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Transportation Research Record 1222

Contents

Foreword

This Record deals with a wide variety of issues relating to ports, waterways, and the transportation of freight by water.

In the paper by Khisty, the concept of level of service is used as a methodology for monitoring and comparing the adequacy of the quality of service for ferry systems. Eight performance measures were used to obtain a composite level-of-service measure.

The second paper, by Osleeb et al., describes a coal transportation and transshipment model, Coal Logistics System (COLS).

A shortage of rainfall in the Mississippi River basin in recent years has caused adverse navigation conditions. The paper by Hall proposes a comprehensive approach to aid in navigation during low-river conditions.

The paper by Antle presents a current assessment of the Inland Navigation Program. It sets forth a strategic planning process for the inland waterways. The plan includes consideration of the physical system, traffic growth, the performance of locks, the investment program, and the Inland Waterways Trust Fund.

The paper by Skaggs and Grier describes the current status of cost-shared, deep-draft harbor projects. Under the Water Resources Development Act of 1986, 39 channel improvement projects were authorized, many of which require local cost sharing. As of January 1989, 15 ports had signed local cooperative agreements and another six were developing such agreements.

The paper by Prather and Wise is a case study that incorporates elements of a statewide planning approach to the operation and maintenance of the Monongahela River navigation system. A major technical challenge in the planning process is risk analysis.

Level-of-Service Measures for Ferry Systems

C. J. KHISTY

Currently there is no evaluation methodology for monitoring and comparing the adequacy and quality of service on the various routes of ferry systems on the basis of the level-of-service concept. Because the level-of-service concept has been applied so successfully in other modes of transportation, particularly highway and public transit, it was strongly believed that this concept could be applied to ferry service as well, albeit with major modifications. Based on an extensive literature survey, a basic model was developed for application to ferry systems. Eight ferry system performance measures are used as indicators in obtaining the composite level of service; these are accessibility, transit time, frequency, reliability, cost, marketing and planning, passenger comfort, and delay. Collectively these indicators provide the operating characteristics and level of service of the ferry as perceived by its users. Fewer criteria can be used at the discretion of engineers and administrators, for example, accessibility, transit time, frequency, and reliability. The methodology of determining the level of service on a route-by-route basis is described. This research can be implemented immediately by ferry systems, and such implementation will be most useful in monitoring, comparing, and controlling the performance of ferry service as well as in allocating the budget for changes and improvements.

Currently all transit and ferry systems across the nation are suffering from increased operating costs. The need for effective evaluation is most evident for labor-intensive systems, such as ferry systems, that require ever-increasing subsidies; Washington State Ferries (WSF) is a good example.

WSF is the largest ferry system in the nation. It includes about 100 nautical mi and transports more than 17 million persons and 7 million vehicles per year to work, to shop, and to attend school and for recreation and the sheer joy of riding the ferry. There is a direct person-to-person contact between WSF personnel and more than 50,000 paying customers on a daily basis. WSF has the responsibility to provide safe, efficient, and reliable transportation along its routes. Hence the quality of service is extremely important (*1*). Currently WSF does not have an evaluation methodology for monitoring and comparing the adequacy and quality of service on various routes of its system. The basic problem is that of integrating a quantitative evaluation and a qualitative one.

This paper contains the results of research regarding the applicability of the concept of level of service (LOS) measures to ferry systems. Various LOS indicators and service quality variables are considered. Collectively they provide a composite measure of the operating characteristics as perceived by users. This research embodies a preliminary investigation, assessment, and application of the LOS concept to ferry service.

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BACKGROUND

During the past 30 years, the LOS concept has been used with much success as an evaluation tool, particularly in the context of highways, for assessing the quality of service offered. Recently some limited work was done in applying the LOS concept to bus transit. However, there is hardly any literature available on such applications to ferry systems. Complications in applying LOS concepts to ferry systems are obvious because of the plethora of parameters involved. Safety, comfort, accessibility, reliability, efficiency, travel time, fares, and loading and unloading time are some of the parameters included in LOS consideration. In spite of these complications it was strongly believed that the LOS measure would prove to be useful in monitoring and controlling the performance of ferry service. In a secondary sense it was also thought that the concept could be used for budget allocation. The bottom line seemed to be that the LOS measure could be adopted as an integral part of a program to increase ferry system efficiency and productivity.

LOS CONCEPT

The level of service is the overall measure of all service characteristics that affect users. Indeed, having a good level of service is basic in maintaining the current level of patronage and in attracting potential users to the system. Level of service comprises two groups of parameters:

1. Performance elements that affect users, such as operating speed, reliability, fares, and safety (*2*);
2. Transportation hygiene factors, consisting of qualitative elements of service, such as convenience, riding comfort, aesthetics, simplicity of using the system, cleanliness, and behavior of passengers and personnel (*2–4*).

The combined effects of these two categories contribute to the setting up of performance measures for ferry service.

The level of service of a system is based on one or more operational parameters that best describe the operating quality for the system. These parameters are called "measures of effectiveness" and represent those measures that best describe the quality of operation. Each level of service represents a range of conditions for which boundary conditions have been established.

LITERATURE SURVEY

The use of level of service in public transit has a relatively short history. However, because of some similarities this use has a direct bearing on LOS application to ferry systems. In the literature surveyed, "performance measures" (PMs) are a combination of selected LOS indicators or measures of effectiveness.

Of the 30 literature references that had some connection with transit level of service, not a single reference was devoted exclusively to ferries. Some of the references were useful in conceptualizing what PMs to consider for ferry LOS application (*4*). For example, the procedure manual produced by the National Committee on Urban Transportation (*5*) was the earliest attempt to standardize operational characteristics of bus systems on fixed routes. Vuchic's (*6*) attempt to qualify and quantify characteristics of public transportation systems and Botzow's (*7*) application of the conventional A to F LOS categories were important breakthroughs. The Pennsylvania Department of Transportation (PennDOT) procedure guide (*8*) and Southern California Association of Governments (SCAG) Transit Service Policy memorandum (*9*) were aimed at making transit operation as efficient as possible. Research done by Bakker (*10*), Allen (*11*), and Alter (*3*) helped greatly to formalize LOS concepts for public transportation systems. In 1978 the California Department of Transportation (Caltrans) published a report introducing a practical method of applying performance measures (*12*). Public organizations and private researchers have proposed several factors in addition to the ones above (*13–23*).

In the literature review, certain similarities in PMs became obvious and the measures most often used are the following:

1. Route density (transit route miles per square mile),
2. Headway,
3. Speed,
4. Reliability of service,
5. Frequency of service,
6. Capacity,
7. Fare,
8. Comfort,
9. Convenience,
10. Directness of route, and
11. Safety and security.

PERFORMANCE MEASURES

A ferry evaluation methodology is developed that can be undertaken by independent observers familiar with the ferry system. Ferry service characteristics are complex and comparatively difficult to evaluate. They differ from highway characteristics but are in some ways similar to express bus characteristics. The users of the ferry system also differ; there are in-vehicle passengers and walk-on passengers.

One way of categorizing ferry users is by mode of travel to and from the ferry. In a recent survey of weekday riders on WSF, it was found that, in general, 40 percent of the passengers walked aboard (walk-on) and 60 percent drove or were driven on board (in-vehicle). The distribution is different during the weekends, when 26 percent are walk-on and 74 percent are in-vehicle passengers (*1*).

The basic input to the task of selecting potential PMs came from transit literature. Nearly a hundred different PMs were extracted from this review and reduced by elimination on the basis of duplication, relevance to the ferry system, and data obtainability.

At meetings held between personnel from WSF and members of the Washington State Transportation Research Center (TRAC), eight PMs were finally selected. They were to be measured on a scale of A through F, with A representing the best and F the worst. These indicators are discussed in the following sections.

Accessibility

For in-vehicle passengers, accessibility would include the time to buy the ticket for the ferry ride, to get into the correct queue, to wait in the queue, and finally to drive onto the ferry. For walk-on passengers, it would include the time to buy the ticket, to wait, and to walk onto the ferry. The in-vehicle and walk-on passenger times and LOS categories are as follows:

	Time (min)	
LOS Category	*In-Vehicle Passenger*	*Walk-On Passenger*
A	<30	<20
B	30–45	20–30
C	45–60	30–40
D	60–75	40–50
E	75–90	50–60
F	>90	>60

Travel Time

Travel time would include locking the car and going upstairs in the ferry, the ferry journey time, and getting into the vehicle and waiting for the vessel to come to its destination. For walk-on passengers, it would include waiting in the ferry, the ferry journey time, and finally waiting till the ferry arrived at its destination.

Because the general public is familiar with automobiles and transit travel time is often compared with the identical automobile travel time (assuming that the same route was taken), it was believed that ferry travel time should in some way measure the ability of the ferry to compete with the private automobile. Although this comparison is hypothetical, it does serve a useful purpose. Simply stated, the index for this indicator is ferry travel time divided by automobile travel time. Note that in this case ferry access time is not included in the calculation of travel time. The distribution is as follows:

LOS Category	*Index*	*Comparison with Automobile*
A	<1.00	Ferry faster
B	1.00–1.10	Ferry 10 percent slower
C	1.11–1.35	Ferry up to 35 percent slower
D	1.36–1.50	Ferry up to 50 percent slower
E	1.51–2.00	Ferry twice as slow
F	>2.00	Ferry more than twice as slow

Frequency

Frequency of service is really a function of demand. In the final analysis, this PM indicates whether riders are satisfied with the current frequencies. Based on occasional surveys, a feel for the satisfaction or dissatisfaction expressed by the public would be the most pragmatic way of measuring frequency. The adequacy of frequency is as follows:

LOS Category	*Percent of Riders Satisfied*
A	100
B	75
C	50
D	40
E	20
F	0

Reliability

Although adherence to schedule is the popular interpretation of reliability, a more pragmatic way of looking at it is the absence of breakdowns. In the long haul, this interpretation of reliability would involve what percentage of sailings are canceled because of breakdowns per week or per month on a particular route. Another way of looking at this problem would be to determine what percentage of sailings are delayed 60 min or more because of breakdowns. In a way, reliability and delay are related. The LOS distribution based on percentage of breakdowns (percentage of delay of 60 min or more) is as follows:

LOS Category	*Percentage of Breakdowns*
A	0.0
B	0.5
C	1.0
D	1.5
E	2.0
F	>2.0

Cost

The individual cost, or fare, depends upon the willingness of the rider to pay for the level of service offered. In some cases willingness is constrained by the ability to pay and the availability of alternative means of travel. Because one thrust of the LOS methodology is to compare ferry service parameters with those for automobile trips, as in the transit time measure, it is recommended that the "cost" measure involve a quantitative comparison of the fare paid by the ferry rider with the cost of operating a private automobile. This latter cost varies from about 20¢ to 25¢ per mile. Using this criterion, the following LOS measures could be used. An on-board survey followed by a telephone survey of those responding to the on-board survey is the means whereby public opinion on costs and alternative fare proposals can be obtained.

LOS Category	*Passenger Fare (PF) Versus Automobile Operating Cost*
A	PF less or the same
B	PF up to 10 percent more
C	PF up to 25 percent more
D	PF up to 50 percent more
E	PF up to 100 percent more
F	PF more than 100 percent more

Public Information

Public opinion about the availability and quality of public information needs to be surveyed periodically to improve ferry service. On-board opinion surveys can be followed with a telephone survey of those who respond. Certain basic components of public information such as timetables, systemwide maps, maps coordinated with land transit systems, public information telephone numbers, and informational signage in the ferry terminals are most important. LOS categories based on satisfaction with public information are as follows:

LOS Category	*Percent Satisfied*
A	100
B	75
C	50
D	20
E	10
F	0

Passenger Comfort

Good seating, appearance, and cleanliness of the vessel and terminals; appearance and cleanliness of food service; quality of food service; and employee attitudes and behavior are aspects of passenger comfort.

The traditional levels of comfort applicable to transit systems can be included as well: crowding and passenger density, odor, ventilation, noise, vibration, acceleration, and deceleration. These levels of comfort are not considered of prime importance, but should be included in opinion surveys. The distribution is shown below:

LOS Category	*Percent Satisfied*
A	100
B	75
C	50
D	20
E	10
F	0

Delay

Delay represents a reduction in the level of service because of unexpected increases in normal running time. Boarding delays, travel delays, starting delays, and unloading delays are random occurrences reflecting the level of service calculated on a route-by-route basis. All these segments of delay can be aggregated, if necessary, to represent total delay.

Total delay affects computations of overall speed and, of course, travel time. Total delay could be broken down into segments, for convenience, because each segment can be individually corrected. Some planners might argue that ferry service should not be expected to adhere to strict on-time performance because so many factors affect its smooth operation. Weather, for example, is one important factor. Loading accidents could be another. However, total delay, which consists of boarding delays, travel delays, and starting delays, could be measured as shown below:

LOS Category	*Delay (min)*
A	0
B	10
C	20
D	30
E	40
F	>40

WEIGHTING-FACTOR METHODOLOGY AND RESULTS

The constant sum, paired-comparison method was employed for computing the results (*24*). It serves two purposes: (a) it helps to reduce, if necessary, the list of candidate PMs to a more manageable size; and (b) it formalizes an approach to evaluation of ferry LOS categories with the use of possibly a single index composed of the final PMs determined. The approach was used to rank PMs in order of perceived importance by a mixed group of 300 consisting of engineers, planners, and actual users of the ferry system.

Briefly, the constant sum, paired-comparison method is a systematic approach for determining the relative importance of each of a large number of factors using group consensus. Thus, not only a ranking of factors by importance is obtained, but also the relative importance or weight of each factor with respect to the other items.

The application of the constant sum, paired-comparison methodology to the eight indicators selected yielded the following results:

Rank	*Indicator*	*Mean*	*SD*	*Percent*
1	E: Cost	.152	.026	15
2	D: Reliability	.146	.020	15
3	B: Travel time	.137	.012	14
4	C: Frequency	.138	.019	14
5	H: Delay	.131	.021	13
6	A: Accessibility	.116	.033	12
7	G: Comfort	.108	.024	10
8	F: Public information	.072	.008	7

These eight indicators were weighted on a percentage basis as indicated in the last column. It is possible to do an extensive survey on a systemwide basis and revise these weights from time to time. It may also be appropriate to develop ranking on a route-by-route basis, if so desired.

The eight indicators (A through H) were measured on a 5-point scale from LOS A = 5 (the best) to LOS F = 0 (the worst). Also, Indicators A, B, D, and H are directly measurable from current data. Indicators C, E, F, and G can be assessed through an on-board or telephone survey.

To use these indicators properly in an evaluation, an aggregation of factors is required.

Finally, each indicator was ranked and weighted according to its importance. Ferry service administrators could develop their own ranking and weighting for the indicators, based on the numerous research survey techniques explored elsewhere. To determine the overall LOS for a particular ferry route, multiply the number of points for the LOS for each indicator by the weighting credits; the total number of points accumulated equals the aggregate level of service.

An example of this procedure follows. Suppose that a ferry route has the following characteristics:

Indicator A: Access time plus loading time = 55 min for in-vehicle passenger and 35 min for walk-on passenger.

Indicator B: The ratio of ferry travel time to automobile travel time = 1.05.

Indicator C: The current frequency of sailings satisfies 42 percent of the riders.

Indicator D: Breakdowns (departing late by more than 60 min) affect 1.2 percent of sailings.

Indicator E: Passenger fare is 8 percent more than automobile operating cost.

Indicator F: Almost every rider is pleased with the public information for the system.

Indicator G: About every other rider feels comfortable with the service provided on board.

Indicator H: Average delay in the sailings is 40 min.

The ranking and weighting of the LOS indicators shown earlier are used to determine the overall level of service for the ferry routes. Levels A through F and the corresponding points are determined from the values provided in this paper. The relevant calculations are as follows:

Indicator	*LOS Category*	*Points*	*Weight*	*Total*
Accessibility	C	3	.12	.36
Travel time	B	4	.14	.56
Frequency	D	2	.14	.28
Reliability	C	3	.15	.45
Cost	B	4	.15	.60
Public information	A	5	.07	.35
Comfort	C	3	.10	.30
Delay	E	1	.13	.13
Grand total				3.03

Because 3.0 corresponds to LOS C, the aggregate level of service for this route is slightly better than C.

It must be pointed out here that it may be appropriate to use fewer criteria, for example, four or five, purely at the discretion of the service operator.

A step-by-step procedure is given below:

Step 1: Choose a set of criteria.

Step 2: Apply the constant sum, paired-comparison method to determine the relative weight of each criterion. The size of the sample can be determined by applying standard statistical methods. For a group response the means and standard deviations of the values can be determined.

Step 3: After examination of the results, the list of candidate criteria may be reduced, if necessary, and a final list of criteria adopted.

Step 4: The mean values of the criteria finally adopted can be used to rate (or weight) the importance of the criteria.

Step 5: A five-point scale for the six levels of service should be adopted. The points may be adjusted if necessary.

Step 6: "Hard" indicators such as accessibility and transit time are directly measurable from current data, whereas "soft" indicators such as passenger comfort can best be assessed through an on-board survey.

Step 7: Indicators may be aggregated as follows:

a. Assign a level of service to each chosen indicator,
b. Assign a point value to each level (A = 5 through F = 0),
c. Assign a weight to each criterion,
d. Multiply points by weight for each criterion,

e. Add the products to obtain a grand total, and
f. Assign a level of service to this grand total.

USES AND BENEFITS

There appear to be at least four primary applications of the results of this methodology. First, the results form a tool to guide decision makers in evaluating the quality of ferry service being delivered. Second, they identify what can be considered an ideal route or benchmark with which other routes can be compared on the basis of either individual attributes or aggregate values. The third primary application is as a planning tool to develop future perspectives of ferry service. The fourth application is for use in budgeting funds for route improvements. There are probably other uses as well.

The need for further refinement and verification of the research methodology used here is clearly indicated. The performance measures must be used over a period of time to verify that they are methodologically appropriate and that the results they produce truly reflect the quality of ferry service being evaluated. The ranges of values proposed for the various measures must be further verified and refined (if needed) by obtaining operational data for a wider array of ferry service configurations. It may also be necessary to decrease the number of indicators if data gathering poses a problem.

CONCLUSION

The increasing necessity to evaluate public transportation services has created a need for a methodology. Two key independent combinations of factors can be directly controlled by policy makers: transportation hygiene factors and LOS indicators. Of these two, only LOS indicators can really motivate potential riders. Nevertheless, poor transportation hygiene factors discourage potential users.

It is vital to perform this evaluation regardless of the level of public funding for ferries. It is only through a thorough evaluation that decisions based upon objective facts may be made. The evaluation model contained herein may contain subjective values: it is a starting point for further analysis and refinement. It should be remembered, however, that any evaluation methodology developed will contain some subjective concepts. This evaluation procedure using the LOS concept provides a useful framework for ferry service administrators, professionals, and decision makers to evaluate ferry service on a route-by-route basis.

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Coal Logistics System (COLS)

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The Coal Logistics System (COLS) is a comprehensive coal transportation and transshipment model that solves for coal flows on a network from supply nodes through transshipment nodes to steam and metallurgical demand nodes on the basis of systemwide cost minimization. The model is solved for a representative time period for the system of ports, and all decision variables are solved for simultaneously. COLS is a constrained optimization model formulated as a linear program with some integer variables. Its solution indicates the sources of the various types of coal, the routes and modes of transportation, and the locations, activity levels, and types of transshipment facilities that together minimize the systemwide costs. Effectively, the COLS model minimizes the cost per delivered British thermal unit of U.S. coal. COLS was designed specifically for the evaluation of coal flows in a competitive multiport framework. Coal can be routed from virtually any mining region by any feasible mode to any port and then to any demand node. Thus, ports need not be restricted by a predefined supply hinterland or a limited destination area. From one scenario to the next, a single destination can receive coal of a different quality from a different origin via a different mode through a different port. Cost reductions from one scenario to the next can thus include transport cost savings, change of origin or destination benefits (including lower coal purchase costs), and change of mode savings as well as port improvements and the use of new technologies.

The Coal Logistics System (COLS) is a comprehensive coal transportation and transshipment model that determines optimal coal flows on a network from supply nodes through transshipment nodes to steam and metallurgical demand nodes on the basis of systemwide cost minimization. The various types of nodes are connected by links consisting of several different transportation modes. The model is solved for a representative time period, and all decision variables are solved simultaneously. COLS is a constrained optimization model formulated as a linear program with some integer variables. Its solution indicates the sources of the various types of coal, the routes and modes of transportation, and the locations, activity levels, and types of transshipment facilities that together minimize the systemwide costs. Costs consist of four main categories: coal purchase, inland and ocean transportation, investment in transfer facilities (if any), and operation of facilities. Effectively, the COLS model minimizes the cost per delivered British thermal unit (Btu) of U.S. coal exports. This model can be used by planners to assess the impacts of port improvements such as the investment in new equipment and infrastructure and dredging. In addition, different technologies—for example, midstream loading versus broad-beam ships—can be directly compared and evaluated.

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The COLS model is described and the calibration of the model that was undertaken for the U.S. Corps of Engineers using 1985 data is discussed. Because of lack of space, the mathematical model is not reproduced here. It has been published in a number of different forms elsewhere (*1–3*).

BACKGROUND

COLS is one of several models of the U.S. coal industry available for planning purposes (*4–9*). Although most are built around a transportation component, each model focuses on a different aspect of the coal industry: mining, coal type differentiation, rail transport, inland waterway transport, transshipment, ocean transport, end use utilization, and so on. COLS includes all these considerations but is set apart from the others by its focus on transshipment and other port activities and on ocean transportation. This focus is the result of the initial model development for the Maritime Administration, U.S. Department of Transportation, and the subsequent model enhancement for the Institute of Water Resources of the U.S. Army Corps of Engineers (*1–3, 10*). While COLS is a comprehensive planning model covering the entire coal logistics system, it is especially well suited to analyzing port and infrastructure development.

