the analysis.

If the arrival pattern of vessels conforms to a Poisson distribution, the inter-arrival times follow an exponential distribution. According to the exponential distribution, the probability of inter-arrival times equal to or greater than 't' is given by:

$$P\ (g \geq t) = e^{(t/T)}$$

where T = mean inter arrival time (the mean of the interval probability distribution)

Since there are three types of vessels to be considered in the model, the mean inter-arrival time was determined for each group by fitting an exponential distribution. The discrepancy between the actual number of lockages in the time interval indicated and the expected number was tested using Chi- square. The Chi - square test showed that the fit is acceptable at the 1 % level. The mean inter-arrival time calculated for a typical weekend day were, 16 minutes for commercial passenger vessels, 15 minutes for recreational vessels, and 720 minutes for commercial barges.

Mean Service Time: A General Distribution was assumed for the service pattern. The mean and variance of service time on all the weekend days of the month of July 1993 were calculated and are shown in Table 6.

Mean Waiting Time: The average waiting time each vessel experienced on every weekend day was calculated and is displayed in tabular form in Table 7.

Level-of-Service at the Lock

Comparing the mean waiting time calculated for each weekend day with the L.O.S table shown in Table 5, it was found that the L.O.S on four weekend days was 'C' and on the remaining five weekend days,'D'. With the help of the predicted future demand, it is possible to estimate the L.O.S and hence the capacity of the lock at any future year, provided the inter-arrival time and service time details are known.

TABLE 5. LEVEL OF SERVICE CRITERIA FOR CHICAGO LOCK

L.O.S	Average Waiting time (min.)
A	< 3 min.
B	up to 10 min.
C	up to 16 min.
D	up to 23 min.
E	up to 26 min.
F	> 26 min.

TABLE 6. MEAN AND VARIANCE OF SERVICE TIME DISTRIBUTION

Day	Mean Service Time (Minutes) (t_s)	Variance
07-03-93	13.09	2.0
07-04-93	13.135	1.85
07-10-93	13.09	1.75
07-11-93	13.08	2.0
07-17-93	11.05	1.476
07-18-93	11.09	1.799
07-24-93	11.0	1.462
07-25-93	11.06	1.497
07-31-93	11.58	1.957

TABLE 7. CALCULATION OF AVERAGE WAITING TIME

Day	N_p	N_r	N_b	t_a	t_s	σ	$\delta = 1/t_a$	$\mu=1/t_s$	$\tau=\delta/\mu$	W min.
07-03-93	129 14 %	822 85.8%	2 0.2%	16.5 5	13	2.0	0.0604	0.077	0.785	23.0
07-04-93	123 19 %	532 80.6%	3 0.4%	18.0 1	13.1	1.85	0.055	0.076	0.729	17.8
07-10-93	163 21.7%	586 77.9%	3 0.4%	18.0 4	13.0	1.75	0.055	0.077	0.721	16.9
07-11-93	127 19.7%	513 79.9%	3 0.4%	18.0 2	13.0	2.0	0.055	0.077	0.721	17.1
07-17-93	126 24%	394 76%	0	15	11.0	1.48	0.059	0.091	0.73	13.4
07-18-93	119 20%	470 79.9%	1 0.001	15	11.0	1.8	0.067	0.091	0.73	15.4
07-24-93	96 23%	315 77%	0	15.2 3	11.0	1.46	0.0659	0.091	0.73	14.9
07-25-93	95 19%	403 81%	0	15.1 9	11	1.49	0.658	0.091	0.73	14.9
07-31-93	147 (18%)	650 (82%)	0	15.1 8	11.5	1.95	0.0659	0.086 9	0.76	18.4

(Please refer next page for explanation of each parameter)

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Where,

N_p	=	Number of passenger vessels on each day (one diection)
N_r	=	Number of recreational vessels on each day
N_b	=	Number of barges on each day
t_a	=	Mean inter arrival time
	=	$N_p * t_p + N_r * t_r + N_b * t_b$
t_p	=	Mean inter arrival time of passenger vessels
	=	16 min.
t_r	=	Mean inter arrival time of recreational vessels
	=	15 min.
t_b	=	Mean inter arrival time of barges
	=	720 min.
t_s	=	Mean service time (refer Table 4.6.)
σ	=	Standard deviation of service time (refer Table 4.6.)
δ	=	Mean arrival rate (=1/t_a)
μ	=	Mean Service rate (= 1/t_s)
τ	=	Traffic intensity (= δ/μ)
W	=	Average waiting time

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4.2.6. Summary: Waterway capacity planning is a means of predicting the extent of delays to vessels as traffic increases over time. In this section, an attempt was made to perform a capacity analysis for the Chicago lock. The principle involved was to estimate the average stopped delay with the help of L.O.S concepts. Queuing theory was adopted for estimating the average delay experienced by a vessel. The results of the analysis show that the traffic flow through the lock is not at capacity on any of the weekends considered. However, this doesn't mean that the flow rate is below capacity at all times during a particular day. Note that the L.O.S level is estimated based on the average stopped delay on a particular day. There could be instances when, for a period of time during a day, the L.O.S of the facility reaches capacity. This kind of estimation of the delay can only be done with the help of a simulation model, which is beyond the scope of this project.