DESCRIPTION OF THE MODEL

COLS incorporates most of the complicating factors in the coal industry. It is a network-based transportation and transshipment model with various transport modes defined on the network and with a detailed representation of port activities. Bituminous, subbituminous, and lignite coal are divided into a spectrum of nine different coal types on the basis of their Btu and sulfur characteristics. The cost of purchasing, shipping, and handling coal is by tonnage, but demand is based on the Btu content of the coal. Both steam and metallurgical coal demand are included. For steam coal demand, the analyst can set a sulfur limit for regions with strict environmental regulations. For metallurgical coal demand, the analyst can define the coal type (or types) that can be used to satisfy the needs of metallurgical buyers. COLS is designed to address the question of the effect of port deepening on coal flows and costs in a competitive, multiport setting. It is also equipped to evaluate the alternatives to dredging, such as topping-off and broad-beam ships.

Network Structure

COLS is, in a sense, two linked models, one nested in the other. In the "outer" model, coal is transported from supply nodes to demand nodes in a linear programming, transportation model formulation. However, the transportation pattern is dependent on the transshipment nodes that are selected as the location of handling facilities in the "inner" model. The inner model contains the operations and limitations of each port: the various sites within the port and their ability to accommodate the various transportation modes and facility types; the facility types and their ability to accommodate the various modes; and the investment and operating costs of coal handling for the chosen facility types. In most other coal industry models, this entire inner port model is replaced by a single transshipment link—with a cost per ton and a capacity—between incoming links by one mode and outgoing links by another. The main advantage of COLS is the way in which port operations are causally linked to the ocean vessel size that serves the port.

Figure 1 is a flowchart showing how coal moves through the various elements of COLS. From supply nodes, coal travels by land transport to either barge-loading ports, domestic demand nodes, or directly to Great Lakes or export ports. Barge coal can be delivered to steam and metallurgical domestic demand nodes, Great Lakes, or export ports. All ports—barge, Great Lakes, or export—are considered to be transshipment nodes that represent junction points at which transport links by certain transport modes terminate and links by other modes originate. Transshipment nodes (ports) are further subdivided in COLS into a number of potential sites, called subnodes. Figure 2 gives an example of a coal export port with three subnodes, each of which has a different channel depth. Each subnode can represent a separate terminal within the port for the location of coal-handling facilities. The types and sizes of such facilities that can be located at a subnode and the size of ship that can be accommodated at that subnode depend on the availability of land, rail connections, channel depths, and docking facilities.

From export ports, coal can be shipped to foreign steam or metallurgical demand nodes by ocean freighters of various sizes. The types of vessels that can be used on a link are uniquely determined by the channel depths specified for the

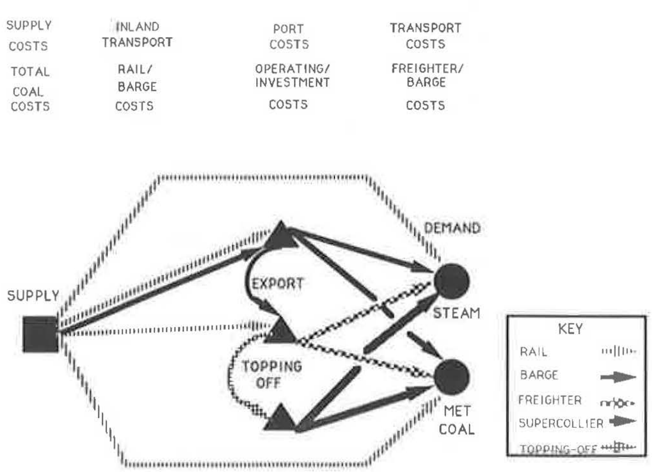

FIGURE 1 Flowchart of coal flows in COLS.

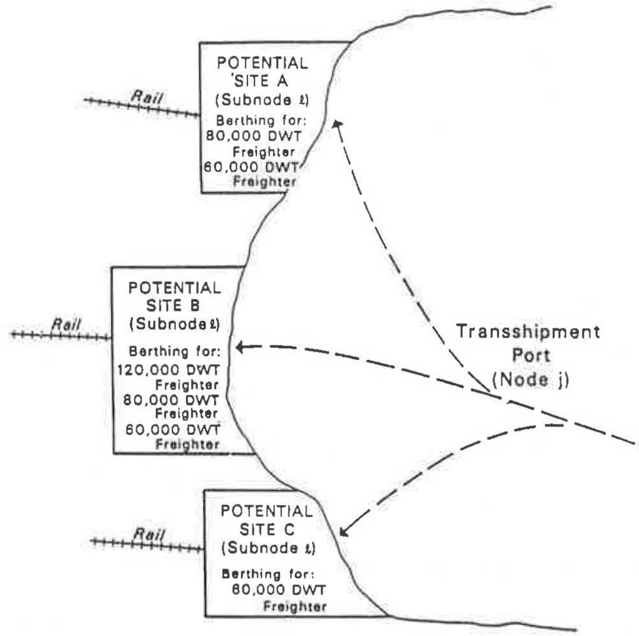

FIGURE 2 Example of coal harbor.

U.S. and foreign ports. If the model contains topping-off nodes, coal can be brought to the topping-off point by self-unloader and light-loaded supercollier and proceed from there by fully loaded supercollier.

Existing facilities are input to the model by stating in the data input tables that a particular type and size of facility is located at a particular transshipment node. Existing facilities are given an investment cost of zero dollars, and COLS does not have to decide whether to build them or not, because they already exist. Port scenarios can be run by changing the type of facility or depth of channel available at a port. Alternatively, COLS can be used at a more advanced level by making subnodes available for new construction and by giving COLS a choice of several configurations and sizes of handling facilities.

COLS has been designed specifically for the evaluation of coal flows in a competitive multiport framework. Coal can be routed from virtually any mining region by any feasible mode to any port and then to any demand node. Thus, ports need not be restricted by a predefined supply hinterland or a limited destination area. From one scenario to the next, a single destination can receive coal of a different quality from a different origin via a different mode through a different port. Cost reductions from one scenario to the next can thus include transport cost savings, change-of-origin or -destination benefits (including lower coal purchase costs), and change-of-mode savings.

Coal Type Differentiation

Coal is by no means a uniform commodity. Coal qualities vary widely both between and within the different regions of the United States. Some of the most important coal characteristics are heat content (Btu), sulfur, ash, volatility, and fixed carbon. There are major differences with respect to these characteristics not only between anthracite, bituminous, subbi-

tuminous, and lignite coals, but also within the bituminous and subbituminous categories.

Although all of these coal quality characteristics are important to coal buyers (particularly metallurgical coal buyers), they cannot all be included in the model because it would cause a proliferation of coal types. COLS uses only Btu and sulfur content to characterize the coal types. The continuous gradations of Btu and sulfur content are subdivided into categories, and single representative Btu and sulfur values are selected for each category. For instance, all coal with between 21 million and 25 million Btus per ton and yielding less than 3.2 lb of sulfur dioxide per million Btus is designated as Type 5.

Btu and sulfur are used to define coal types because they are the most important criteria for both steam and metallurgical coal buyers. For steam coal, heat production is the main criterion although concern over acid precipitation has led to sulfur emissions limitations in several countries. Environmental regulations may become more strict in the future, which could lead to a shift in the balance of coal types and therefore supply regions and export ports.

For metallurgical coal, the important coal characteristics include ash and volatility in addition to Btu and sulfur. However, only bituminous coals have the proper coking properties that allow them to soften and solidify into a porous solid mass (coke) when heated to high temperatures in an oxygen-free environment. Sulfur and ash concentrations must be kept low because these impurities create inferior steel quality and because removal of impurities is expensive. The significance of the volatility characteristic is that a blend of volatilities is required, because high volatility coal produces a weaker coke, whereas low volatility coals added in excess can expand and damage the coke oven. All bituminous coals can be used to a certain extent in producing coke, but in practice the overwhelming majority of coking coal is produced in relatively few areas of the country and contains greater than 26 million Btus per ton and less than 1 percent sulfur. The National Coal Model, developed by the Department of Energy with a focus on end-use utilization, has been successful in defining metallurgical coal in terms of Btus and sulfur only, because most bituminous coal with the proper Btu and sulfur contents is generally acceptable for metallurgical use in terms of ash and volatility as well (*8*). The COLS model thus follows the National Coal Model in this respect.

Steam and Metallurgical Coal Demand

In COLS, the costs of purchasing, transporting, and transshipping coal are costs per ton; supply and handling capacities are also measured in tons. However, demand is not measured in tons because a single ton of low-Btu coal cannot substitute for one ton of high-Btu coal. Therefore, in the COLS model, tons are supplied and transported on the network but are converted to the equivalent amount of Btus for that coal type at the demand nodes. The requirements of the demand nodes are stated in terms of Btus rather than tons.

In satisfying steam coal demand, COLS allows different coal types to be blended. At demand nodes, the number of tons of each coal type is converted to an amount of Btus and sulfur dioxide based on the representative Btu and sulfur content of each coal type. These amounts are summed over all coal types at each node. Steam coal demand constraints require the total number of Btus to equal the requisite amount, whereas the sulfur dioxide production must not exceed the given environmental limitation.

Blending of coal types for metallurgical purposes is much more complicated and much less forgiving. Therefore, COLS can restrict the use of coal for metallurgical purposes to a subset of the coal types—anthracite, subbituminous, and lignite coal types can be prohibited entirely from being used for coke production. The remaining bituminous coal types can then be grouped into sets, with a given percentage of the metallurgical Btus coming from the various sets. For instance, the majority of metallurgical coal generally must be of the highest Btu and lowest sulfur quality, whereas a smaller proportion may be permitted from a slightly lower-quality group of coal types. Alternatively, the analyst can require all metallurgical coal to be of the highest quality.

USING COLS

There are four steps to using COLS: (a) data preparation and input, (b) generation of the mathematical model from the data input tables, (c) solution of the model, and (d) analysis of results. A flowchart of the steps in using COLS is shown in Figure 3.

Data Preparation and Input

The data for logistics planning scenarios to be analyzed with COLS are input to the model by the use of standardized data input tables called COLTABs. Each of the 14 COLTABs contains data on one component of the model. The data input tables cover the four basic components of the logistics system:

1. Coal supply characteristics
   a. Mine locations
   b. Mine capacities
   c. Coal types (sulfur and Btu per ton)
   d. Minehead prices
2. Transportation network characteristics
   a. Rail network
      (1) Rail links
      (2) Rail rates
   b. Water network
      (1) Inland water links
      (2) Barge transportation rates
      (3) Ocean water links
      (4) Ocean vessel sizes
      (5) Water transportation rates by vessel size
      (6) Light loading of vessels
   c. Port interface
      (1) Water linkages
      (2) Rail linkages
      (3) Coal transshipment sites
      (4) Depth of harbor
      (5) Dredging costs
      (6) Topping-off anchorages
      (7) Cost multipliers

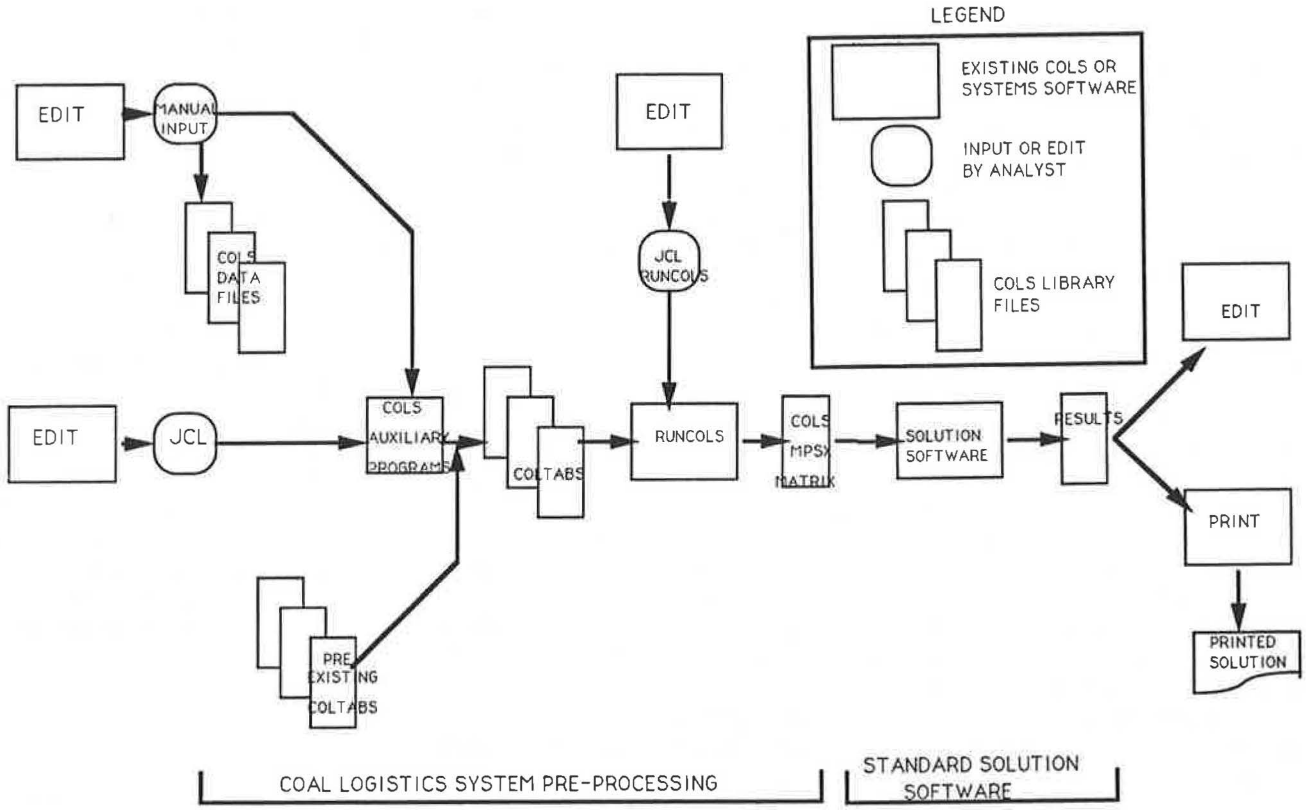

FIGURE 3 Flowchart of steps in using COLS.

3. Coal-Handling characteristics
   a. Facility costs
      (1) Existing and new facilities
      (2) Fixed costs
      (3) Variable costs
   b. Facility capacities
      (1) Throughput
      (2) By mode
4. Coal demand characteristics
   a. Demand locations
   b. Transport linkages
   c. Steam coal demand
      (1) Btu requirements
      (2) Sulfur limitations
   d. Metallurgical coal demand (limited by coal type)

The data for the COLS model and the model itself are separate, independent entities. Users can provide their own data to be used in COLS as long as it is in the proper format, or they can use the data base developed for the Corps of Engineers for the coal export system as it existed in 1985.

Generation and Solution

After the data input tables have been created they are used to generate a mathematical model. The core of the COLS model consists of the matrix generating programs (COLS1 and COLS2) that convert input data on supplies, transportation rates and distances, transshipment, and demand into a mathematical programming model. The COLS matrix is generated in Mathematical Programming System (MPS) format—the industry standard—and can be used on any compatible solution software package such as Control Data Corporation's APEX or IBM's Mathematical Programming System Extended (MPSX). The solution output from COLS provides the user with comprehensive results from each scenario as follows:

- Purchase costs for coal by type;
- Routes, transport modes, and amounts of coal to be transported from mining regions to domestic demand nodes and ports of export;
- Cost of inland coal transportation;
- Number of tons transported through each port;
- Types of coal-handling facilities used to transfer coal between modes at transshipment sites;
- Costs of handling the coal at these sites;
- Degree to which existing capacity at transshipment sites is utilized;
- Amount and type of new transshipment capacity or infrastructure improvements (or both) that would make the transshipment and supply of coal more efficient (if the user chooses to ask this question);
- Investment costs associated with these new facilities and improvements;
- Routes, modes, and amounts of coal by type that is transported to foreign demand sites for steam and metallurgical purposes; and
- Costs associated with overseas transport.

Analysis

COLS was designed to facilitate the running of various scenarios. Once the COLTABs have been created, data elements on any table can be easily changed to generate a new scenario. For instance, the depth of a harbor can be changed by altering a single character on one COLTAB; for example, changing F3 to F5 would change the harbor depth for a port from 42 ft to 50 ft. Similarly, the transfer capacity of a terminal can be changed, ports or waterways can be added, or user fees can be assessed. The model is sensitive in varying degrees to all the input data, including harbor depths, transport rates, coal prices, coal supply, and demand.

CALIBRATION OF COLS TO 1985 HISTORICAL COAL FLOWS

The calibration stage of model building is especially crucial with large, complex systems such as the COLS model. A model must first prove that it can simulate the historical record before it can be trusted to answer what-if questions or to make future projections. Given a data set describing the system in a recent historical year, the model must generate results similar to what actually occurred in that year; otherwise, the model is not functioning as it should, which is as a simplified representation of reality that maintains the most essential interrelationships that determine the outcome of the system in question. In the case of COLS, the model should respond to data describing the demands, supplies, networks, transport costs and capacities, and any government regulations that existed in a given year in much the same way that the market responded, by routing coal through the same ports in roughly the same quantities.

In the project undertaken, the criterion set up in advance by the Corps of Engineers for evaluating the performance of COLS was that explanations be provided for any discrepancies for major ports where calibrated flows were not within a precision of ±15 percent of the flows for the representative year, 1985. The calibration results achieved by COLS in this study were within 10 percent of the historical flows except for the port of Los Angeles/Long Beach, which was the port that exported the smallest amount of coal in that year.

There are many reasons why a model might deviate from the anticipated results; "calibration" is the process of discovering and correcting these problems. First, it could be that the objective of the model—cost minimization—does not faithfully characterize the real world. Although recognizing that the real world tends toward an equilibrium, network-based cost-minimization models have a well-established history based in part on the idea that all individual coal buyers try to minimize their costs for the quality they require. Concomitantly, the buyer that saves the most costs by using a low-cost resource or advantageous port is able to bid the highest for it, and thus the allocations that accomplish overall systemwide minimization reflect bidding ability.

Second, with a complex system such as COLS, it is possible for mistakes and inconsistencies to slip into the data. The calibration runs performed caught several such problems.

But looking beyond mistakes, the most important role that calibration plays is in identifying weak areas in the data. The procedure followed by the authors was to run the model with the 1985 data base and then to compare the results to the corresponding historical results for 1985. When the results did not closely match, all components of the flows that did occur were carefully analyzed versus the flows that might have been expected, to check for a systematic error. [A complete discussion of data changes that were made in the calibration of COLS may be found elsewhere (*3*).]

Base-Case Results

Table 1 presents the results for the base-case run compared with historical results for 1985. The run was made using 1985 costs, capacities, channel depths, networks, supply, demand, and so on. The base case comes well within the contracted performance standards of 15 percent allowed deviation for each of the major ports. In fact, all major ports are within 10 percent, and three of the five are within 2 percent.

Figure 4 shows the model results in comparison with the historical data for 1985 in millions of tons per year for the five major ports plus Los Angeles/Stockton. For each port, the first bar shows the actual tonnage and the second shows the model results.

Cost Summary

The total system cost per day is $12,789,323. Based on a total export tonnage of 241,065 per day (87.99 million tons per

TABLE 1 COMPARISON OF BASE-CASE CALIBRATION RUN WITH HISTORICAL PORT LOADINGS FOR 1985

Port	COLS Node Code	Port Loadings (mtpa) Model	Port Loadings (mtpa) Historical	Model Results as Percentage of Historical
Major				
Philadelphia	SC	3.24	3.6	90.2
Baltimore	SE	7.59	7.7	98.6
Norfolk	SH	43.47	43.1	100.9
Mobile	SO	9.89	9.0	109.9
New Orleans	SP	8.15	8.3	98.2
Minor				
Los Angeles/Long Beach	PK	0.04	1.0	46.0[a]
Stockton	PI	0.42	0.0	

NOTE: mtpa = million tons per annum.
[a]Combined total for California port loadings.

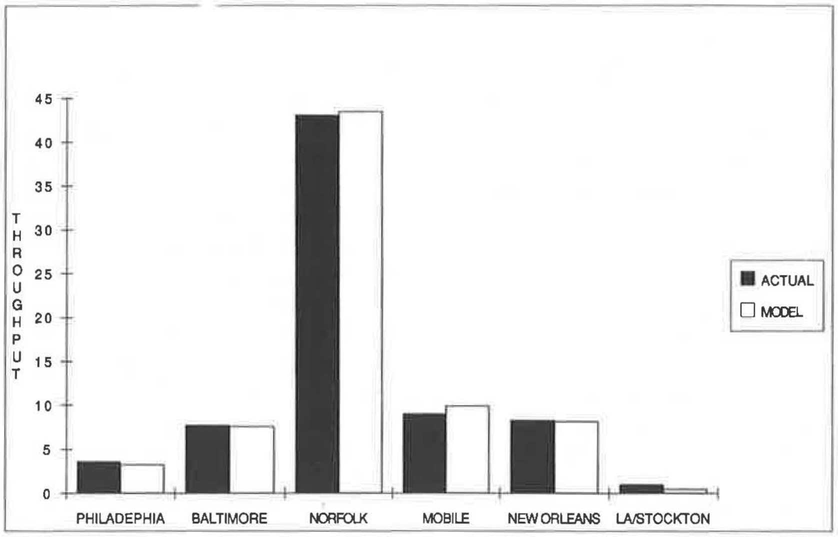

FIGURE 4 Comparison of model results with historical data (total coal throughput: actual = 72.70 mtpa; model = 72.81 mtpa.

TABLE 2 TOTAL COSTS IN BASE CASE BY COST CATEGORY

Type of Cost	Cost per Day ($)	Cost per Year ($)	Percent of Total
Coal purchase	7,567,577	2,762,165,605	59.17
Type 1	0	0	0.00
Type 2	0	0	0.00
Type 3	0	0	0.00
Type 4	0	0	0.00
Type 5	29,354	10,714,210	0.23
Type 6	33,819	12,343,935	0.26
Type 7	1,245,060	454,446,900	9.74
Type 8	703,264	256,691,360	5.50
Type 9	5,556,079	2,027,968,835	43.44
Coal transportation	4,770,289	1,741,155,485	37.29
Rail/truck	2,862,196	1,044,701,540	22.38
Barge	274,402	100,156,730	2.15
Laker (F1)	23,447	8,558,155	0.18
Panamax (F2)	954,694	348,463,310	7.46
42-ft (F3)	110,210	40,226,650	0.86
45-ft (F4)	544,744	198,831,560	4.26
Supercollier (F5)	595	217,175	0.01
Coal handling	451,021	164,622,665	3.53
Total	12,789,323	4,668,102,891	

year), the average delivered cost is $53.05 per ton. A summary of costs by cost category is provided in Table 2.

Coal purchase costs at the minehead make up 59 percent of the total system costs. This fact indicates the continuing dominance of the localization of the coal resource as the main determinant of export flows. A full 43 percent of the total is for purchasing Type 9 premium metallurgical quality coal only; this purchase accounts for 73 percent of the total minehead costs.

Coal transportation costs account for 37 percent of the total. Of the total transportation costs, 65.8 percent is for inland transportation (rail, truck, and barge), and 34.2 percent is by freighter for overseas and Canadian demand. Rail and truck accounts for over 91 percent of the inland costs, with barge accounting for less than 9 percent. Rail rates continue to dominate the inland and the overall transportation structure. Overseas, 40-ft Panamax freighters and 45-ft freighters from Norfolk dominate the picture. Supercolliers account for less than 0.01 percent of the total cost, with a minimal amount of coal being shipped from Long Beach.

Coal-handling costs account for just 3.5 percent of the total system costs, despite the fact that some coal is handled twice—once at barge tippling points and once at export terminals.

Coal Origin Summary

Forty-nine different coal-producing nodes were active in the model results. All coal shipped to Philadelphia (COLS node code SC) originates in Pennsylvania except for a negligible amount originating in Ohio; it arrives by rail. The 3.2 million tons per year (mtpa) of Philadelphia-bound coal is high-Btu steam coal. The 7.5 mtpa shipped to Baltimore (SE) goes by rail from northern West Virginia and Maryland, mostly from DOE District 3, with smaller amounts from Districts 1 and 8. Baltimore's coal is predominantly high-Btu, high-sulfur steam coal, with smaller amounts of low-sulfur steam coal and metallurgical coal. Norfolk (SH) handles 43.4 mtpa of coal by rail, of which 39.8 mtpa (92 percent) is metallurgical coal. Norfolk draws coal from a four-state region: southern West Virginia, eastern Kentucky, northern Tennessee, and Virginia. Toledo (RH) draws all of its 15.1 mtpa of coal by rail from eastern Kentucky, split evenly between steam and metallurgical coal. In the base case, no coal is shipped to New York, to Atlantic Coast ports south of Norfolk, or to Great Lakes ports other than Toledo.

In comparison with the eastern and Great Lakes ports, the Gulf ports of Mobile (SO) and New Orleans (SP) receive all of their coal by barge. Mobile handles 9.9 mtpa from Alabama. Of this amount, 3.2 mtpa travels from Tennessee and one node in south central Kentucky through the Tennessee-Tombigbee Waterway. The remaining 6.7 mtpa of metallurgical Type 9 coal comes from central Alabama. New Orleans, on the other hand, receives steam and metallurgical coal via

the Mississippi River system. Half a million tons of metallurgical coal originates on the Arkansas system; 0.9 mtpa of high-sulfur/medium-Btu steam coal originates in western Kentucky and Indiana on the Ohio and Green rivers; 4.9 mtpa of metallurgical and high-sulfur/high-Btu steam coal originates in the Cincinnati-Wheeling-Charleston area of the Ohio and Kanawha rivers; and 2.2 mtpa of steam coal originates on the Allegheny and Monongahela rivers. None of the Texas Gulf ports are active in the base case, which parallels actual flows in 1985.

On the Pacific Coast, only Los Angeles-Long Beach (PK) and Stockton (PI) handle any coal in the model. Long Beach handles 38,000 tons per year of high-Btu/low-sulfur coal from southeast Colorado and northern New Mexico, whereas Stockton transships 0.4 mtpa of similar coal from central Colorado and southern Utah. In the West, as in the East, the model ships none of the four low-Btu coal types. This is generally true of the U.S. export business, because the low price of the low-Btu coal is more than offset by the higher transport cost per Btu. Twice as much of the low-Btu coal would have to be shipped to achieve the same heat value as high-Btu coal, which is why low-Btu coal generally is transported very short distances or used at mine-mouth power plants.

Foreign Demand Allocation Summary

Philadelphia ships only steam coal to Europe by 40-ft draft Panamax (F2) vessels. Because F2 is the largest vessel that the port of Philadelphia can handle, the largest share of Philadelphia's coal goes to Piraeus, Greece, which has a harbor only 40 ft deep. Baltimore ships mainly steam coal to Europe by 42-ft draft freighter (F3) whenever the foreign port can accommodate it, and otherwise by Panamax class. Norfolk ships a small amount to the Panama Canal and South America, but otherwise, like the other East Coast ports, ships exclusively to Europe. Norfolk ships mostly by 45-ft draft freighter (F4) and only ships by smaller vessels to metallurgical demand nodes, to which Philadelphia cannot ship because it handles no metallurgical coal.

All coal destined for Canada is shipped via Toledo and the Welland Canal (VB) by 27-ft Laker (F1). All coal from Mobile and New Orleans goes either through the Panama Canal (VA) to East Asia or to South or Central America by Panamax (F2). Long Beach and Stockton ship by their maximum vessel sizes to East Asia.

These routings are generally realistic, further confirming the fidelity of the model, because not only are the amounts loaded at each port realistic, but the origins and destinations are also fairly accurate.

Of the minor ports (ports with coal-loading capacity but shipping 1 mtpa or less in 1985), only Los Angeles and Stockton were active in the model results. The other minor ports that were not active in the model but were included in the network are New York, Morehead City, Charleston, and Savannah on the East Coast and Port Arthur and Corpus Christi on the Gulf Coast. Of all the minor ports, only Los Angeles actually shipped more than 100,000 tons of coal in 1985. Thus, the model was also accurate in not shipping coal through ports that shipped no coal in 1985.

The only major discrepancy was in West Coast shipments, where 1 million tons were actually shipped through Los Angeles-Long Beach (LA/LB) in 1985. In the model, a small amount was shipped through Los Angeles, and 400,000 tons was shipped through Stockton. A reasonable explanation for why Stockton was favored over LA/LB is as follows. Both ports are served by both the Santa Fe and Southern Pacific railroads, and the railroads may set discounts that encourage coal traffic to LA/LB instead of to Stockton. Rail rates in COLS are set strictly by region of origin, distance, and number of interlines, so there is no mechanism for favoring LA/LB over Stockton. Furthermore, the port costs in the model for the two West Coast ports are nearly identical: $4.58 per ton for LA/LB and $4.78 for Stockton. In actuality, LA/LB was probably much less expensive than Stockton, but because LA/LB's average cost, $4.58, was used as the estimate for the smaller ports everywhere (including Stockton), it does not enjoy as significant a cost advantage over Stockton as perhaps it should. The lowest port cost estimate for the LA/LB port area was used ($4.58 at Long Beach).

The foregoing discussion explains the relative shares of LA/LB and Stockton, but not why the total for the two West Coast ports is lower than the actual total for 1985. This discrepancy can most likely be traced to the methodology for estimating supply-node export production capacities. The methodology used works well except in areas where a very small percentage of coal is exported and where most of the export coal comes from a few high-quality counties. In the production capacity methodology for this model, the actual county production is multiplied by the percentage exported from that DOE district, plus a leeway factor of 10 percent. In the western DOE districts, the highest proportion exported from any district was 4.3 percent in Utah and 1.8 percent in Colorado. For example, the production in every Colorado county is multiplied by 0.018, and to that is added 10 percent—0.0018—for a total of 0.0198 multiplied by the total 1985 county production. However, in actuality, most of the export coal probably comes from one or two high-Btu counties in Colorado (e.g., Pitkin County, Type 9 coal), which probably export a much greater percentage of their coal than 1.98 percent, whereas the majority of Colorado counties export no coal at all. If the node capacities in the model for these high-Btu (Types 7 and 9) western nodes were larger, it would surely be expected that more western coal would be shipped out via LA/LB and Stockton.

The methodology for estimating the capacity of supply nodes for producing coal for export purposes works quite well in Appalachia and the Midwest, where export coal (generally high-Btu coal) is plentiful. However, in the western United States, where high-Btu coal is a localized phenomenon, the district average percent exported is too low for the few counties that do export and too high for the counties that have never exported any of their low-Btu coal. This entire problem, therefore, is isolated in the western United States, and, in a sense, is due to (a) a lack of export data at the county scale and (b) the author's unwillingness to abandon an unbiased methodology even in these few problem areas.

CONCLUSIONS

The COLS model calibration runs revealed the competitive aspect of the coal export system and confirmed that cost structure or capacity changes can lead to some very complicated

trade-offs between ports. In the example mentioned earlier, when the capacity of all supply nodes was increased by 4.54 percent (from leeway = 10 percent to leeway = 15 percent), the amount shipped via Mobile and New Orleans decreased, and the amount through Philadelphia, Baltimore, and Norfolk increased. This was because the most expensive mine-port combinations per Btu were being shipped via the two Gulf ports, and these were the first to drop out of the solution when replaced by greater shipments via the East Coast.

Using a more elaborate example in another scenario, a series of switches was prompted by a decrease in the short-haul rate from $1.80 to $1.60 per ton (base case is $1.80). At $1.60, supply nodes DF and DA (high-sulfur, high-Btu Ohio and Pennsylvania coal) were able to ship coal to New Orleans by barge and then through the Panama Canal. This flow replaced mines CT and CO (similar-quality Tennessee and Kentucky coal) that had been shipping to Mobile. This freed CT and CO to ship coal to Norfolk, replacing Types 7 and 8 coal going from various supply nodes to all three East Coast ports. In all, New Orleans was up by 1.52 mtpa, Norfolk was up 0.43 mtpa, and Mobile, Baltimore, and Philadelphia dropped by a combined total of 1.95 mtpa.

What is most interesting about this example is that it shows how a lowering of barge-related costs actually helped Norfolk at the expense of Mobile, which is the opposite of what was expected from a cost change that favors barge traffic. However, coal from Ohio/Pennsylvania shipped to Japan via New Orleans replaced coal from Pennsylvania and West Virginia to Europe via Philadelphia and Baltimore. This prompted a destination change of the Kentucky/Tennessee coal—to Europe via Norfolk instead of to Japan via Mobile. To put it another way, as the New Orleans hinterland extended up the Ohio River, the hinterlands of Baltimore and Philadelphia receded. This caused a corner of Kentucky and Tennessee to switch hinterland from Mobile to Norfolk. Moreover, the Kentucky/Tennessee coal changed modes from barge to rail.

There are numerous scenarios that the COLS model has been used to evaluate, including user fees, dredging, mid-stream transfers, and topping-off at Richards Bay, South Africa, to name a few. In these cases the model results appear reasonable and therefore provide the decision maker with a yardstick by which to make policy analysis within a multiport framework.

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Integrated Water Management for River Transportation

JAMES R. HALL

A comprehensive water management plan that responds to adverse navigation conditions on the Mississippi River does not exist. An integrated approach to water management for navigation during low river flow conditions is suggested. An integrated approach would examine the combined capabilities of all basin sources to respond to low flow conditions on the Mississippi. Primary water sources that could augment flow of the Mississippi, and therefore the ones examined in this paper, include the Lake Michigan (Chicago) diversion, the Missouri River main stem reservoirs, and the Minnesota headwaters lakes. This paper is conceptual and therefore does not address all benefits or problems associated with the development of an integrated plan.

A comprehensive water management plan that responds to adverse navigation conditions on the Mississippi River does not exist. The need for such a plan was dramatically illustrated by the low Mississippi River flows resulting from the 1988 drought. These conditions actually halted river transportation for extended periods and greatly increased the cost of transportation. In addition, the low flow conditions caused untold damage to the ecological river community and left upstream cities facing the many problems associated with salt water intrusion.

An integrated approach to water management for navigation during low flow conditions is suggested in this paper. Such an approach would examine the combined capabilities of all basin sources to respond to low flow conditions on the Mississippi. Primary water sources that could augment flow of the Mississippi, which are therefore the ones examined in this paper, include (Figure 1)

1. The Lake Michigan (Chicago) diversion,
2. The Missouri River main stem reservoirs, and
3. The Minnesota headwaters lakes.

These sources will be discussed in more detail in later sections of this paper. This work is conceptual and therefore does not address all benefits or problems associated with the development of an integrated plan.

THE PROBLEM

Severe drought conditions during the spring and summer of 1988 resulted in record low stages on the nation's river transportation system. The U.S. Coast Guard imposed operating restrictions on the allowable draft, length, and width of tows. Operators often had to break up their tows and move smaller sections individually, a process known as "double tripping" or "triple tripping." Around-the-clock dredging was required to keep channels open. Shippers were turning to railroads and the Great Lakes/St. Lawrence Seaway for grain exports.

In July 14, 1988 testimony before the Senate Subcommittee on Merchant Marine, Robert W. Page, Assistant Secretary of the Army for Civil Works, described the problem: "The flow on the Mississippi River is 28 percent of the normal season flow at St. Louis and Memphis." Page testified that the Corps had reported 27 closures on the Mississippi and its major tributaries since early June. Of the more significant closures, he said:

> For instance, the closure at Greenville, Mississippi, had at one point in time 130 tows waiting. If each tow were configured with 30 barges, which is the common size of tows using the Mississippi River, 234,000 semitrailer trucks would have been required to move an equivalent amount of cargo; enough trucks to stretch from New Orleans to Portland, Oregon. This backup would equate to 58,500 railroad cars, enough to stretch from New Orleans to Kansas City.

Also in a July 1988 statement before the Senate Subcommittee on Merchant Marine, John Zick of Continental Grain Company said:

> Barges cannot be loaded to optimum draft—9′0″ or greater—but rather to just 8′6″, which reduces the volume, or bushels in a barge, by 10 percent. Secondly, tow sizes handled by each tow boat have been reduced in size from 25–30 barges per tow to just 16, again reducing capacity by nearly 50 percent. Thirdly, and most importantly, the turnaround time from St. Louis to New Orleans and back to St. Louis has gone from 16 days to 30 days, which means less barges for the system to load up river.

Zick stated further, "We estimate the additional costs of operating in this environment to be 5 to 10 cents per bushel, which ultimately is paid by the farmer in reduced prices for his grain."

RECOMMENDED ACTION

A comprehensive water management plan is needed to respond to low flow navigation conditions on the Mississippi River. The Corps of Engineers should press ahead with its proposed "drought contingency" study for the Mississippi River Basin. The Corps has proposed this study under authority of Section 216 of the Flood Control Act of 1970. The study should investigate how best to manage the basin's water resources for navigation and other purposes during periods of drought. The

Bureau of Policy and Information, Iowa Department of Transportation, Ames, Iowa 50010.

FIGURE 1 Mississippi River system.

proposal has been included in the Department of the Army budget request for Fiscal Year 1990. This study should accomplish the following:

- Provide an inventory and assessment of the Mississippi River Basin resources, problems, needs, and opportunities as they relate to inland commercial navigation.
- Review capacity constraints and inefficiencies in the system during low flows.
- Evaluate and develop structural and nonstructural alternatives to minimize low flow problems.
- Investigate reallocation of existing reservoir storage as well as development of potential new storage.
- Review environmental considerations and develop a systemwide environmental impact assessment.
- Review and evaluate legal and institutional constraints.

In the interim, while a long-range comprehensive plan is being developed, the Corps should use existing authority to augment low Mississippi River flows to the extent possible. The Corps has authority to make temporary changes in project operations under the broad authority granted the Secretary of the Army under 33 USC 1, which provides:

> It shall be the duty of the Secretary of the Army to prescribe such regulations for the use, administration, and navigation of the navigable waters of the United States as in his judgment the public necessity may require for the protection of life and property, or of operations of the United States in channel improvement, covering all matters not specifically delegated by law to some other executive department. Such regulations shall be posted, in conspicuous and appropriate places, for the information of the public; and every person and every corporation which shall violate such regulations shall be deemed guilty of a misdemeanor and, on conviction thereof in any district court of the United States within whose territorial jurisdiction such offense may have been committed, shall be punished by a fine not exceeding $500, or by imprisonment (in the cast of a natural person) not exceeding six months, in the discretion of the court.
>
> Any regulations prescribed by the Secretary of the Army in pursuance of this section may be enforced as provided in Section 413 of this title, the provisions whereof are made applicable to the said regulations.

POTENTIAL FOR LOW FLOW AUGMENTATION TO MISSISSIPPI RIVER

Increased diversions of 7,000 cubic feet per second (cfs) from Lake Michigan to the Mississippi River would provide an additional foot of water at St. Louis. Increased releases of 7,000 cfs over present navigation target flows from the Missouri River reservoir system would also provide an additional foot of water at St. Louis. The combined releases from these two sources, providing 2 ft of additional water at St. Louis, would go a long way toward solving problems experienced by commercial navigation during low flow conditions. However, the Minnesota headwaters lakes do not appear to be a viable source of water to the middle or lower Mississippi because of the small quantities of water available and extended water travel times.

There are many issues involved with the diversion or reallocation of water from any source. Most of these issues involve competing water uses for commercial navigation, hydroelectric power production, recreation, irrigation, municipal and industrial water supply, or for fish and wildlife needs. Any efforts to increase diversion of Lake Michigan water will require discussions with all the Great Lakes states and the Canadian federal and provincial governments. Also, inclusion of Mississippi River navigation needs in the Missouri River Reservoir Operating Plan must be accomplished with complete consideration of other water users.

The three possible sources of water to augment river flow during periods of low water are discussed in the following sections.

PROPOSED LAKE MICHIGAN (CHICAGO) DIVERSION

In a June 23, 1988, letter to the U. S. Army Corps of Engineers, Illinois Governor James R. Thompson recommended that the Corps authorize a temporary increase in diversion of water from Lake Michigan to aid shipping on the Mississippi River. The water would flow through the Illinois Waterway for 300 mi and then join the Mississippi just above St. Louis. This temporary diversion would have been in addition to the present diversion allowed by Illinois pursuant to a 1967 U.S. Supreme Court decision, which limits Illinois diversion to 3,200 cfs, although the hydraulic limit of the diversion structures approaches 10,000 cfs. It takes 14 days for Lake Michigan water to reach St. Louis.

The Governor's recommendation was denied because of the following determination by the Corps (personal communication, R. W. Page to Gov. J. R. Thompson, July 14, 1988):

> At this time, and in the foreseeable future, we believe that any additional water in the lower Mississippi resulting from

> the increased diversion of Lake Michigan water would not make a significant difference either in the navigability of the channel or in the need for continued dredging of the river crossings as shoaling occurs. . . . Based on discussions with the Department of Justice, we believe there is authority to support the proposed increase in the diversion from Lake Michigan were it determined that such an increase were appropriate. Prior to proceeding with any diversion, however, the Department of the Army would consult with the affected States and, in coordination with the Department of State, engage in appropriate discussions with the Government of Canada.

Table 1 shows the effects, as estimated by the Corps of Engineers, of an increased diversion of 7,000 cfs from Lake Michigan to the Mississippi River. Although Corps hydrologists concur that additional water would increase river stage, they emphasize the river's complexity and suggest that adding another foot of water does not necessarily equal 1 ft more in depth. According to the Corps, the river bottom can shift depending on the river's reaction to the rise (*1*).

The towing industry does not agree with the Corps of Engineers assessment that more water would not help. In July 14, 1988, testimony before the Senate Subcommittee on Merchant Marine, Joseph Farrell of the American Waterways Operators said:

> Some claim that such river level increases are insignificant. Pose the choice to a river pilot and you will discover that just one-half foot will significantly improve the ability to navigate and lessen the need for and extent of emergency dredging. These added inches increase the flow of the river—the scouring action so important to cleansing the siltation that otherwise builds up and results in channel blockages.

Lake Michigan (Chicago) Diversion

Water diversion from Lake Michigan to the Mississippi River Basin dates back to 1848 with completion of the Illinois and Michigan Canal. The canal, built primarily to serve transportation, provided a connecting watercourse between Lake Michigan and the Mississippi River System. Water diversion averaged about 500 cfs (*2*).

In the mid- to late 1800s, development of Chicago's drainage and sewer systems led to contamination of Lake Michigan waters. The newly constructed sewers moved water and wastes into the Chicago River, which in turn drained into Lake Michigan. In 1854 and 1885 large amounts of untreated sewage were carried into the lake by major storms. This contaminated water entered Chicago's water intakes and caused outbreaks of typhoid and cholera. It is reported that 90,000 people died in the 1885 epidemic (*3*).

The Metropolitan Sanitary District of Greater Chicago took major steps to remedy this situation:

- In 1900 construction of the Sanitary and Ship Canal was completed, reversing the flow direction of the Chicago River (Figure 2). This new, larger canal followed the course of the old Illinois and Michigan Canal. The Chicago River Controlling Works (CRCW) was constructed at the mouth of the Chicago River in the early 1940s. The CRCW Lock serves shipping and regulates the amount of Lake Michigan water that is allowed to pass into the river. The structure also restricts river flooding from entering Lake Michigan.
- A second sanitary canal, the North Shore Canal, was completed in 1910. It extended for 6.14 mi to connect Lake Michigan at Wilmette to the Chicago River. Water flow from Lake Michigan is regulated by the Wilmette Controlling Works.
- A third canal, the Calumet Sag Canal, was completed in 1922. It connects Lake Michigan, through the Grand Calumet River, to the Sanitary and Ship Canal. The canal was constructed primarily to carry sewage, but also served transportation needs. The O'Brien Lock and Dam, located on the Grand Calumet River, regulates the flow of Lake Michigan water down the canal.