It is possible that recreational vessel operators may be able to learn when the congestion at the lock is most likely to occur, thus modifying their behavior pattern by using the lock at non-peak times.

SECTION 5.

5.1 POTENTIAL SOLUTIONS FOR TRAFFIC CONFLICTS

The conflicts created on the Chicago River are mainly caused by the concentration of vessels at certain locations of the river and by the vessels themselves. The major causes of conflicts are reckless operation, speeding, and lack of operating knowledge among users. As mentioned previously, vessel conflicts are a safety issue and, in the worst case scenario, result in accidents. The accident statistics in Chicago and Illinois show that the primary causes of accidents are excessive alcohol abuse, careless operation, excessive speed, improper attention. Also, failure to possess or wear safety devices contributes to fatalities. Conflicts at the lock area are mainly caused by increases in the number of vessels using the lock during certain periods of time, particularly in the summer months. In short, congestion itself is a cause of conflicts among users.

The potential solutions that are recommended for reducing such conflicts fall into four groups, namely:

1. Recommended policies
2. Licensing
3. Substituting licensing with a mandatory certificate
4. Law enforcement

The following paragraphs explain the merits and limitations in implementing these solutions.

1. Recommended Policies: The following policies are recommended for the free and safe movement of vessels on the Chicago River and Lock.

(a) Restricting new tour boat companies: Currently there are about eight passenger tour boat company docks located along the main branch of the river. The names of the cruise line or their vessels are, Mercury, Wandela, Admirals, Skyline Queen/Skyline Princess, Sunliner, Islander, Island princess and Jamaica. At some spots two docks are located on either side of the river (for example, Mercury and Wandela docks on either ends of the Michigan Avenue Bridge). Each of these companies has at least one boat at the dock most of the time during the summer season. During the summer weekends, traffic created in these areas is very heavy and these docked vessels reduce the effective navigational waterway thereby affecting the smooth maneuvering of other vessel traffic, especially barges. With the predicted increase in future traffic through the corridor, this also will have an impact on future conflicts. Thus, it is extremely important that a thorough evaluation of the impacts on the current and future traffic be done, before allowing any more commercial tour boat companies on the main branch of the river.

(b) Demarcate No-Wake-Zones: One of the major factors contributing to the conflicts at the lock area is the violation of the no - wake - zone ordinance. It is important that no - wake - zone ordinances be enforced wherever necessary. Currently, the Chicago River Channel (from Chicago Lock to Lake Shore Drive Bridge) which is within the Federal Waterway boundaries is demarcated as a no - wake - zone. Apart from this, the river area in front of marinas and a few private docks are also demarcated. No-wake zone signs which are visible enough to draw attention of the vessel operators need to be displayed at these locations. The punishment for offenders also can be indicated on these signs. Blue flashing lights or flags also can be used to alert operators.

2. Licensing: About fifty percent of the recreational boaters, as well as all the other agencies who were interviewed suggested that licensing is the most effective solution for the conflicts that occur on the Chicago River. Recreational boaters are found to be responsible for most of the conflicts identified. A considerable number of users are ignorant about safety rules, defensive operation of the boat near a large vessel, and proper docking at the marina or inside the lock chamber. Another factor which leads to conflicts is the age of the boater. Licensing is an effective means of making boaters responsible for their actions, forcing them to learn the navigational rules, and demanding that a proper age limit be made a mandatory requirement.

The best way of measuring the intensity of conflicts between vessels is to study the accident statistics of the river. The low rate of accidents reported every year (less than ten) in effect lessens the seriousness of conflicts on the Chicago River. A move towards licensing requires considerable effort and a very high capital investment. Moreover, licensing if implemented would require more law enforcement personnel for effective management. Thus, it is felt that it may not be worth trying such an alternative, at least in the short run, as it is very difficult to gain enough support with the legislature. Therefore, this alternative is removed from the list of recommendations.

3. Certification: Under this proposal the following policies are suggested.

- Any user to be eligible for operating a recreational boat should possess a valid certificate that is issued by an agency such as, the United Safe Boating Institute. The certificate can be acquired by successfully completing a boating course that is offered by any of the following agencies.

    1. United States Power Squadrons
    2. United States Coast Guard Auxiliary
    3. United States Yacht Racing Union
    4. American Red Cross

The boater should possess the certificate every time he/she is making a trip on water. Those with sufficient experience need not attend the course. The certificate also may be obtained by passing the test.

- The minimum age for obtaining the certificate is 16 years.
- The Coast Guard, City or State Police can impose penalties for failure to possess the certificate. The punishment clauses include operator fines, suspension of operator privileges,

and suspension of boat registration.