Diversion was originally limited through all channels to a combined total of 4,167 cfs. Diversion reached a high of 10,000 cfs by the late 1920s, but was reduced to a low of 1,500 cfs by subsequent court decisions. Today's diversion of 3,200 cfs was established in 1967. An increased diversion to 8,500 cfs was authorized by the Supreme Court for a 2½-month period in 1956–1957 to aid low flow conditions on the Illinois Waterway and Mississippi River due to a prolonged drought (*3*).

TABLE 1 ESTIMATED EFFECTS OF INCREASING DIVERSION TO 7,000 CFS FOR 120 DAYS

Location	Base Flow cfs (30 June)	Flow Time (Days	Increase In Stage
St. Louis	70,000	14	1.0 ft
Cairo	103,000	15	0.6 ft
Memphis	118,000	18	0.6 ft
Vicksburg	150,000	22	0.5 ft
Drawdown of Lake Michigan/Huron			-0.06 ft

Present-Day Diversion at Chicago

Lake Michigan diversion at Chicago can be discussed in the following use categories: domestic water supply, direct diversion, and stormwater runoff.

Domestic water supply accounts for 52 percent of the present-day allowable 3,200-cfs diversion. Chicago alone withdraws about 1,500 cfs from Lake Michigan at its two water treatment plants. Thirteen other plants located along the Illinois shoreline also withdraw water.

Direct diversion to the Sanitary and Ship Canal from Lake Michigan provides for safe navigation and improves water quality in the canal system. Navigation diversions require about 215 cfs, and water quality diversions are set by law at 320 cfs. Structures control direct diversions at three locations:

- At the mouth of the North Shore Channel at Wilmette,
- At the mouth of the Chicago River, and
- At the mouth of the Calumet River.

Stormwater runoff of about 700 cfs, diverted by the reversal of the Chicago and Calumet rivers, is also included in the allowable 3,200 cfs.

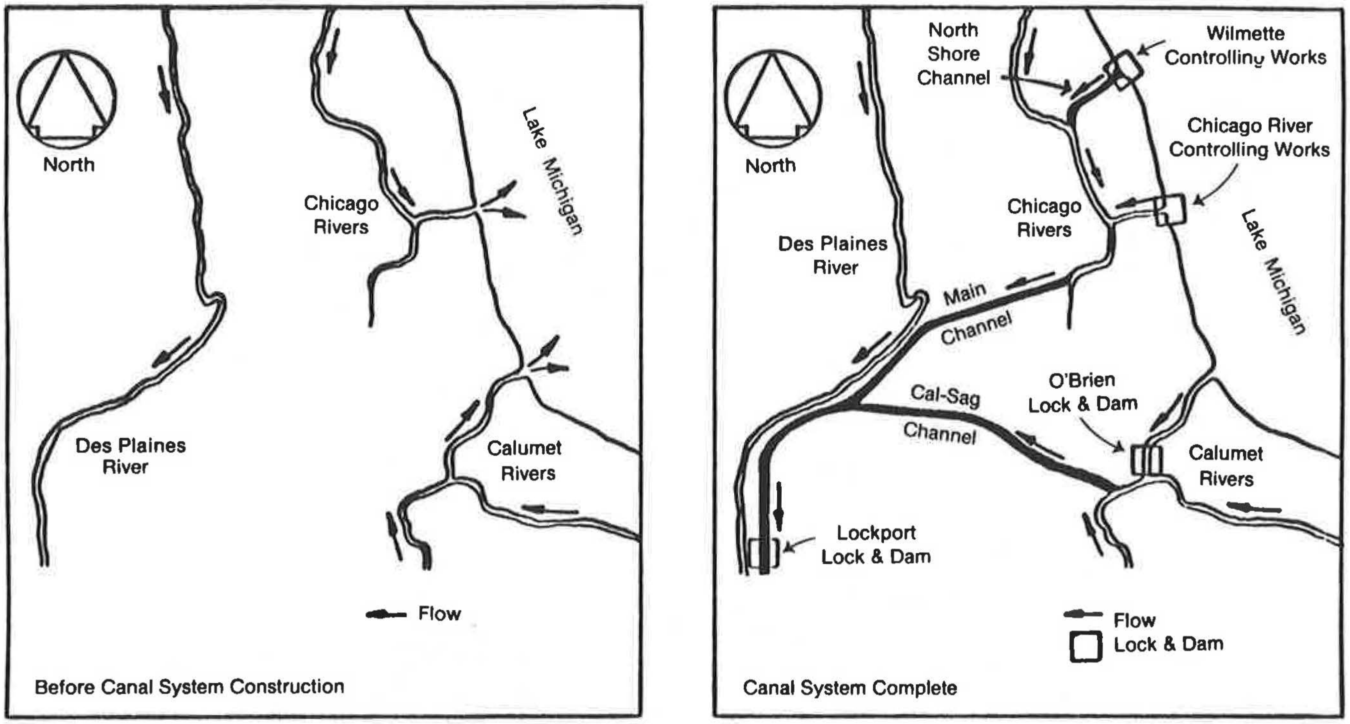

FIGURE 2 Lake Michigan (Chicago) Diversion. (Source: Division of Water Resources, Illinois Department of Transportation.)

Past Legal Decisions

Since its conception, diversion of Lake Michigan water has generated controversy between the Great Lakes states and lower Mississippi River states. The Supreme Court resolved issues on several occasions as follows (*2*):

- A 1925 decree allowed the Secretary of War to issue diversion permits. A permit to divert 8,500 cfs was issued in March 1925.
- A 1930 decree reduced the allowable diversion (in addition to domestic pumpage) to the following amounts:
  —6,500 cfs by July 1, 1930
  —5,000 cfs by December 30, 1935
  —1,500 cfs by December 31, 1938
- A 1956 decree authorized an increased diversion to 8,500 cfs for a 2½-month period to aid low flow conditions on the Illinois Waterway and Mississippi River due to a prolonged drought.
- A 1967 decree limited diversion to 3,200 cfs, including domestic pumpage, effective March 1, 1970. A five-year running average determined compliance with the 3,200-cfs limitation.
- A 1980 decree amended the 1967 decree to extend the averaging period from 5 to 40 years.

INCREASED MISSOURI RIVER FLOWS

Although the Missouri River provides up to 50 percent of the water supply for the Mississippi River at St. Louis, it is not managed to facilitate Mississippi River navigation. The potential for including Mississippi River navigation needs in the Missouri River operating plan was brought out by the extended drought of 1988. The Mississippi was experiencing low water problems from St. Louis south. At the same time, there were huge water reserves in the Missouri River reservoir system (Figure 3). To place the issue in perspective, reservoirs are generally maintained at about 63 million acre-feet (maf) of water. The river flow rate at Sioux City to maintain Missouri River navigation is 31,000 cfs, or about 21 maf per year. At this rate it would take nearly 3 years to empty the reservoir system, assuming no additional inflow. The Missouri River reservoirs can be managed to provide an additional foot of water on the Mississippi River at St. Louis in time of drought. However, historically the Corps has managed this water very conservatively, and for in-basin user needs only. In September 1981 the Missouri River Division Corps of Engineers completed a study on the Missouri River contributions to flow on the Mississippi (*4*). One conclusion presented by the study states:

> Travel time of releases from the main stem dams, in excess of 11 days, is too long to permit regulation for specific Mississippi low flow events. Therefore, the most viable regulation plan would be to revise the main stem operation criteria by reducing releases from April through July to provide increased discharge during the period of normally low Mississippi River flows, August through February.

Other conclusions deal with the effects on Missouri River users of altering the regulation plan. All conclusions need to be reevaluated in view of the Corps' increased amount of experience in reservoir management and because of the new economic perspective brought about by extended low flow on the Mississippi. For example, the argument that the 11-day travel time is too long is no longer valid.

A primary benefit to this suggested management proposal would be the additional establishment of need for Missouri

FIGURE 3 Missouri River Basin: 1987 (*8*).

River water for navigation. Several arid western states are interested in Missouri River water for irrigation purposes. The High Plains states irrigate 14.3 million acres from the underlying Ogallala aquifer through use of 170,000 irrigation wells. Although the aquifer receives some recharge each year, the quantity of water being withdrawn far exceeds the quantity being replaced. Over 5 million acres currently irrigated will be returned to dryland production or native vegetation by the year 2020 because of declining water supplies (*5*). The High Plains Ogallala Aquifer Regional Study, authorized by Congress in P.L. 94-587, looks at alternatives to increase water supply to the High Plains area. Figure 4 (*6*) shows interstate water transfer route alternatives, assessed by the Corps, to divert water to the High Plains area. Routes A and B consider diverting up to 3.4 maf of Missouri River water annually to this region (*5*). This would represent about 16 percent of the total Missouri River flow.

Missouri River Basin Development

The Missouri River flows for 2,300 mi from northwestern Montana to its confluence with the Mississippi River near St. Louis, Missouri. The Missouri River drainage basin covers parts of 10 states, comprising one-sixth of the nation's land area. Average annual precipitation ranges from 8 in. in areas of the northwestern plains to 42 in. in the lower basin. The

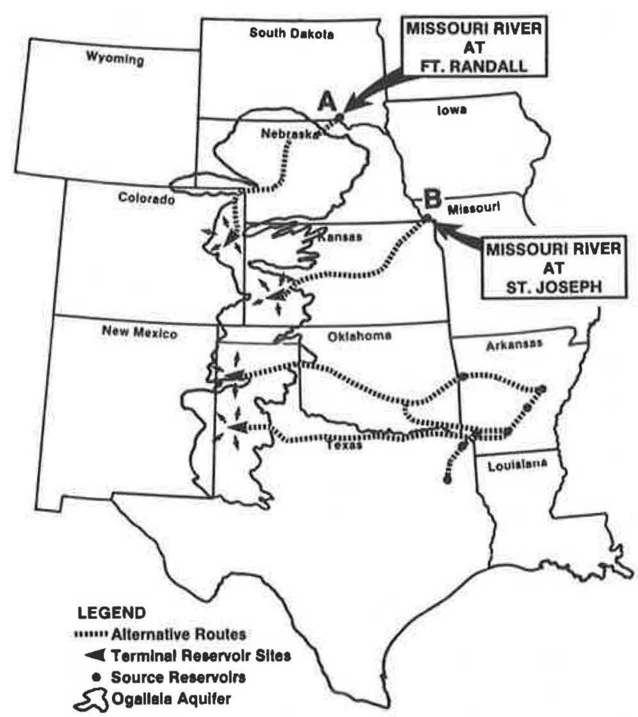

FIGURE 4 Ogallala Region water transfer route alternatives (*6*, Figure 5).

central two-thirds of the region receives about 20 in. of rainfall annually. The basin's drainage is via a system of streams and rivers that contributes to the flow of the Missouri River.

The comprehensive plan for Missouri River basin development was authorized by the Flood Control Act of 1944, commonly known as the Pick-Sloan Plan. The principal features are the six Missouri River main stem reservoirs, located in Nebraska, North and South Dakota, and Montana (Figure 3). These reservoirs have a total water surface area of 1.2 million acres and 5,940 mi of shoreline (7).

Reservoir Management

The reservoirs are managed for the Missouri River basin requirements of flood control, commercial navigation, hydroelectric power generation, irrigation, municipal and industrial water supply, water quality control, conservation of fish and wildlife, and public recreation.

The Missouri River reservoirs are operated according to a repetitive annual cycle. Most of the year's water supply is produced by winter snows and spring and summer rains, which result in increased storage. Runoff averages about 25 maf annually, although it can vary from a low of about 10 maf to a high of 40 maf. After reaching a peak between July and early August, storage declines until late in the winter when the cycle starts again. A similar pattern is found in releases from the system. From mid-March to late November, high levels of flow are required for navigation and to evacuate accumulated flood storage. This is followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats (*8*). The unpredictability of the weather sometimes creates problems for reservoir managers. For example, at a time when the reservoirs are at a record low of about 47 maf, the 1988 inflow to the system was only 12.7 maf. The Corps projects 1989 inflows of 21.4 maf.

The six main stem reservoirs contain a total storage capacity of 74 maf of water. Figure 5 shows the storage capacity in each reservoir. Note that 88 percent of the total capacity is contained in the three uppermost reservoirs (Garrison is the third largest reservoir in the United States). Gavins Point, the lowermost reservoir, contains only 0.5 maf.

If the six reservoirs were added together into one project, it would look like the diagram in Figure 6. The total 74 maf of storage is allocated into four separate storage zones as follows:

1. The lowermost (25 percent) is inactive—this zone provides an adequate head to generate hydroelectric power and to support a minimum fishery.
2. The multipurpose carryover (53 percent) is usable storage designed to support navigation, hydropower, and other functions during extended periods of drought. As of October 1988, 47.1 maf remained in the reservoir system. Water supply is projected to be at 46.1 maf by March 1, 1989. At this level of depletion, the three largest (uppermost) reservoirs are drawn down about 21 ft. However, they were designed for 70 ft of fluctuation.
3. The annual flood control and multiple use zone (16 percent) is intended for use annually. Water is stored in this zone during the flood runoff period, March through July, and evacuated during the balance of the year. According to present operating practices, this is the desired operating range.
4. The exclusive flood control zone, the top 6 percent, is reserved for remote floods only.

Specific Users

Figure 7 shows the time sequence of reservoir management events. Annual inflow and release requirements are projected, and regulation plans may vary to meet the multipurpose needs of the system. Reservoir managers often find themselves in the position of providing a balance between the needs of upstream and downstream users.

Flood Control

Flood control is the only authorized project function requiring evacuation of reservoir storage space; all other functions require storage of water. The high-risk flood season begins about March 1 and extends through the summer. The major portion of flood control space in the system must be evacuated before

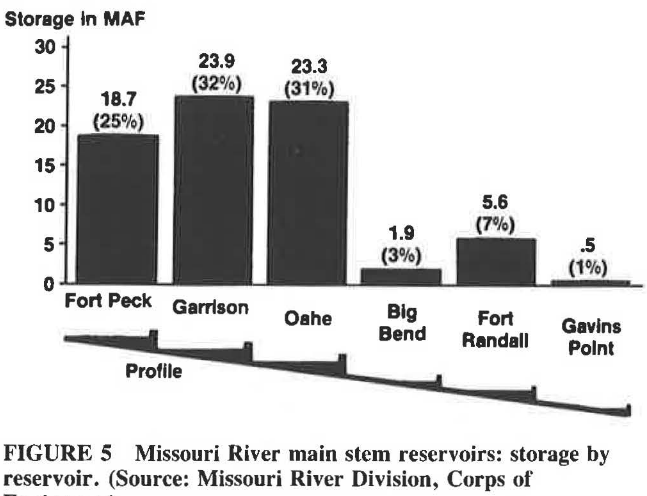

FIGURE 5 Missouri River main stem reservoirs: storage by reservoir. (Source: Missouri River Division, Corps of Engineers.)

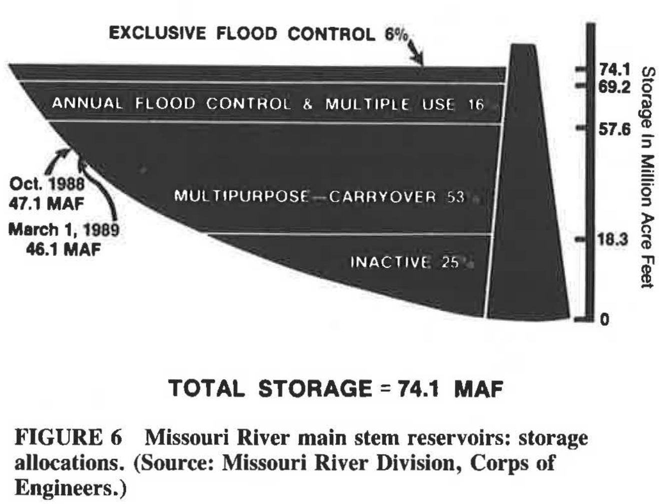

FIGURE 6 Missouri River main stem reservoirs: storage allocations. (Source: Missouri River Division, Corps of Engineers.)

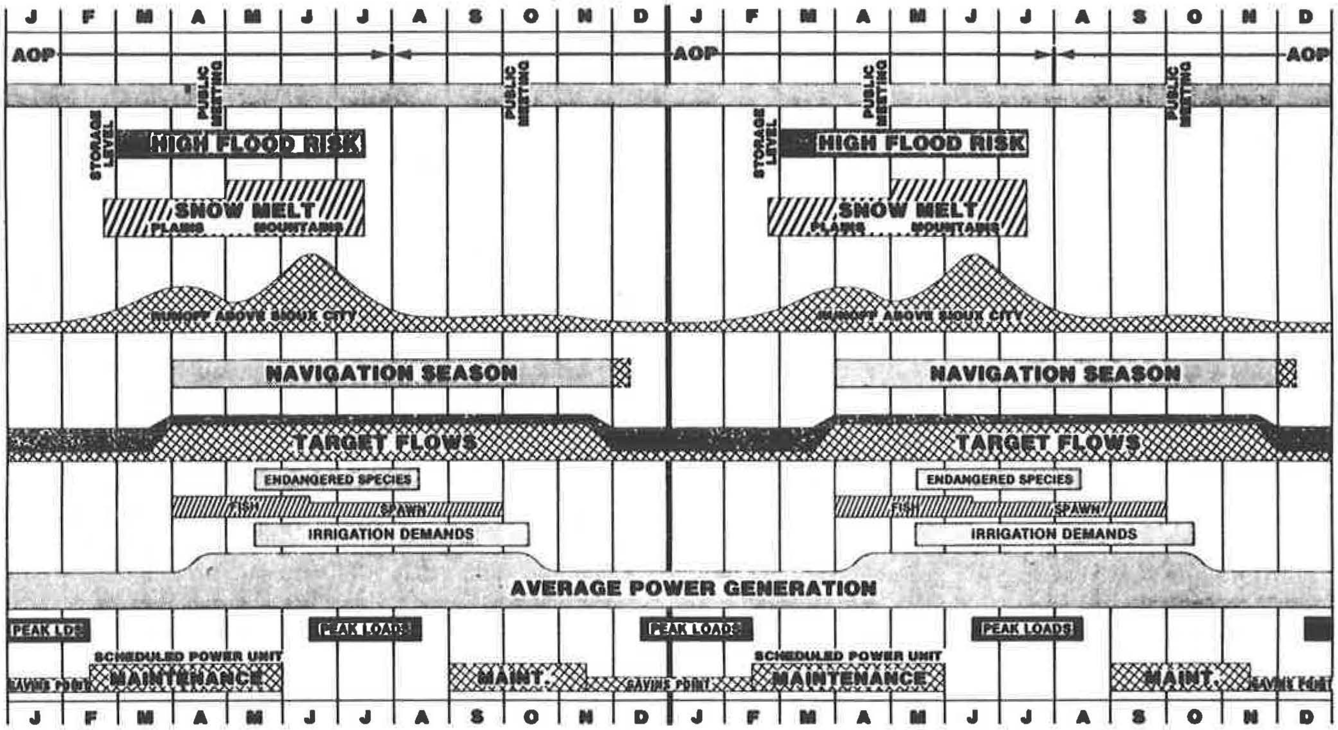

FIGURE 7 Water control calendar of events (*8*).

the winter season, when ice covers the Missouri. Maximum releases of 20,000 to 25,000 cfs can be maintained under ice conditions.

Severe Missouri River flooding occurred in 1844, 1881, 1903, 1908, 1909, 1915, 1927, 1932, 1942, 1943, 1951, and 1952. This type of flooding has been eliminated with development of the Missouri River Reservoir System, resulting in flood damage prevention of $2.7 billion (*7*).

Commercial Navigation

The Missouri is navigable for 732 mi from Sioux City, Iowa, to St. Louis, Missouri. Missouri River traffic has grown from about 300,000 tons in 1954 to a record high of 3.3 million tons in 1977. Since then, tonnage has steadily decreased to the level of 2.3 million tons in 1986.

Reservoir releases are scheduled to maintain Missouri River navigation target flows of 31,000 cfs at Sioux City, Iowa; 37,000 cfs at Nebraska City, Nebraska; and 41,000 cfs at Kansas City, Missouri. These flows generally provide a navigation channel 9 ft deep and 300 ft wide. The normal 8-month navigation season extends from April 1 through December 1. On the basis of perceived available water supply, the Corps often extends the navigation season by about 10 days. However, in times of severe drought, the target flows listed above are shortened by up to 6,000 cfs (*9*). The 1988 navigation season was shortened by 2 weeks and the 1989 season will be shortened by 5 weeks. Also, releases from Gavins Point Dam were cut to only 12,500 cfs during the winter of 1988–1989 to conserve water.

Hydroelectric Power Generation

Hydroelectric power is generated at all the main stem dams. Almost all of the water released from the reservoirs is used to generate hydroelectric power. Nearly 10 billion kilowatt hours of electricity are generated annually. This power serves 900,000 customers at a retail value of $485 million. The power is marketed by the Western Area Power Administration in the states of Colorado, Iowa, Minnesota, Montana, Nebraska, North and South Dakota, and Wyoming. Releases from the reservoirs are varied to allow generation of the greatest amount of energy at the times of greatest demand. Power generation is highest in the summer months and lowest in the winter.

Irrigation

Irrigation was a key purpose of the Pick-Sloan Plan. The original plan called for irrigation development of nearly 5 million acres of land (Table 2). However, irrigation development has been plagued with both economic and environmental difficulties, and only 8 percent of the planned development has occurred (*10*).

Today approximately 400 permits exist for irrigation withdrawals in the reservoir area, but these are relatively small. Irrigation, as developed today, does not significantly affect reservoir operation.

Section 1 of the Flood Control Act of 1944 (O'Mahoney-Millikan Amendment) gives priority to the use of water for irrigation and water supply over navigation. This amendment is strongly defended by upstream states still looking for the

TABLE 2 IRRIGATION DEVELOPMENT UNDER PICK-SLOAN MISSOURI RIVER BASIN PROGRAM

State	Acres Planned For Development	Acres Federally Developed	Percent
Montana	967,130	47,782	5
Wyoming	281,560	71,773	25
North D.	1,266,440	9,019	1
South D.	961,210	15,282	2
Colorado	101,280	0	0
Nebraska	989,445	177,230	18
Kansas	193,335	72,598	38
Total	4,760,400	393,684	8

development of irrigation. The amendment is viewed as counterproductive by downstream states that consider the development of new irrigation wasteful in this era of agriculture overproduction.

Water Supply and Quality

Numerous intakes are located along the Missouri to satisfy the needs of municipalities, irrigation, and thermal electric power plant cooling. Water supply needs do not significantly affect reservoir management. A minimum release rate of 6,000 cfs is required to facilitate water supply and water quality needs.

Fish and Wildlife and Public Recreation

Construction of the main stem reservoirs has contributed significantly to sport fishing in the Missouri River basin. Fish and wildlife needs are an important part of reservoir management. Reservoir levels and releases directly affect fish production, particularly during spawning periods. Water supply is not always adequate to allow the annual operation of each reservoir for optimum fish management. Therefore, to the extent possible considering other water needs, emphasis is given to the fishery management needs at one or two reservoirs each year. For example, water levels may be raised to where shoreline vegetation or rock spawning habitat is present during the spring spawning season.

Migrating waterfowl use the reservoirs in the fall months until the water freezes. Recreational use of the Missouri River increases each year. Nearly 12 million visitor days of use were recorded in 1986 (*7*).

In 1985 new challenges were introduced to operation of the Missouri River reservoirs with listing of the least tern and the piping plover as endangered and threatened species, respectively. These small birds nest on barren sandbars near the water's edge downstream from Garrison, Fort Randall, and Gavins Point dams. The nesting period is from May 15 through August 15. These nesting sites are prone to periodic inundation due to required reservoir management for flood control, hydroelectric power generation, and navigation.

The Endangered Species Act of 1973 requires federal agencies to ensure that their actions do not jeopardize the continued existence of threatened or endangered species or result in the destruction or adverse modification of their habitats (*7*). The Missouri River Division Corps of Engineers has outlined two basic options in managing the main stem reservoirs for the least tern and the piping plover:

- Stabilize river stages during the May–August nesting period.
- Provide nesting habitat at higher elevations (surveys are currently being conducted aimed at providing additional habitat).

During the 1988 period of low water flow in the Mississippi River, the Missouri River Division Corps of Engineers announced that the current release of 32,000 cfs from Gavins Point Dam was the maximum flow that could be sustained without significantly affecting the least tern and the piping plover (*11*). The maximum release rate from Gavins Point Dam is 45,000 cfs.

INCREASED FLOWS FROM THE MINNESOTA HEADWATERS LAKES

The Minnesota headwaters contain a relatively small amount of water (1.6 maf) when compared with the huge reserves of the Great Lakes and Missouri River main stem reservoirs. This lack of water supply, combined with excessive water travel times (2 months) from the headwaters to St. Louis, makes any plan for their use to supplement middle or lower Mississippi River flows infeasible. However, these reservoirs are important to provide regulated flow adequate for the operation of three navigation locks at St. Paul. Minimum releases of 350 cfs are required for uninterrupted service of the locks.

Minnesota Headwaters Development

The Minnesota headwaters were developed under the 1880 and 1882 River and Harbor acts. This development consists of a system of six reservoirs constructed by the Corps of Engineers between 1881 and 1913 (Figure 8). The reservoirs were originally authorized primarily to provide adequate flows for Mississippi River navigation from St. Paul to Lake Pepin (Pool 4). Later construction of the 9-ft channel and the lock-and-dam system on the Upper Mississippi significantly reduced the need for regulation of the reservoirs for navigation under normal conditions (*12*).

Today, with reduced need of releases for navigation, the reservoirs are operated for flood control, recreation and tourism, and fish and wildlife. Private property owners and resort interests have requested that the reservoirs be kept at uniform levels during the resort season. The reservoirs are also operated to support the production of wild rice, which is an economically and culturally significant resource for the Chippewa people. The regulated outflow from the reservoirs contributes to improved water supply, waste assimilation, stream habitat quality, downstream power generation, and industrial water supply.

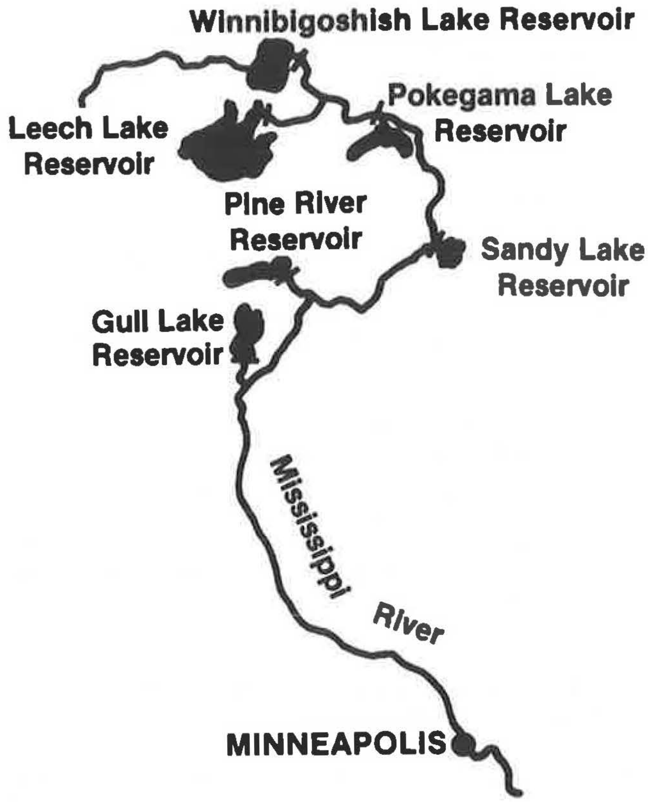

FIGURE 8 Minnesota headwaters lakes.

Regulation Plan

Through the 1888 River and Harbor Act, Congress gave the Secretary of the Army authority to develop regulations for operation of the headwaters reservoirs. These regulations were published in February 1936 and amended in January 1945. The published regulations indicate that the St. Paul District Corps of Engineers should regulate the headwaters reservoirs between the elevations shown in Table 3 whenever possible. (The normal summer regulation range is also shown for comparison.)

In addition, minimum flow releases have been established for each reservoir as follows:

Reservoir	*Minimum Release (cfs)*
Winnibigoshish	100
Leech	100
Pokegama	0
Sandy	20
Pine	30
Gull	20

Each of the reservoirs has a point of "mandatory minimum release" that coincides with the lower range of the "normal summer elevation" shown in Table 3. When a reservoir recedes below this stage, the regulations indicate that no release greater than the specified minimum should be made until the reservoir stage exceeds this level. If reservoir elevations decline further to the "minimum elevations" shown in Table 3, the release rates are reduced to 50 percent of the values shown above.

The total available storage in acre-feet, based on normal summer storage and the constraint of mandatory minimum release, is 177,180 for Winnibigoshish; 43,140 for Pokegama; 251,000 for Leech; 16,000 for Sandy; 48,400 for Pine River; and 20,000 for Gull. This results in total storage of 555,720 acre-feet available for flow augmentation from the headwaters projects under the present regulations for operation.

The most recent report on the headwaters reservoirs is the September 1982 feasibility study (*13*), which recommended only minor changes in reservoir operation that could be implemented under existing authorities.

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TABLE 3 HEADWATER RESERVOIR REGULATION LEVELS

	Minimum		Maximum		Normal Summer
Reservoir	Elev.	(Stage)	Elev.	(Stage)	Elevation Range
Winnibigoshish	1294.94	(6.0)	1303.14	(14.2)	1297.94 - 1298.44
Leech Lake	1292.70	(0.0)	1297.94	(5.24)	1294.50 - 1294.90
Pokegama	1270.42	(6.0)	1276.42	(12.0)	1273.17 - 1273.67
Sandy	1214.31	(7.0)	1218.31	(11.0)	1216.06 - 1216.56
Pine River	1225.32	(9.0)	1231.32	(15.0)	1229.07 - 1229.57
Gull	1192.75	(5.0)	1194.75	(7.0)	1193.75 - 1194.00

Source: St. Paul District Corps of Engineers

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Investment Strategy for the Inland Waterways

LLOYD G. ANTLE

A current assessment of the Inland Navigation Program is presented. The program sets forth a strategic planning process for the inland waterways. The plan includes consideration of the physical system, traffic growth, the performance of locks, the investment program, and the Inland Waterways Trust Fund.

Uncertainty has dominated decision making for the inland waterways. Capital and manpower resources for building new navigation structures, rehabilitating old ones, and operating and maintaining more than 200 navigation structures on the nation's waterways have been constrained by policies, priorities, and conflicts among competing claims for public and private resources.

Planning strategically—systematic and realistic assessment of needs and problems, formulation of alternatives, and evaluation and recommendation of measures that respond to needs and constraints—is as inevitable for the inland waterways as for any other transportation mode. Deregulation of prices and service requirements have made market forces a more active ingredient of decision making in both the private and public transportation sectors.

With the advent of the Water Resources Development Act of 1986 (WRDA 86) (P.L. 99-662), the pace of change has quickened and the U.S. Army Corps of Engineers and the waterways industry have begun the process of adapting strategically. WRDA 86 authorized construction of eight new inland navigation projects, established a cost-sharing policy for inland navigation projects (up to 50 percent of the cost of construction or rehabilitation from a trust fund consisting of fuel tax revenues and accrued interest), and created an Inland Waterways Users Board composed of representatives of the shippers and operators who utilize the waterway system to make recommendations to the Corps and Congress on priorities and projects.

Following an impasse of almost 20 years in getting waterway projects authorized, a 5-year period of lowered traffic levels, and overcapacity and low earnings in the waterway industry, WRDA 86 sparked many adjustments both in the process by which waterway investment decisions are made and in the outlook of the players in the private and public sectors. The Corps and the Users Board have educated each other at a rapid rate. The Users Board wants to be an active player in fashioning investment decisions and in influencing these decisions. Its members are impatient with the intricate planning and decision-making process, and they are amazingly quick to digest large quantities of technical and policy information.

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The Corps has sought to listen to and respond quickly to the requests, suggestions, and recommendations of the Users Board. Study schedules, design schedules, and construction schedules have been altered to speed up work on projects that are high-priority investments from the Users Board's point of view. Although the Corps has slowed and stopped some studies that the Users Board has assigned lower priority, it is harder to slow or stop projects under construction. The Users Board has discovered that not only the Executive Branch priorities but the Legislative Branch priorities must be taken into account, because Congress carries the initiative in appropriating funds. It is now clear that the Users Board will express priorities in a more sophisticated way than in their first attempts, but projects that are not attractive in their perception of commercial navigation interests will probably continue to receive lower priorities.

It is now clear that the Inland Waterways Trust Fund will generate enough revenue to fund perhaps four to six navigation lock-and-dam replacement projects per decade. This assumes that the 20-cent fuel tax rate will be implemented by 1995, that fuel usage will increase at 1.5 percent per year, and that project costs will continue to inflate by 6 to 7 percent per year. Management of cost inflation on a number of projects in the investment backlog will ultimately control the rate at which projects can be replaced. This limited rate of replacement will result in a gradual increase in average project age and place greater emphasis on improved project maintenance. The Administration and Congress could decide to alter the cost-sharing ratio (now 50 percent from the IWWTF) or increase the fuel tax and therefore increase the replacement rate. Those decisions will be very hard to make.

This writer's view is that the political consensus that produced WRDA 86 is likely to remain unchanged for a substantial period, and therefore the challenge for the investment strategy is to find the best way to use sharply constrained funds.

With this background, the remaining parts of this paper will present a current assessment of the Inland Navigation Program. It is based primarily on the recently completed 1988 Inland Waterway Review (*1*).

PHYSICAL SYSTEM

The inland waterways include about 11,000 mi of commercially navigable bodies of water. The waterway segments subject to the fuel tax include 216 lock chambers at 167 projects. Open river fuel tax segments (i.e., those that have no locks and dams) include the Missouri River (735 mi), the White

River (255 mi), and the Lower Mississippi River (720 mi). Tables 1 (*2*) and 2 show the lock projects and fuel tax segments.

The locks and dams are aging. More than 90 lock chambers are at least 50 years old. Capital and manpower resources will continue to be necessary in making maintenance, rehabilitation, and replacement decisions. Table 3 shows the distribution of locks by age for each of the major fuel tax segments. Note that the Upper Mississippi, Illinois, and Ohio River System segments contain the majority of aged projects. On the Ohio River System, the main stem is generally improved with 1,200- by 110-ft locks (except the first three locks below Pittsburgh), but the tributaries are both predominately undersized and old.

About 5,000 towboats push more than 33,000 barges to transport 500+ million tons of traffic annually. No new towboats or barges have been constructed since the early 1980s, but investment in fuel- and labor-saving technology has continued.

TRAFFIC GROWTH

Moderate but irregular traffic growth has resumed on the inland waterways. Improved prospects for exports of grain and coal are now materializing. Currency reform, the grain export enhancement program, reduction in worldwide carryover stocks of grain, and other factors have contributed to a solid increase in exports. The waterways are well positioned to handle a significant flow of grain and coal exports.

As the rationalization of domestic manufacturing has moderated, domestic shipments on the waterways have increased. In fact, the Ohio River System has for several years increased its volume of coal traffic because of the location of coal-fired power plants and coal mines with respect to the navigation system.

Figures 1 (*3*) and 2 show some historical data and the overall traffic projection envelope to the year 2000. Table 4 gives projections by major segments of the inland waterways. The projection integrates the information about dispersion around the trends into the envelope and into the baseline from which growth rates are introduced.

PERFORMANCE OF LOCKS

The Inland Waterway Review (*1*) made a substantial effort at analyzing data from the Corps Lock Performance Monitoring System (LPMS). In general, the group of locks with the most delay, the slowest lock processing time, the most stall events, and the most down time is relatively small. Although the "top 40" in each performance indicator changes to a degree, the locks with the most significant performance problems are on the Upper Mississippi, Illinois, Ohio River System, and the Gulf Intracoastal Waterway (GIWW) at and west of New Orleans (including the Inner Harbor Lock). Table 5 gives those projects that have high capacity utilization as well as high delays and down times. The last column of Table 5 shows the rank of each project, giving equal weight to all performance indicators. These are believed to be the projects that deserve continuing study in terms of measures that would economically improve transit of traffic.

Another concern is competition between commercial and recreational craft for lock capacity, which is increasing on several segments of the inland waterways. The problem is primarily peak use on summer weekends. Projects that had more than 50 percent lockages by recreational craft are shown in Table 6.

INVESTMENT PROGRAM

The 11,000 mi of inland waterways received outlays of $771 million in FY 1988 for construction and operations and maintenance. O&M outlays averaged 1.5 mills per ton-mile in 1986. Figure 3 shows the average O&M costs per ton-mile for the nine major waterway segments.

TABLE 1 INLAND WATERWAY LOCK PROJECTS ON FUEL TAX SEGMENTS (*2*)

			Status	
Segment Number and Name	Lock Projects	Lock Chambers	Under Construction with Fuel Tax Funding	Undergoing P.E.&D.[a]
1, Upper Mississippi	28	33	1[b]	0
2, Middle Mississippi	2	3	0	0
3, Lower Mississippi	24	24	0	0
4, Illinois Waterway	8	8	0	0
5, Ohio River System	58	95	4[c]	1[d]
6, Gulf Intracoastal Waterway	16	18	0	0
7, Mobile River and Tributaries	19	19	1[e]	0
8, Atlantic Intracoastal Waterway	3	3	0	0
9, Columbia-Snake-Willamette	9	13	1[f]	0
Total	167	216	7	1

[a]P.E.&D. = preconstruction engineering and design.
[b]Locks and Dam 26.
[c]Gallipolis, Grays Landing, Point Marion, and Winfield.
[d]Olmsted.
[e]Oliver.
[f]Bonneville.

TABLE 2 FUEL TAX WATERWAY SEGMENT LENGTHS

Segment/Waterway	Length (miles)
1. UPPER MISSISSIPPI	
Mississippi, Mpls, MN to Mo. R.	663
2. MIDDLE MISSISSIPPI	
Mississippi, Mo. R. to Ohio R.	195
Kaskaskia River	36
Missouri River, Sioux City to Mouth	735
3. LOWER MISSISSIPPI	
Mississippi River, Ohio R. to Baton Rouge, LA.	720
McClellan-Kerr Arkansas River	448
White River to Newport, AR	255[2]
Ouachita - Black Rivers	351
Red River to Shreveport, LA	236[2]
Atchafalaya River and Old River	220
4. ILLINOIS WATERWAY	357
5. OHIO RIVER SYSTEM	
Ohio River	981
Monongahela River	129
Allegheny River	72
Kanawha River	91
Kentucky River	82[2]
Green River[3]	149
Cumberland River	387
Tennessee and Clinch Rivers	652
6. GULF INTRACOASTAL WATERWAY	
GIWW: St. Marks, FL to N.O., LA	437
GIWW: N.O. to Brownsville, TX	690
GIWW: Morgan City-Port Allen	65
Apalachicola, Chattahoochee and Flint	297
Pearl River	58[2]
7. MOBILE RIVER AND TRIBUTARIES	
Mobile, Black Warrior, and Tombigbee Rivers	453
Tennessee-Tombigbee	234
Alabama River	305
8. ATLANTIC INTRACOASTAL WATERWAY	
AIWW: Norfolk-Jacksonville, FL (2 routes)	793
IWW: Jacksonville to Miami, FL	370
9. COLUMBIA-SNAKE WATERWAY	
Columbia R.: The Dalles to Richland, WA	135[1]
Snake R. to Lewiston, ID	230
Willamette River to Corvallis, OR	118[2]
Total U.S. Fuel Tax Segments	10,944
Segments not suject to fuel tax	
Minnesota, St. Croix and Black R.	52
Okeechobee Waterway	154
Cape Fear River	111
New York State Waterways	522
Total	11,783

NOTE: 1. Deep Draft Segment is not subject to fuel tax.
2 Depths less than 9 feet.
3 149 miles are taxed; however, navigation is possible for only 103 miles. Lock # 3 is no longer operable.

TABLE 3 AGE DISTRIBUTION OF LOCK CHAMBERS ON FUEL TAX WATERWAYS BY SEGMENT

	No. of Chambers by Age (years)								
River Segment	0–10	11–20	21–30	31–40	41–50	51–60	61–70	>70	Total
Upper Mississippi	0	0	3	1	17	11	1	0	33
Middle Mississippi	0	1	0	2	0	0	0	0	3
Lower Mississippi	4	19	1	0	0	0	0	0	24
Illinois	0	0	1	0	2	5	0	0	8
Ohio	4	19	20	6	11	21	4	7	92
GIWW	1	0	3	16	0	1	0	0	21
Mobile	10	4	3	1	1	0	0	0	19
AIWW	0	0	0	0	2	1	0	0	3
C-S-W	0	4	2	1	1	0	0	5	13
Total	19	47	33	27	34	39	5	12	216

NOTE: Ages are as of 1987. See Table 1 for complete river segment names.

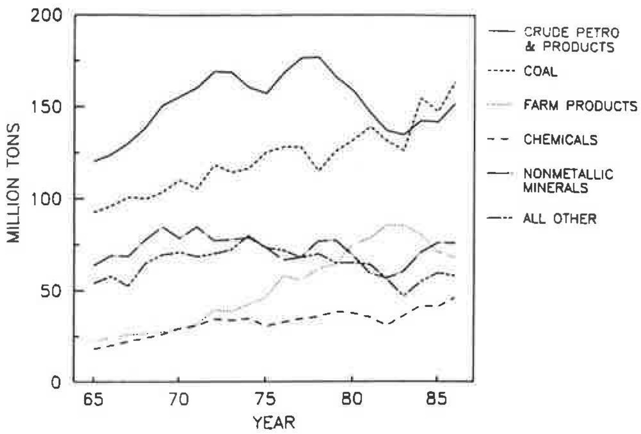

FIGURE 1 U.S. inland waterway traffic by commodity, 1965–1986 (*3*).

Construction or preconstruction engineering for eight replacement locks, funded in part by the Inland Waterways Trust Fund, was under way in FY 1988. Twelve rehabilitation projects were under way in FY 1988. Seven navigation projects started before WRDA 86 are continuing.

The Corps study program has identified 12 potential construction projects in the Ohio River System (four on the Ohio River main stem, three on the Monongahela, one on the Kanawha, and four on the Tennessee River). New studies are being programmed on the Upper Mississippi and Illinois systems, and continuing studies are under way on the GIWW (Inner Harbor Lock and the GIWW west of New Orleans). Table 7 gives an overall summary of projects under construction or rehabilitation, or both, or potentially available for construction and rehabilitation.

INLAND WATERWAYS TRUST FUND

The Inland Waterways Trust Fund was authorized by the Inland Waterways Revenue Act of 1978 (P.L. 95-502) and amended by WRDA 86. These laws establish the Trust Fund, fuel taxes (ranging from $0.10 per gallon of fuel before 1990 to $0.20 per gallon after 1994) for tows operating on 27 waterways, and appropriations from that fund. According to the law, the fund will be available "for making construction and rehabilitation expenditures for navigation on the inland and coastal waterways." To date, $99.8 million has been appropriated by Congress, $7.8 million in FY 1985, $26 million in FY 1987, and $66.2 million in FY 1988. FY 1988 expenditures are helping to fund the construction of five lock projects authorized by WRDA 86: Bonneville, Gallipolis, Lock and Dam 26 (second chamber), and Oliver and Grays Landing.