4. Law Enforcement: Law enforcement efforts have a great role in eliminating conflicts between vessels. As of now, there has not been enough policing/patrolling on the Chicago River. It has been keenly felt that some navigational rules need to be enforced more effectively.

(a) "Boating While Intoxicated" (BWI) laws

Alcohol is reported to be the primary cause for most of the boating accidents that occur in Illinois. Undoubtedly, it has lead to conflicts between vessels. Stringent anti-alcohol recreational boating laws need to be enforced. The enforcement clauses should include special alcohol patrols on the river , preliminary alcohol breath tests and blood and /or urine drug (or alcohol) tests. Special alcohol patrols, including sobriety checkpoints, need to be intensified on the river especially on special holidays such as July fourth weekend and Venetian Night.

(b) Laws against negligent operation

Examples that constitute negligent or grossly negligent operations are;

- Operating a boat at excessive speed in no-wake-zone areas and in the vicinity of other boats, especially barges and manually operated vessels such as canoes and rowboats.
- Displaying navigation lights improperly
- Neglecting the rules to be followed at the lock area, for example: squeezing into the front of the queue, moving in and out of the lock chamber at a higher speed, and not obeying the requests of the lock personnel.

The daily police patrol on the river and lock area need to be done on a more frequent basis in order to control these violation of laws.

SECTION 6.

6.1 CONCLUSIONS AND RECOMMENDATIONS

When this study was first initiated, it was not entirely clear which problems connected with the river and lock were critical. However, when all of the data were analyzed and the results of the interviews were carefully studied, it was abundantly clear that the problems were most severe during the weekends, particularly during the summer season, with the high recreational traffic. The analysis of the capacity of the lock system revealed that although the lock was still performing satisfactorily for the most part, there is the probability that in the years to come the performance would deteriorate as the number of transits through the lock increased. Safety related problems seemed to be the most important issues connected with the system, and critical problems appeared to be hinged around efficiency and safety concerns.

In order to have an effective and safe management of the waterway system, all agencies and operators involved in the waterway transportation must be aware of each other's responsibilities. The peculiarity of the Chicago River and Lock system is that many agencies are involved in the management and law enforcement (US Army Corps of Engineers, Illinois Department of Transportation, Chicago Park District , US Coast Guard, Illinois Department of Conservation, and Chicago Marine Police are among them). It is therefore imperative that the vessel operators know without ambiguity, each of these agency's roles and responsibilities. Moreover, coordination between public and private agencies must be improved so that it will aid the law enforcement agencies in their momentous task of keeping the waterway transportation system safe and effective. It appeared from the information collected during this study that there is a tremendous potential for increase in the waterway traffic, especially recreational traffic, through the Chicago River. This should be a major concern for all of the regulatory agencies. The impact of recreational traffic in the total transportation system is substantial, hence the highest attention needs to be paid to dealing with conflicts created between vessels and accommodating the future traffic projected. In view of the wide range of efforts that are going on to develop the river for recreation, it should be recognized that the exchange of information among different agencies promoting the recreational and other uses of the river is very important for the effective management of the system.

The detailed study on the current and future traffic and causes of conflicts between different types of vessels leads to the following recommendations.

- The conflicts between different types of vessels were found to be mainly caused by the concentration of vessels in limited areas. This leads to the notion that the recreational development of the river should be expanded to a greater area of the river. More efforts should be made to address the issues that are perceived by the users about the river such as water quality , aesthetics, and safety. This will explore more areas of the river (for example, North - South branch of the river) for recreational use.

- Recreational vessel operator education is strongly recommended for reducing conflicts. Enforce operator education as a primary requirement for operating a vessel.

- Enforce tough anti-alcohol and drug boating laws.

- Increase the frequency of law enforcement patrols on the river and lock area, especially during periods of heavy vessel traffic.

The following suggestions or actions are recommended for improving the lock operations and reducing the conflicts.

- There should be adequate understanding and coordination between the lock operators and the boat users. This helps to avoid confusion in obeying the rules at the lock.

- The lock masters and users must use every precaution to prevent unnecessary delay at the lock. The arrival posts and markers that are established must be exhibited to the users in form of writing or signs. The lockmaster can prescribe such departure from the normal order of precedence as is warranted to achieve best lock utilization.

- Smaller recreational craft must be allowed to tie up to the side wall only after making sure that all the larger vessels get their chance to moor securely to the side wall. This suggestion is more in keeping with safety. Also, it is possible that the Lock wallmooring areas could be separated for smaller and larger boats

- All the vessels shall be requested to moor properly before expediting the lockage. It was noticed that most of the operators of recreational craft only hold the lines hanging on the lock side wall. Also, tying to the lock ladders should be strictly prohibited.

- The rules at the lock (safety rules, rules regarding no-wake zones, order of precedence) and operating procedure should be made available to all users in the form of fliers and should be written in such a way to avoid confusion.

- The following signs should be displayed in bigger letters at different locations in the lock area.

- No-wake zone rules along with penalty for violating the law.
- General and safety rules to be followed at the lock area.
- The different types of signals that are followed at the lock.

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