Trust Fund fuel taxes were first collected in FY 1981 at the rate of $0.04 per gallon. The first year's revenue was $20.4 million. Because waterway traffic has shown no sustained growth since 1981, annual fuel consumption has not increased. Taxes received have grown annually because of the increasing tax rate, not because of greater traffic levels. The balance in the Trust Fund grew rapidly in the early years because no expenditures were authorized by Congress until FY 1985. The fuel tax rate continued to increase, and interest earned on the Trust Fund balance increased as the balance increased. FY 1987 Trust Fund receipts were about $48.3 million. Interest on these receipts and the prior balance amounted to about $16.5 million.

Future receipts are linked to both the fuel consumption and the applicable tax rate. The forecast future receipts shown in Table 8 are based on an analysis using traffic growth rates of 1.0 and 2.0 percent per year, which it is assumed will be matched by a similar growth rate in fuel consumption. No inflation factor is applied to the calculation of receipts. The forecast future annual revenues without accrued interest grow from $48.3 million in FY 1987 to $111 million in FY 2000 at a 1 percent growth rate or to $124 million if total traffic grows closer to 2 percent annually. These revenues will be supplemented by interest earned on the balance in the Trust Fund. The balance will be affected by the number and cost of projects funded in a particular fiscal year. The increase in receipts is heavily influenced, as in previous years, by the doubling of the tax from $0.10 per gallon in FY 1989 to $0.20 per gallon in 1995. The rate is scheduled to increase from $0.10 to $0.11 in 1990, $0.13 in 1991, $0.15 in 1992, $0.17 in 1993, $0.19 in 1994, and $0.20 in 1995 and beyond.

Figure 4 shows the Trust Fund receipts, expenditures, and balance through 2000. The graph incorporates a 1.5 percent growth rate in receipts (the middle range cited above and in Table 8) and 50 percent funding of eight authorized projects and one anticipated project on the fuel tax waterways. Receipts include accrued interest on the balance from each previous year.

There is considerable uncertainty in estimates relating to forecasts of ton-miles. The impact of the fuel tax increases

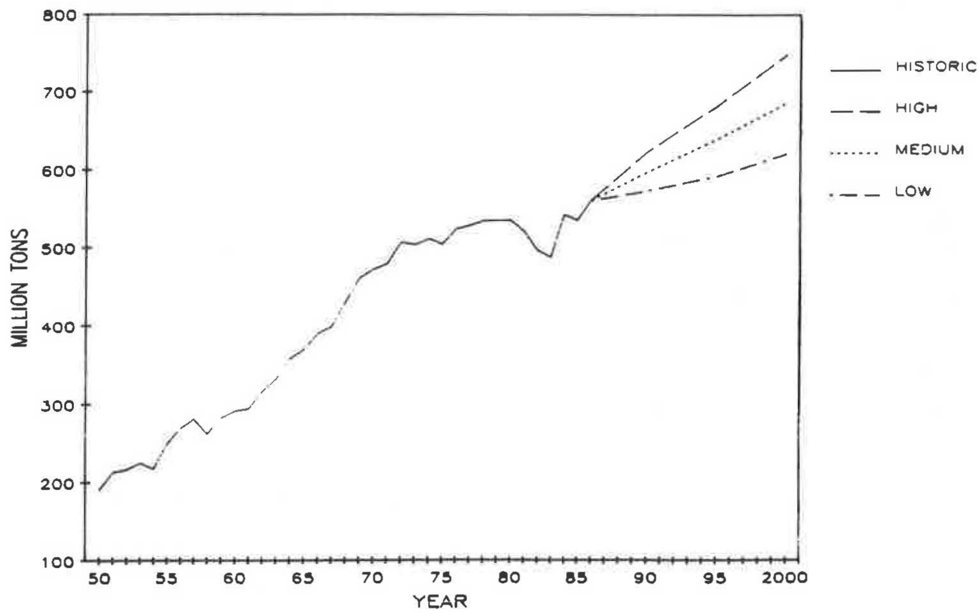

FIGURE 2 U.S. total internal waterborne commerce: historic, 1950–1986, and projected, 1990, 1995, and 2000.

TABLE 4 U.S. INTERNAL WATERWAY TRAFFIC PROJECTIONS BY SEGMENT: LOW AND HIGH, 1990, 1995, AND 2000

Waterway Segment	Actual, 1986	1990		1995		2000		Growth Rate (%)	
		Low	High	Low	High	Low	High	Low	High
Upper Mississippi	73.7	82.5	92.0	87.6	102.1	93.3	112.4	1.7	3.1
Middle Mississippi	97.7	106.3	117.4	112.9	130.3	120.3	144.8	1.5	2.9
Missouri River	7.0	6.8	7.6	6.5	8.5	6.2	9.4	−0.9	2.1
Lower Mississippi	156.2	168.5	187.8	178.3	209.6	189.5	234.0	1.4	2.9
Arkansas River	8.4	8.9	11.5	9.1	13.5	9.6	15.5	1.0	4.5
Illinois Waterway	42.3	44.5	49.9	47.2	54.9	50.1	60.1	1.2	2.5
Ohio River System	222.2	232.3	254.2	248.2	288.1	266.8	327.0	1.3	2.8
Ohio River (mainstem)	195.6	204.1	224.3	217.7	253.9	233.7	287.7	1.3	2.8
Monongahela River	29.5	38.5	42.1	40.5	48.6	43.1	56.2	2.7	4.7
Kanawha River[a]	16.8	18.1	21.4	19.5	24.6	21.2	28.4	1.7	3.8
Cumberland River[a]	14.2	15.7	18.0	16.2	20.8	17.0	23.7	1.2	3.5
Tennessee River	39.6	41.3	44.4	44.0	50.1	47.1	56.6	1.2	2.6
Gulf Intracoastal WW	105.7	102.0	112.4	99.9	121.3	101.7	131.0	−0.3	1.5
Black Warrior-Tombigbee	17.9	22.1	24.1	23.6	26.9	25.3	30.2	2.5	3.8
Atlantic Intracoastal	4.4	4.7	5.2	5.2	6.5	5.7	8.1	1.9	4.5
Columbia River	14.1	15.8	21.5	16.4	22.6	17.3	24.7	1.5	4.1
Total U.S. Internal	560.5	572.7	622.3	591.6	681.6	620.1	748.2	0.7	2.1

[a]Kanawha total shown is 1986 data from the Corps of Engineers Waterborne Commerce Statistics Center (WCSC). Ohio River Division estimates actual tonnage at 18.2 million. Cumberland total shown is 1985 data. Preliminary 1987 data from WCSC show 16.1 million tons.

NOTE: These projections were calculated in millions of tons by the Institute for Water Resources using

1. National growth rates by commodity group adapted from Data Resources, Inc.; Wharton Economic Forecasting Associates; U.S. Department of Agriculture; U.S. Department of Energy; and Institute for Water Resources. Waterway segment projections based on an average share of commodity traffic from national projections, which varied by waterway depending on historic patterns and commodity group. Projections are preliminary and subject to revision.
2. Linear adjusted projections calculated by adding the difference (positive or negative) between the original base and the linear adjusted base to each projected number. Linear adjusted base is 1986 calculated value using linear trend analysis for 1965–1986 data by waterway and for the national total. Only selected waterways were calculated because of a lack of data or because historic data exhibited no linear relationship over time.
3. Trend projections based on linear regression analysis of time series tonnages from 1965–1986 and are only shown for those segments that displayed a linear relationship over time.
4. For waterways with nonlinear historic data or incomplete data, two standard deviations of the historic data were calculated. This range was then applied to mean values of the high and low projections to generate new projections for the year 2000. Intermediate projections were the interpolated.
5. These waterway projections account for the maximum range of forecasts, low to high, calculated by using all of the above techniques.

TABLE 5 CAPACITY UTILIZATION: LOCKS WITH HIGH DELAYS AND DOWN TIME

Top 40 Locks and Rivers	Estimated Lock Capacity (ton millions) Low	High	Lock Traffic (ton millions)	Percent Capacity Used Low	High	Avg Delay Time (min)	Avg Process Time (min)	Total Delay Time (hrs)	Total Stall Time (hrs)	Performance Monitoring System Rank Equal Basis
Inner Harbor (GIWW)[a]	31	35	26.3	87.7	75.1	548	592	106,551	1616	103
L&D 26 (Upper Mississippi)[a]	70	75	69.3	99.0	92.4	465	552	56,165	377	86
No. 20 (Upper Mississippi)[b]	53	57	31.9	60.2	56.0	867	961	46,030	244	84
Gallipolis (Ohio)[a]	45	55	34.5	76.7	62.7	291	392	20,608	1141	83
No. 17 (Upper Mississippi)	53	54	29.2	55.1	54.1	334	420	15,981	62	73
Winfield (Kanawha)[a]	18	22	17.3	96.1	78.6	244	416	13,066	785	70
McAlpine (Ohio)[c]	82	116	55.9	68.2	48.2	296	356	26,186	287	69
Meldahl (Ohio)	97	133	46.3	47.7	34.8	200	269	14,387	3235	68
L&D 52 (Ohio)[a,b]	100	115	N.A.	N.A.	N.A.	169	216	27,523	1834	68
LaGrange (Illinois)[b]	46	49	30.3	65.9	61.8	295	371	15,384	230	64
Kentucky (Tennessee)[c]	35	39	30.1	86.0	77.2	247	356	15,786	194	62
No. 24 (Upper Mississippi)	59	60	35.5	59.8	58.8	246	335	13,328	62	56
Algiers Lock (GIWW)	26	29	26.7	102.7	92.1	217	262	36,565	165	56
No. 25 (Upper Mississippi)	59	60	35.3	59.8	58.8	231	315	12,285	141	50
No. 16 (Upper Mississippi)	48	49	27.2	56.7	55.5	216	294	11,256	158	44
Pickwick (Tennessee)	75	80	17.8	23.7	22.3	130	231	5,448	1255	43
No. 22 (Upper Mississippi)[b]	44	52	34.2	77.8	65.8	204	300	11,132	105	43
No. 21 (Upper Mississippi)[b]	52	57	33.4	64.2	58.6	135	218	7,264	692	40
Montgomery (Ohio)[b,c]	37	39	23.0	62.2	59.0	104	157	7,383	6652	39
Chickamauga (Tennessee)[c]	5	7	3.3	66.0	47.1	106	419	1,365	65	35
No. 15 (Upper Mississippi)	49	50	25.2	51.4	50.4	121	188	8,288	389	30
Lockport (Illinois)[b]	33	33	13.9	42.1	42.1	127	198	7,259	336	28
No. 18 (Upper Mississippi)	55	56	29.8	54.2	53.2	111	193	5,385	513	26
Port Allen (GIWW)	32	35	19.2	60.0	54.9	77	136	6,688	2402	25
Watts Bar (Tennessee)[c]	5	7	1.9	38.0	27.1	42	332	275	27	22
Peoria (Illinois)[b]	44	52	26.4	60.0	50.8	125	188	6,947	155	22
Kaskaskia	30	35	3.1	10.3	8.9	58	83	289	1558	18
Maxwell (Monongahela)	59	95	16.3	27.6	17.2	2	37	249	1301	17
London (Kanawha)	18	22	3.9	21.7	17.7	39	140	2,267	1039	17
Calcasieu Lock (GIWW)	N.A.	60	N.A.	N.A.	70.3	68	95	15,661	265	16
Racine (Ohio)	107	138	31.6	29.5	22.9	18	71	1,631	1008	13
L&D 2 (Monongahela)[c]	50	74	17.7	35.4	23.9	15	59	1,065	981	12
Leland Bowman (GIWW)	N.A.	N.A.	42.2	N.A.	N.A.	51	74	12,111	5	10
Hannibal (Ohio)	110	132	N.A.	N.A.	N.A.	12	65	605	769	10
Ft. Loudon (Tennessee)[c]	5	7	0.6	12.0	8.6	52	188	245	163	9
Marmet (Kanawha)[c]	18	22	10.1	56.1	45.9	35	183	3,300	96	8
Markland (Ohio)	89	133	53.9	60.6	40.5	32	87	2,509	552	8
No. 14 (Upper Mississippi)[b]	51	52	24.4	47.8	46.9	78	146	3,969	79	7
L&D 27 (Upper Mississippi)	142	158	78.0	46.2	41.7	49	88	9,125	246	7
Bonneville (Columbia)[a]	12	12	8.9	74.2	74.2	69	165	2,373	18	7

NOTE: GIWW = Gulf Intracoastal Waterway.
[a]Construction of replacement scheduled or under way.
[b]Major rehabilitation recently completed or under way.
[c]Replacement or improvement under study.

on waterway traffic share is not known with certainty and may affect the movement of different commodities in different ways. Other sources of uncertainty include the overall increase in grain exports, which are generally long-haul movements, and the application of fuel efficiency measures to vessels.

As noted, outlays from the Trust Fund shown in Figure 4 are based on specific appropriations for nine authorized projects on the fuel tax waterways. Table 9 shows the estimated cost of these projects and an estimate of the year in which construction could begin. Five of these projects actively drew from the Trust Fund in FY 1988. There are 12 additional candidate projects currently under study. In addition, problems may emerge in the next few years with projects not yet under study, creating another wave of funding needs.

According to Section 102a of P.L. 99-662, one-half of construction costs "shall be paid only from amounts appropriated from the Inland Waterways Trust Fund." Table 9 displays starting and estimated completion dates (some projects may be open to navigation earlier), total costs, and Trust Fund contributions for projects authorized to receive Trust Fund appropriations. The total expenditure of $2,626 million for these nine projects includes an allowance for inflation during construction. Out-year projections are best estimates prepared by the Corps of Engineers and do not reflect fixed commitments or budget amounts for specific years. Looking at expenditures for these nine projects only, outlays are scheduled to peak in FY 1995 at $147 million, and the Trust Fund balance dips accordingly.

Several studies now under way for the Ohio River System are likely to result in favorable recommendations for construction of replacement projects. Table 10 shows the estimated cost of these projects and an estimate of the year in which construction could begin. These studies are targeted to the parts of the Ohio River System where age and capacity

TABLE 6 RECREATION USE OF THE INLAND WATERWAY SYSTEM

WATERWAY/LOCK NAME OR NUMBER	LOCK UTILIZATION RATE IN 1986 (%)	RECREATION LOCKAGES 3RD QTR 1986 (MAIN/AUX) (%)[1]	RECREATION UTILIZATION RATE (%)[2]
Upper Mississippi			
No. 1	69	51/25	35.2/17.3
No. 2	61	49	29.9
No. 3	60	56	33.6
No. 4	59	52	30.7
No. 5	57	50	28.5
No. 5a	57	56	31.9
No. 6	59	56	33.0
No. 7	60	57	34.2
No. 8	60	51	30.6
No. 9	59	52	30.7
No. 10	58	53	30.7
No. 11	56	55	30.8
No. 12	54	55	29.7
No. 13	52	48	25.0
No. 14	62	28/99	17.4/61.4
No. 15	45	6/86	2.7/38.7
No. 16	57	32	18.2
No. 17	58	26	15.1
Arkansas River			
L&D 3	21	53	11.1
L&D 4	18	48	8.6
L&D 5	21	64	13.4
David T Terry	23	77	17.7
Murray	20	79	15.8
Toad Suck	19	46	8.7
Arthur V Ormond	16	47	7.5
Dardanelle	18	53	9.5
Ozark	17	46	7.8
James W Trimble	21	42	8.8
W D Mayo	22	53	11.7
Robert S Kerr	25	56	14.0
Webbers Falls	27	51	13.8
Illinois Waterway			
Starved Rock	53	37	19.6
Marseilles	64	35	22.4
Dresden Island	53	35	18.6
T J O'Brien	38	77	29.3
Tennessee River			
Chickamauga	41	54	22.1
Watts Bar	29	60	17.4

[1] The number of recreational lockages during July, August, and September expressed as a percent of all lockages in these months.

[2] Utilization rate times percent of recreation lockages.

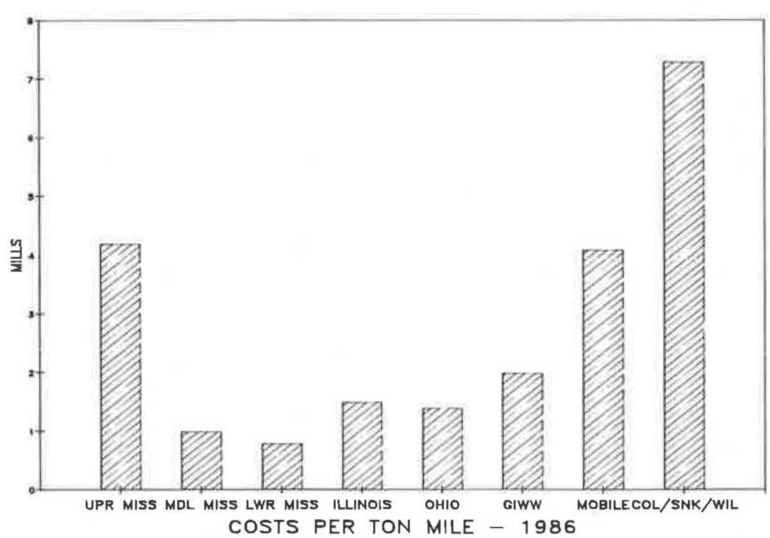

FIGURE 3 Operations and maintenance costs per ton-mile in 1986 for inland waterways subject to fuel tax.

TABLE 7 SUMMARY OF PROJECTS UNDER CONSTRUCTION OR REHABILITATION OR POTENTIALLY AVAILABLE

	Funding FY 1988 ($ millions)	Balance to Complete ($ millions)
Waterway projects under construction before WRDA 86	304	3,135
Projects started as a result WRDA 86 (partly funded by Trust Fund)	174	2,535
Projects authorized in WRDA 88 (partially funded by Trust Fund)	—	775
Potential projects under study (12)	—	2,295
Rehabilitation projects under way	NA	111.2

TABLE 8 FUTURE INLAND WATERWAY TRUST FUND FUEL TAX RECEIPTS

Fiscal Year	Tax Rate (¢/gal)	Receipts Under Alternative Growth Rates of Fuel Consumed[a] ($ millions)		
		1 Percent	2 Percent	Difference
1987	10	48	48	0
1990	11	55	56	1
1995	20	105	113	8
2000	20	111	124	13
2005	20	116	137	21
Cumulative total, 1981–2005		1,946	2,117	171

[a]Based on forecasts prepared by the Corps Institute for Water Resources.

TABLE 9 KNOWN POTENTIAL EXPENDITURES FROM TRUST FUND, FY 1987–FY 2002

Waterway	Authorized Project	Date		Costs[c] ($ millions)	
		Start[a]	Complete[b]	Total	Trust Fund
Columbia River	Bonneville Lock, Oregon and Washington	1986	1992	200	100
Ohio River	Gallipolis Lock and Dam, West Virginia and Ohio	1986	1995	335	167
Middle Mississippi River	Lock and Dam 26, second lock, Illinois and Missouri	1986	1991	214	107
Black-Warrior River	Oliver Lock and Dam, Alabama	1986	1991	122	61
Monongahela River	Grays Landing, Lock and Dam 7, Pennsylvania	1986	1995	146	73
Monongahela River	Point Marion, Lock and Dam 8, Pennsylvania	1986	1993	94	47
Kanawha River	Winfield Lock and Dam, West Virginia	1987	1997	190	95
Gulf Intracoastal Waterway	Missouri River Gulf Outlet, Inner Harbor, Louisiana	1986	2000	580	193[d]
Ohio River	Olmsted Lock and Dam, Illinois and Kentucky	1986	2000	775	373
Total				2,626	1,216

[a]Includes PED (Planning, Engineering and Design) start date.
[b]Or earliest date open to navigation.
[c]Cost estimates in Oct. 1986 dollars include allowance for inflation during construction.
[d]Allocation tentative, cost sharing yet to be determined.

of locks and dams are likely to produce significant delays to waterway traffic or where capacity constrains movement of potential traffic.

The balance in the Trust Fund was about $300 million at the end of FY 1987, the first year in which new projects actually drew from this fund. The nine scheduled projects will reduce the balance to approximately $200 million in the period FY 1991 through FY 1993. If no other projects are started, the balance would increase to reflect revenues and interest on the Trust Fund balance, as shown in Figure 4. However, there are other potential claims for funding from the Trust Fund. WRDA 86 specifically authorizes, which is also the policy of the Corps, 50-50 funding for both rehabilitation and construction of inland navigation payments from the Trust Fund. At this time, 12 projects are being rehabilitated and there is the potential for several additional projects by the year 2000. If the rehabilitation program is funded on a 50-50 basis from the Trust Fund, outlays from the Trust Fund would increase accordingly. This would reduce the Trust Fund balance but could be essentially accommodated from anticipated revenues. However, funding of the nine scheduled projects and the projected rehabilitation program could limit the capability to fund additional capacity-related replacement needs for the 11,000-mi system. The 12 projects under study on the Ohio River System may cost about $4.7 billion, fully funded. (Fully funded means total estimated outlays required to build the 12 projects. This is calculated by adding projected inflation to the yearly outlays required to fund the scheduled construction.) The Trust Fund balance will not contain enough to fund 50 percent of the costs of these projects if construction starts as soon as planning, engineering, and design permit. Other parts of the fuel tax segments appear at this time to warrant

TABLE 10 INLAND WATERWAYS TRUST FUND: ANALYSIS OF ESTIMATED INCOME AND OUTLAYS

Year	Estimated Outlays ($)	Tax Revenues ($)	Interest Earnings ($)	Year-End Balance ($)
1987	33,658,000	48,000,000	0	279,000,000
1988	66,245,000	48,720,000	22,320,000	283,795,000
1989	87,371,000	49,450,800	23,838,780	269,713,580
1990	129,600,000	55,211,818	23,195,368	218,520,766
1991	116,750,000	66,229,086	18,792,786	186,792,638
1992	96,399,000	77,564,448	16,250,959	184,209,045
1993	114,645,000	89,224,970	16,210,396	174,999,412
1994	113,088,000	101,217,856	15,224,949	178,354,216
1995	169,599,229	108,143,288	15,338,463	132,236,739
1996	159,494,229	109,765,438	11,372,360	93,880,307
1997	155,739,229	111,411,919	8,073,706	57,626,704
1998	150,739,229	113,083,098	4,840,643	24,811,216
1999	140,739,229	114,779,344	2,059,331	910,663
2000	106,138,229	116,501,035	75,585	11,349,054
2001	73,674,076	118,248,550	930,622	56,854,150
2002	65,704,076	120,022,278	4,662,040	115,834,393
2003	153,428,827	121,822,613	9,498,420	93,726,598
2004	153,428,827	123,649,952	7,685,581	71,633,304
2005	153,428,827	125,504,701	5,873,931	49,583,109
2006	167,859,792	127,387,272	4,065,815	13,176,403
2007	121,685,716	129,298,081	1,080,465	21,869,233
2008	121,685,716	131,237,552	1,793,277	33,214,346
2009	119,184,569	133,206,115	2,723,576	49,959,469
2010	119,184,569	135,204,207	4,096,676	70,075,783
2011	119,184,569	137,232,270	5,746,214	93,869,697
2012	104,753,604	139,290,754	7,697,315	136,104,162
2013	104,753,604	141,380,115	11,160,541	183,891,214
2014	225,555,462	143,500,817	15,079,080	116,915,649
2015	120,801,857	145,653,329	9,587,083	151,354,204
2016	188,029,601	147,838,129	12,411,045	123,573,778
2017	188,029,601	150,055,701	10,133,050	95,732,928
2018	188,029,601	152,306,537	7,850,100	67,859,964
2019	223,816,459	154,591,135	5,564,517	4,199,157
2020	103,014,601	156,910,002	344,331	58,438,888

NOTE: Scenario based on number of projects that may be found justified, construction timing determined by available fund balances, ultimate cost determined by timing of construction and interest/inflation assumptions. Anticipated projects include nine authorized to draw from the Trust Fund and 12 additional projects under study.

studies for consideration of replacement projects. These will add to the claims for funding.

One should not yet conclude that there is a funding crisis that cannot be solved. There will emerge convincing evidence either that the fuel tax rate should be increased or that budget priorities should stretch funds by delaying new starts, choosing not to fund lower-priority projects, increasing funding of low-cost capacity-increasing measures, or all three of these alternatives, which, along with other alternatives, will undoubtedly receive serious attention in planning studies and in the budget priority process.

CONCLUSION

The nation's inland waterway industry is showing renewed strength and vigor after laboring through declines during the recession years earlier in the 1980s. Coal traffic is booming and grain exports have surged. Traffic growth is reflecting the increased strength in many sectors of the economy. Now the question becomes whether the waterway infrastructure will be able to keep pace with future demand.

The Inland Waterways Trust Fund will be a critical part of maintaining the physical integrity of the system. The Trust Fund can provide 50 percent funding for nine new lock-and-dam projects now scheduled. Under projected growth in revenue, it could also fund rehabilitation projects now under way and several new ones. It is also clear that several additional construction projects could exhaust the Trust Fund if scheduled as rapidly as current studies anticipate.

Therefore, an inland navigation budget priority process is unavoidable. There will undoubtedly be a significant budget constraint, surely from the Trust Fund and very likely from the general tax funds available to the U.S. Treasury. The budget priority system should be systemwide and based primarily on net system benefits available for each budget alternative, subject to budget constraints. This will inevitably lead to emphasis on lowering the capital intensity of many of the alternatives prepared for funding. Smaller-scale investments for measures with high immediate payoff will attract funding priorities.

FIGURE 1 Principal deep-draft channel improvement projects authorized or under way (November 1988).

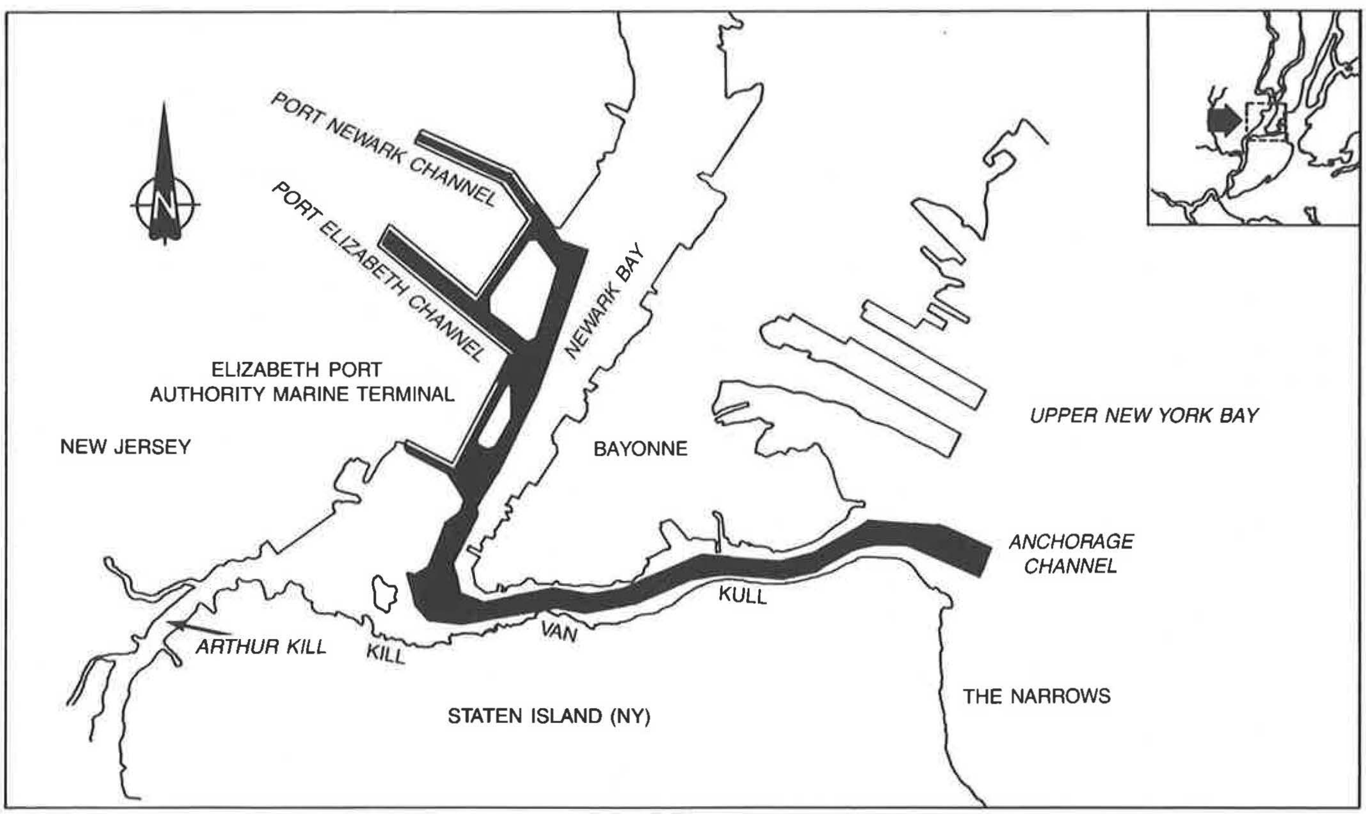

FIGURE 2 Kill Van Kull-Newark Bay channels, New York and New Jersey deepening project.

WRDA 86 also authorized four other projects in the New York–New Jersey area: Arthur Kill Channel, Howland Hook Marine Terminal, New York; Arthur Kill South to Fresh Kills and Carteret, New Jersey; Gowanus Creek Channel, New York; and Port Jersey Channel, New Jersey. All are currently in the design stage and LCAs have yet to be negotiated. The first Arthur Kill segment would deepen the existing 35-ft channel to 40 to 41 ft from its junction with the Kill van Kull for about 3 mi to Howland Hook Marine Terminal on Staten Island and Exxon Bayway, New Jersey, at a cost of about $43 million (with a federal share of $27.5 million). Construction is tentatively scheduled to begin in 1990. Current channel depths on the Arthur Kill require extensive lightering of tankers before they can proceed to refineries on the waterway. The second Arthur Kill segment would continue a 40-ft channel another 4.5 mi southward to Carteret, New Jersey, at a cost of about $26 million (about $19.5 million for the federal share). Design of this stretch is scheduled for completion in 1993, with construction to start in 1994.

The deepening project at Port Jersey would serve the Global Marine Container Terminal on the New Jersey side of the Hudson River. It is authorized to be deepened to 45 ft, but current plans anticipate deepening only to 40 ft initially. The total estimated cost is $13.4 million. The project is currently in the design stage, which is scheduled to be completed during 1991.

Gowanus Creek is a tidal estuary of Upper New York Bay in Brooklyn, New York. The project would deepen the current 30-ft channel to a maximum of 40 ft in certain locations. The cost is estimated at $3.9 million and design is scheduled to be completed in 1990.

DELAWARE RIVER IN THE VICINITY OF CAMDEN, NEW JERSEY

Deepening of the Beckett Street Terminal in Camden, New Jersey, from 34 to 37 ft was completed in 1987 under earlier authorizations at a cost of about $2.2 million. The project involved deepening a trapezoidal-shaped area connecting the terminal with deeper water in the Delaware River closer to the Pennsylvania shore. This configuration allows arriving vessels to swing alongside the terminal and then depart again in a forward direction. The terminal handles a variety of bulk commodities including coal, lumber, gypsum, iron ore, and titanium slag. Many bulk ships currently calling at the terminal cannot enter or leave fully loaded, requiring costly lightering, light loading, and waiting for high tides. The problem is projected to worsen with increasing vessel sizes in the dry bulk and general cargo fleets (*2*). WRDA 88 authorized additional deepening from 37 to 40 ft. Preconstruction engineering and design is under way for the 40-ft project and is expected to be completed by July 1990. Construction is estimated to cost $5.3 million, with the federal share being about $3.2 million. The local sponsor is the South Jersey Port Corporation, which is expected to sign an LCA during the design stage. The additional deepening to 40 ft at the Beckett Street Terminal will involve removal of about 550,000 yd^3 of material.

An additional project along the Delaware authorized by WRDA 88 would deepen the lower Schuylkill River at Philadelphia from 33 to 40 ft. This $8.5 million project is currently unscheduled. The local sponsor is the City of Philadelphia, which would pay the difference between the total project cost and the estimated $6.1 million federal share. About 1.5 million yd^3 of material would be dredged (U.S. Army Engineer District—Philadelphia, Public Affairs Office, unpublished data).

BALTIMORE HARBOR AND CHANNELS, MARYLAND AND VIRGINIA

The project to deepen channels connecting Baltimore Harbor with the Atlantic Ocean began construction in February 1987. It was authorized by the River and Harbor Act of 1970 and amended in the Supplemental Appropriations Act of 1985 and WRDA 86 to meet cost-sharing provisions. The project authorizes deepening from 42 to 50 ft, with channel widths generally 800 ft in Maryland waters and 1,000 ft in lower Chesapeake Bay in Virginia waters. Baltimore Harbor is located 175 mi from the entrance to Chesapeake Bay at the Virginia Capes. A total of about 57 mi requires dredging to achieve project depths, including the Cape Henry, York Spit, and Rappahannock Shoal channels in Virginia and the Craighill, Brewerton, Curtis Bay, Fort McHenry, and Northwest Branch channels in Maryland (see Figure 3).

Dredging of the entire authorized project will require the removal of 66 million yd^3 of material (32 million in Virginia and 34 million in Maryland) at a cost of about $330 million. An LCA was signed in June 1986 with the State of Maryland acting as the local sponsor. Maryland proposed phased construction of the project, with the first phase providing fully authorized depths in all channels but with channel widths reduced from 1,000 to 800 ft in the York Spit and Rappahannock Shoal channels; 800 to 700 ft in the straight reaches of the main approach channels in Maryland; and 600 to 400 ft in the Curtis Bay branch channel (*4*).

Construction of the initial phase will result in a reduction in dredging quantities from 66 to 52 million yd^3 (25 million in Virginia and 27 million in Maryland). Costs for the first phase are estimated at $246 million (versus $330 million for the full project), of which about $107 million will be the federal share. Dredging is proceeding under six separate contracts, three of which have been completed. The remaining work is scheduled to be completed by September 1990. Incremental dredging to the full project dimensions is not currently scheduled. Dredged material from the Maryland channels is being disposed of at the Hart–Miller Island Containment Facility in Chesapeake Bay at the mouth of the Patapsco River. Open water disposal areas in Chesapeake Bay are being used for material from York Spit and Rappahannock Shoal channels, and the Dam Neck ocean disposal area is being used for material from the Cape Henry Channel. In addition, 964,000 yd^3 of material from the Cape Henry Channel will be deposited on Virginia Beach as a beach nourishment project. The federal government and Virginia will cost-share this effort 50-50 under terms of an LCA between Virginia and the Assistant Secretary of the Army (Civil Works).

NORFOLK HARBOR AND CHANNELS, VIRGINIA

In December 1988, the port of Hampton Roads dedicated newly deepened 50-ft outbound channels serving coal terminals in Norfolk and Newport News. The 50-ft outbound

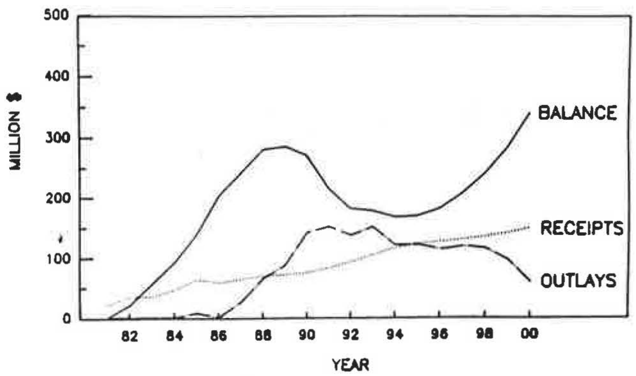

FIGURE 4 Inland Waterways Trust Fund receipts, outlays, and balance for nine projects.

Keeping the inland waterway system operating with the maximum efficiency possible while facing inevitable budgetary constraints will be a major challenge, but not an insurmountable one. By establishing sensible budget priorities, and with guidance from the Inland Waterways Users Board, the Corps will work to ensure a future waterway system that best serves the needs of the nation.

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Current Status of Cost-Shared Deep-Draft Harbor Projects

L. LEIGH SKAGGS AND DAVID V. GRIER

With passage of the Water Resources Development Act of 1986 (WRDA 86), a 16-year hiatus in major harbor improvement authorizations ended. This act authorized 39 channel improvement projects ranging in depth from 12 to 76 ft. It also introduced provisions requiring local sponsors to share the cost of harbor improvements with the federal government, the percentage being dependent upon the depth of the improvement. As of January 1989, 15 ports had signed local cooperation agreements, and another six are likely to be signed in 1989. In addition, passage of WRDA 88 authorized three additional deep-draft harbor projects and reinforced a goal of biannual water resources legislation, thus ensuring a steady pace of the new harbor improvement projects needed to keep U.S. ports competitive in the world economy.

On October 17, 1986, the last day of the 99th Congress, WRDA 86 was passed. This landmark legislation ended a 16-year hiatus in major harbor improvement authorizations as well as the historic tradition of 100 percent federal funding of navigation projects. Federal funds are still used for lands, easements, rights-of-way, relocations, and dredge material disposal sites (LERRD). Altogether, WRDA 86 authorized 39 channel improvement projects ranging in depth from 12 to 76 ft. It also introduced provisions requiring local sponsors to share the cost of harbor improvements.

The cost-sharing provisions of WRDA 86 applied not only to new projects, but also to those previously authorized but not yet constructed. The legislation requires local sponsors to cover 50 percent of the cost of deepening below 45 ft, 25 percent of the cost of deepening in the range of 20 to 45 ft, and 10 percent of the cost of deepening for projects 20 ft deep or less. For all depth categories, local sponsors must also repay an additional 10 percent of the total project cost that is initially covered by the federal government over a 30-year period. However, this 10 percent can be partially or totally offset on the basis of the value of the LERRD provided by the local sponsors (*1*). The legislation also authorized local entities to enact user fees that would help recoup their investment. However, intense competition between ports has precluded this option among the projects completed to date.

As of January 1989, 15 ports had signed Local Cooperation Agreements (LCAs) with the Assistant Secretary of the Army (Civil Works), which specified local and federal responsibilities for funding channel improvements (Office of the Chief of Engineers, Washington, D.C., unpublished data). Another six LCAs are being negotiated and are likely to be signed in 1989. Some of these agreements cover the full congressionally authorized project, but many only cover an initial phase of the total project and defer further improvements to a later date. Such project phasing has a number of advantages for local sponsors, including lower initial capital requirements, earlier realization of project benefits, and the opportunity to reassess various components of a project before making additional investments.

U.S. Army Corps of Engineers Water Resources Support Center, Institute for Water Resources, Casey Building, Ft. Belvoir, Va. 22060.

Figure 1 shows the location of pending deep-draft harbor improvement projects authorized by WRDA 86, the recently passed WRDA 88, or earlier legislation. Of these numerous authorized projects, only 12 were actually under construction in 1988. Each of these projects will be discussed in more detail in the following paragraphs.

KILL VAN KULL AND NEWARK BAY CHANNELS, NEW YORK AND NEW JERSEY

Deepening of Kill van Kull and Newark Bay channels was authorized by the Supplemental Appropriations Act of 1985 and then modified by WRDA 86 to comply with cost-sharing provisions. The Port Authority of New York and New Jersey is the local sponsor for the project. Kill van Kull Channel separates Bayonne, New Jersey, from Staten Island, New York, and connects Newark Bay with Upper New York Bay (see Figure 2). It provides access to terminals at Port Newark and Port Elizabeth on Newark Bay, which together form the nation's largest container port, handling over 13 million tons per year. The channel also provides access to refineries and other liquid and dry bulk terminals in New Jersey. Current channel depths limit the ability to handle the new generation of larger container vessels, as well as necessitating the loading and unloading of tankers by barges (lightering) in deeper water in Upper New York Bay.

The authorized project involves deepening about 5 mi of the Kill van Kull Channel and 3 mi of channels in Newark Bay from 35 to 45 ft, a turning basin at Port Elizabeth, and a 5-mi pierhead channel at Port Newark and Port Elizabeth. The total project cost is estimated at $342 million, of which $167.3 million would be funded by the federal government (*2*). However, the port has elected to construct the project in phases, and the current LCA (signed in May 1986 and modified in May 1987) provides for deepening to 40 ft initially. This first phase is estimated to cost $212 million, with the federal share anticipated to be $96.5 million. The first dredging contracts were let in July 1987 and completion of the 40-ft channel is scheduled for September 1989. Dredging is proceeding under five separate contracts; the last is scheduled to be awarded in February 1989 (*3*). Incremental deepening to the full project depth of 45 ft is unscheduled at this time.

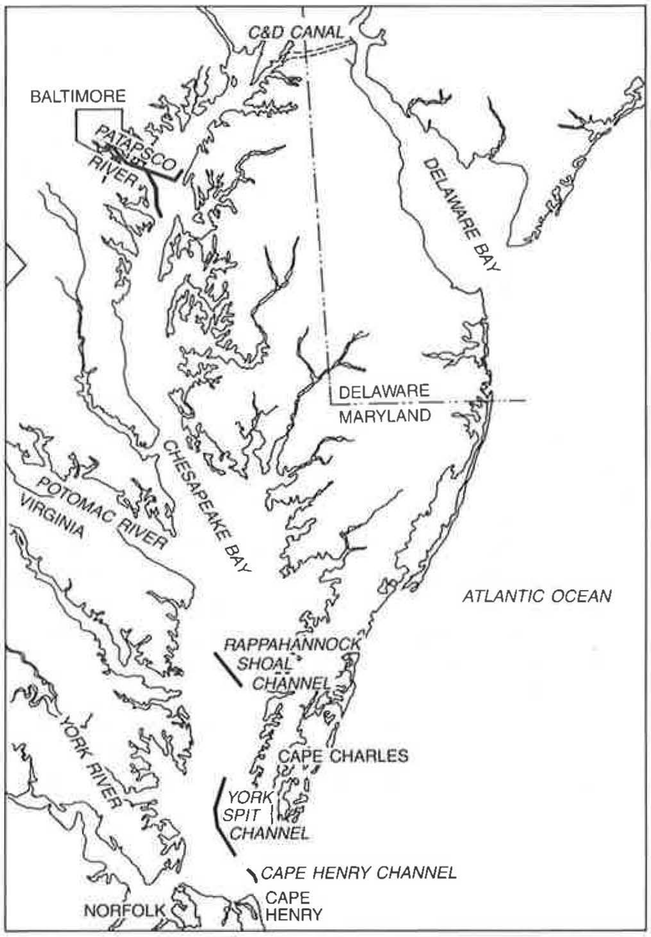

FIGURE 3 Baltimore Harbor and channels, Maryland and Virginia, deepening project.

channel was Phase I of a four-phase deepening project authorized by the Supplemental Appropriations Act of 1985 and WRDA 86. The authorized project includes deepening main channels from 45 to 55 ft in the harbor area and dredging a new 60-ft channel in the Atlantic Ocean approach lane. Widths vary from 800 to 1,300 ft over a total project distance of 37.6 mi (*5*). The authorization also includes deepening the Elizabeth River to 45 ft over a 6-mi stretch and to 40 ft over an additional 2.5 mi, as well as the deepening of two anchorage areas. The total project cost is estimated at nearly $232 million, of which about $102 million would be provided by the federal government. The Commonwealth of Virginia, acting through the Virginia Port Authority (VPA), is the local sponsor for the project. The project serves bulk commodities, particularly coal, which is generally shipped in vessels exceeding 100,000 deadweight tons, which cannot be fully loaded in 45-ft channel depths. The 55-ft project would allow these vessels to load to capacity, decreasing transportation costs to overseas markets and enhancing the U.S. position in the world coal trade.

VPA elected to construct the project in phases. An LCA was signed in May 1986 and modified in February 1987 to reflect cost-sharing provisions of WRDA 86. The agreement covered only the Phase I 50-ft outbound channel. The Commonwealth of Virginia will be required to modify the existing LCA or prepare a new LCA to provide for the cost-sharing of Phase II, which would further deepen the 50-ft outbound channel to 55 ft. The newly completed 50-ft channel was constructed at a cost of less than $33 million, with the federal share amounting to $17.5 million. The project involved 28 mi of channels (see Figure 4). Outbound lanes of the Norfolk Harbor and Thimble Shoal channels were widened to 650 ft. An 800-ft width (the full authorized dimension) was provided in the channel to Newport News to address safety concerns

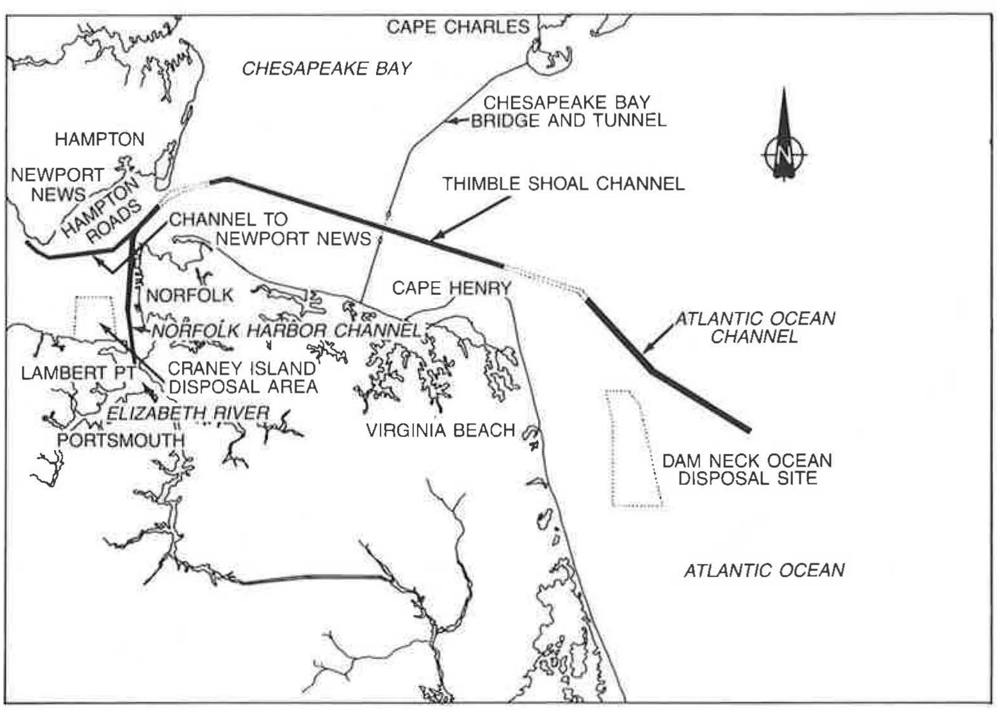

FIGURE 4 Norfolk Harbor and channels deepening project.

over currents in this section of the James River. The outbound channel improvements allow loaded coal colliers to exit the harbor while empty colliers travelling in ballast use the existing 45-ft inbound channel (*6*).

Plans for Phase II are not yet finalized, but local authorities hope to negotiate an LCA during 1990 and begin construction in 1991. Phase II would deepen the Norfolk Harbor, Thimble Shoal, and Newport News outbound channels to 55 ft and create a new 9.6-mi Atlantic Ocean Channel with a 60-ft depth. This project would also require the creation of a protective rock covering for the twin tubes of the Chesapeake Bay Bridge-Tunnel connecting Virginia Beach with the Delmarva Peninsula across the mouth of Chesapeake Bay. The estimated cost of Phase II is $133 million, of which $58.5 million would be federal funds. Phases III and IV would involve deepening the inbound channels to 50 and 55 ft, respectively. Both phases are unscheduled at this time.

CHARLESTON HARBOR, SOUTH CAROLINA

Deepening of the 35-ft channel at Charleston began in March 1988. The project was authorized by WRDA 86 and provides for a depth of 40 ft in the inland channels, 42 ft in the jetty and entrance channel, and 40 ft in the Wando River Extension (*2*). The project extends 27.6 mi from the 42-ft depth in the Atlantic Ocean to Goose Creek. The Wando River Extension is 2 mi long. Channel widths vary from 500 to 700 ft for the inland channel, 1,000 ft in the jetty entrance channel, and 450 ft in the Wando River (see Figure 5). The full project is scheduled for completion in 1995; however, project depths will be available in 1990. The total cost is estimated at about $125 million, of which $83 million would be federal.

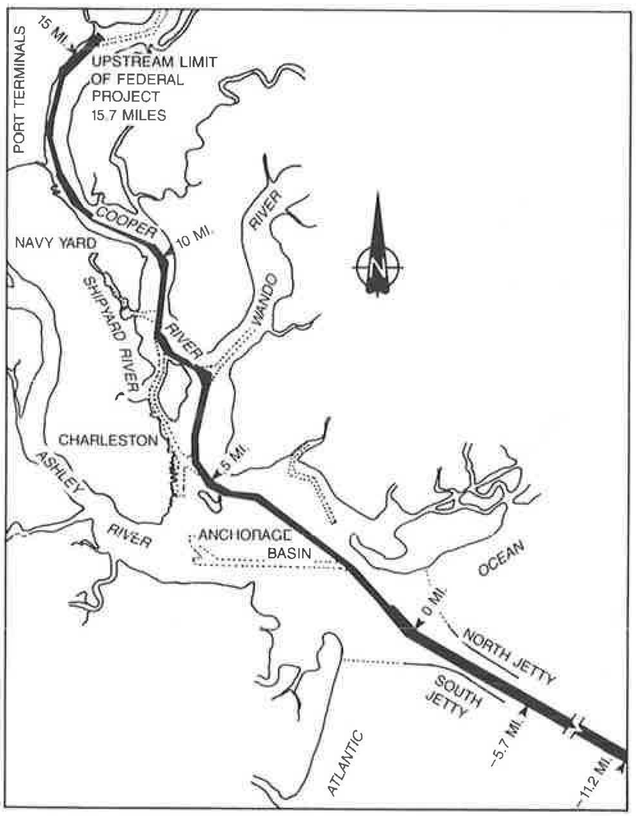

FIGURE 5 Charleston Harbor deepening project.

The South Carolina State Ports Authority is the local sponsor for the deepening project, and an LCA was signed in February 1988. The project was approximately 11 percent complete in October 1988. Four dredging contracts were awarded in 1988, and five were scheduled for 1989. By the end of 1990 most of the channel work is scheduled to be completed, including deepening to the upstream limit of the project. Remaining work will include a branch channel around Drum Island adjacent to downtown Charleston and an anchorage area in the open harbor near Ft. Sumter.

The Port of Charleston handles a wide variety of cargo that will benefit from a deeper channel, including containerized cargo and such bulk commodities as iron ore, soybeans, petroleum products, pulp, and fertilizer. The 40-ft channel will permit vessels of 80,000 to 90,000 deadweight tons to more fully load at the port and enter and leave with improved safety. Plans for the deeper channel have already helped Charleston secure additional traffic, such as a commitment by Maersk, Inc., to make a minimum of 100 vessel calls at Charleston and to load or unload at least 65,000 container 20-ft equivalent units (TEUs) (*7*). Containerized traffic at Charleston has been increasing about 20 percent per year since 1985, and for the year ended June 30, 1988, the port handled 645,000 TEUs, placing it second only to New York on the U.S. Atlantic Coast (*8*).

PONCE HARBOR, PUERTO RICO

Deepening of Ponce Harbor was authorized in 1976 under provisions of Section 201 of the 1965 Flood Control Act. The project provides for deepening the existing 30-ft channel to a 36- by 600-ft channel from the Caribbean Sea approximately 2.8 mi up to the port, a 36- by 400-ft channel in the port area, and a 36- by 950-ft diameter turning and maneuvering basin adjacent to the main port berthing area (*9*). The project was originally estimated to cost $10.4 million, of which $6.5 million was federal funds. However, the estimate for federal funds was subsequently lowered by half. In addition, bidding for the dredging contract was very competitive. Ultimately, the project cost is now estimated at only $3.0 million, of which $2.4 million would be federal (*10*).

The local sponsor for the project is the City of Ponce. An LCA was signed by the Mayor of Ponce on April 8, 1988. A contract was awarded in August 1988 and construction was initiated in December. Construction, originally scheduled to be completed by April 1989, was ahead of schedule and likely to be completed during February 1989.

Ponce has historically been a central distribution system for the southern region of Puerto Rico, and the recent improvement in facilities will enable the port to make a significant contribution to regional transportation. The deeper channel at Ponce will provide improved access to new and proposed terminal development and permit more efficient loading and unloading of vessels at the port. Containerized traffic particularly is expected to benefit. Other important commodities at Ponce include petroleum and petroleum products, fresh fish, cement, limestone, and basic chemicals.

TAMPA HARBOR AND BRANCH CHANNELS, FLORIDA

The port of Tampa is a major bulk center, ranking among the nation's 10 largest ports in terms of tonnage handled (*11*). Primary commodities handled by the port are bulk phosphate rock, phosphate products, fertilizers, coal, petroleum products, and sulfur (*11*). Transportation cost savings resulting from the employment of larger or more fully loaded bulk vessels have been used to justify past and continuing investment in channel improvements.

Several projects in the Tampa Bay area have been authorized or are under construction. The current project at Tampa Harbor was first authorized by the River and Harbor Act of 1970, and work began on the main channel in 1976. This initial authorization included deepening and widening the Tampa Bay entrance and main channels (to 45 and 43 ft by 700 and 500 ft, respectively), Hillsborough Bay Channel (to 43 by 500 ft), and three branch channels (Sparkman to 41 by 400 ft; Ybor to 39 by 300 ft; and Port Tampa Channel to 41 by 400 ft). Funds were never appropriated by Congress, however, for the branch channels and upper reaches of Hillsborough Bay Channel, known as Cut D. The Supplemental Appropriations Act of 1985 reauthorized these projects.

The project was reevaluated after implementation of the new cost-sharing legislation, and an LCA was signed in June 1986. The LCA with Tampa Port Authority specified deepening only two channels, not four, at a reduction in total cost from an estimated \$52 million to \$13 million. The federal share dropped from \$34 to \$8.6 million. Hillsborough Bay Cut D Channel would be deepened to the authorized 41 ft, and Sparkman Channel would be deepened to 36 ft instead of the original 41 ft (*12*). Another LCA was signed after passage of WRDA 86 and included federal assumption of maintenance dredging of East Bay Channel.

Construction began in February 1988 on Hillsborough Channel Cut D (see Figure 6). The first contract involved dredging 300,000 yd^3 and 3,700 ft of channel. Another contract was let in 1989. The schedule for future progress depends on availability of local funds. Because the project has been authorized and an LCA is in place, work will continue as Tampa Port Authority obtains additional funds. Eventually a total of about 1 million yd^3 will be dredged and placed in an existing diked disposal area in Hillsborough Bay.

In addition to the Tampa Harbor Branch Channels project, two other Tampa Bay projects have been authorized. WRDA 86 authorized the construction of a turning basin and enlarged widener on the southeastern shore of Tampa Bay and federal maintenance of the locally constructed 40 ft deep channel to Port Manatee. All material from initial construction and future maintenance is to be placed in diked upland disposal areas adjacent to the harbor. To mitigate the 6.6 acres of shallow

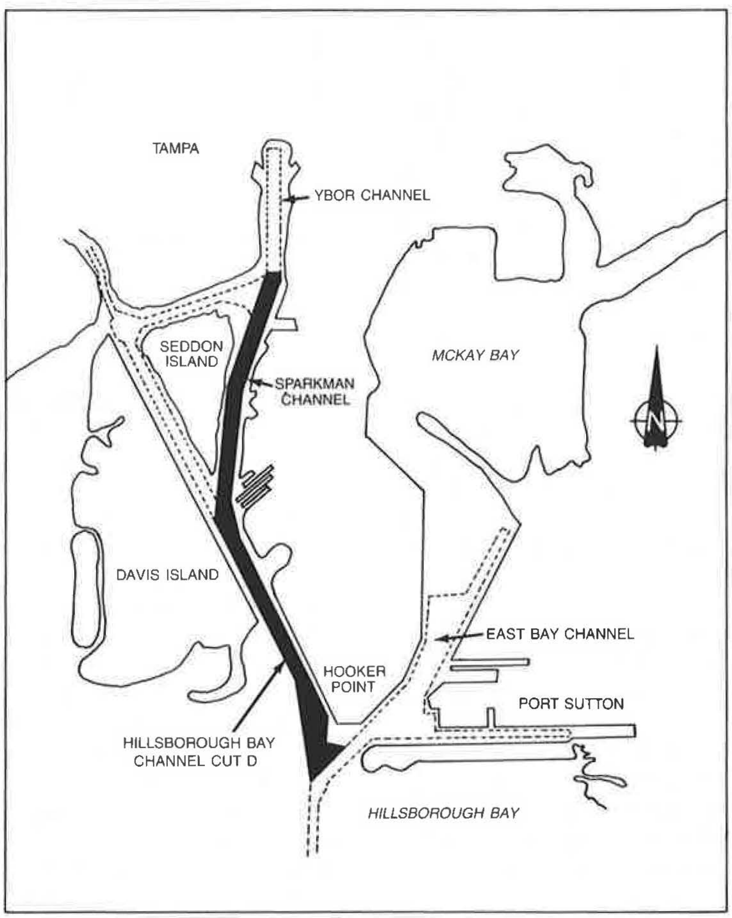

FIGURE 6 Tampa Harbor branch channels deepening project.

bay bottom lost in enlarging the turning basin, 10 acres of the emergent near-shore disposal island is to be excavated 2 ft below mean low water (*13*). The Corps is currently negotiating an LCA with Manatee City Port Authority. Construction should begin in 1990.

The channel at Port Sutton, located across the East Bay Channel from the port of Tampa, was authorized by WRDA 88 to be deepened to 42 ft for a length of 3,700 ft. Project benefits would accrue chiefly to large bulk vessels carrying phosphate rock and sulfur. Total costs are estimated to be $2.7 million (a $1.2 million federal share) (*2*). However, no LCA or construction schedule is in place.

MOBILE HARBOR, ALABAMA

Situated at the mouth of Mobile River and the head of Mobile Bay, Mobile Harbor is one of the nation's largest export ports, handling over 37 million tons of cargo annually (based on the most recently published data from the Army Corps of Engineers) (*11*). Mobile's role as an export center is enhanced by its access to the U.S. agricultural and industrial heartland via the Gulf Intracoastal and Tennessee-Tombigbee waterways, as well as by a vast inland river network. Commodities transshipped at the port are primarily bulk products: coal and lignite, gasoline, fuel oil, iron ore, crude petroleum, limestone, sand, gravel and crushed rock, soybeans, corn, and wheat (*11*).

The economies of scale enjoyed by large bulk carriers and the resulting transportation cost savings have been used to justify past and continuing investment in channel improvements. Large coal vessels calling at McDuffie Coal Terminal, in particular, require channel deepening and navigational improvement features for safe and efficient transits. Savings of $5 to $6 per ton on coal exports to Europe and $16 per ton on shipments to Japan would be realized by using larger bulk vessels (in the 100,000+ deadweight tonnage range) (*14*). Coal exports are expected to reach 19 million tons annually by 2015, pushing Mobile's total cargo throughput to 45 million tons (*2*).

Improvements to Mobile Harbor were authorized in the 1985 Supplemental Appropriations Act and WRDA 86. The authorization provides for deepening and widening the existing ship channel from 40 by 400 ft to 55 by 550 ft along the present ship channel alignment. The ship channel extends from the Gulf of Mexico through Mobile Bay to the Mobile River for 39 mi (see Figure 7). The total estimated cost of the entire project is $482 million (of which $213 million would be federal) and will require the excavation of 121 million yd^3 of dredged material.

The project will be constructed in phases. The LCA signed in June 1986 between the state of Alabama and the Army Corps of Engineers (and subsequently amended in 1987) applies only to the first phase. Phase I consists of deepening the bar channel to 47 by 600 ft and the bay channel to 45 by 400 ft from the Gulf of Mexico to the vicinity of the McDuffie Coal Terminal in Upper Mobile Bay, a total length of approximately 37 mi. Because Phase I does not include widening the channel and because of the reduction in deepening from the original 55 to 45 ft, Phase I will require excavation of only 18 million yd^3 (versus the original 121 million yd^3). This downsizing also produced a corresponding reduction in estimated

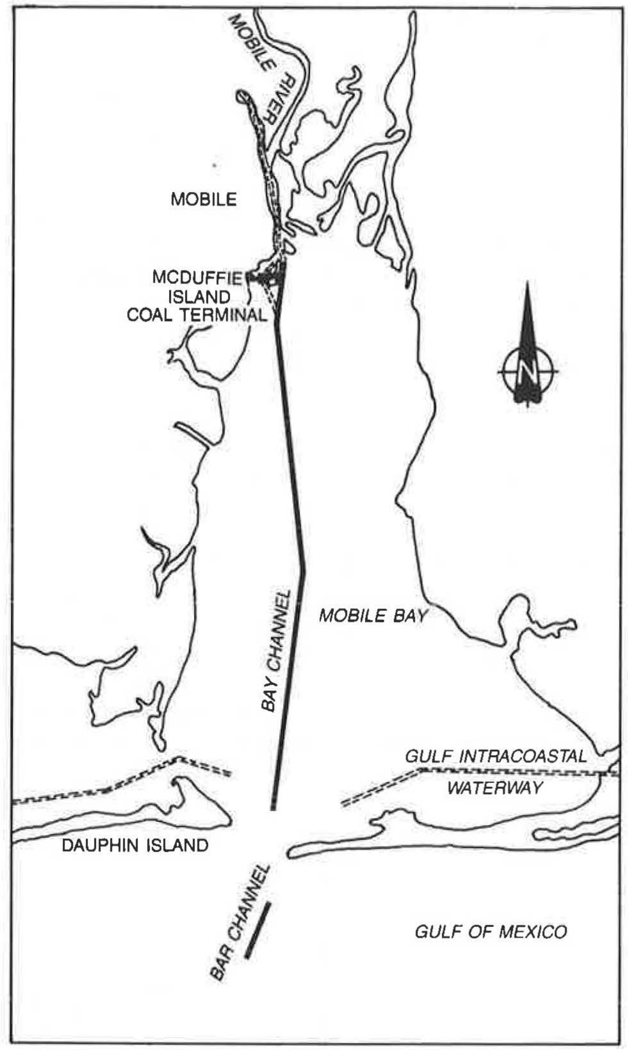

FIGURE 7 Mobile Harbor deepening project.

construction costs: Great Lakes Dredge and Dock Company won the $38.2 million contract in May 1987 ($28.7 million of this amount will be funded by the federal government). This cost represented only 8 percent of that originally estimated for the total project.

Dredging commenced in October 1987. The Great Lakes Company developed a larger, more efficient clamshell dredge for the Mobile project, capable of excavating 50 yd^3 per movement (*3*). Because of the dredge's enhanced capacity and speed, Phase I is 35 percent complete and on schedule, and should be completed by June 1990. The remaining authorized project (unofficially dubbed Phases II and III, which would bring the bay channel down to 50 and 55 ft, respectively) is currently unscheduled. Future construction depends on the availability of local funds from the state of Alabama.

The material being dredged from Mobile Harbor will be placed in an offshore stable berm structure south of Dauphin Island, Alabama, as part of an ongoing study on the beneficial uses of dredged material. The underwater berm structure is expected both to provide fish habitat and to reduce the height of potential storm waves.

MISSISSIPPI RIVER SHIP CHANNEL, GULF TO BATON ROUGE

The ports of New Orleans and Baton Rouge, Louisiana, are the largest and fifth largest in the United States, respectively, on the basis of the most recent traffic statistics published by the U.S. Army Corps of Engineers (*11*). Situated at the confluence of shallow-draft (mostly domestic) barge traffic and deep-draft (mostly foreign) ocean-going traffic on the lower Mississippi River, both ports are major bulk centers for the import and export trades. Primary commodities handled by the ports include crude petroleum, petroleum products, chemicals, fertilizers, coal, wheat, corn, feed grains, soybeans, iron and aluminum ores, and sulfur (*11*).

Before initiation of Phase I deepening (identified below), depth restrictions imposed by the then-existing deep-draft approaches to the ports of New Orleans and Baton Rouge prevented an increasing percentage of vessels in the world fleet from navigating the approaches fully loaded. This limitation, together with the projected increase in commerce through the ports, justified initial deepening (*2*). In addition, transportation cost savings resulting from the employment of larger or more fully loaded bulk vessels contribute to the overall benefits from improved navigation.

The Mississippi River Ship Channel project was authorized by the Supplemental Appropriations Act of 1985. WRDA 86 formalized the cost-sharing provisions and gave the local sponsors the right to charge user fees to recoup their share of the cost. The authorized project calls for deepening the channel from 40 to 55 ft and widening it to 750 ft from the Gulf of Mexico through the Southwest Pass to Baton Rouge, Louisiana, at River Mile 233 above head of passes (AHP); the total estimated cost was $490 million ($120.7 million federal). See Figure 8 for a map of the project area.

In addition to the increased channel dimensions, the plan includes the construction of an underwater sill of dredged fill across the Mississippi River at River Mile 63.7 AHP. Its purpose is to mitigate the increased saltwater intrusion into the New Orleans metropolitan area's water supply during the river's low-flow periods. The submarine sill was constructed and functioned for the first time as planned during the record-breaking drought of 1988. A permanent plan to mitigate the increased saltwater intrusion into the water of towns downstream of the sill in the lower Delta area is currently being negotiated with the state of Louisiana and Plaquemines Parish. In the interim, fresh water was shipped by barge to the area in 1988 and will be in the future, if needed.

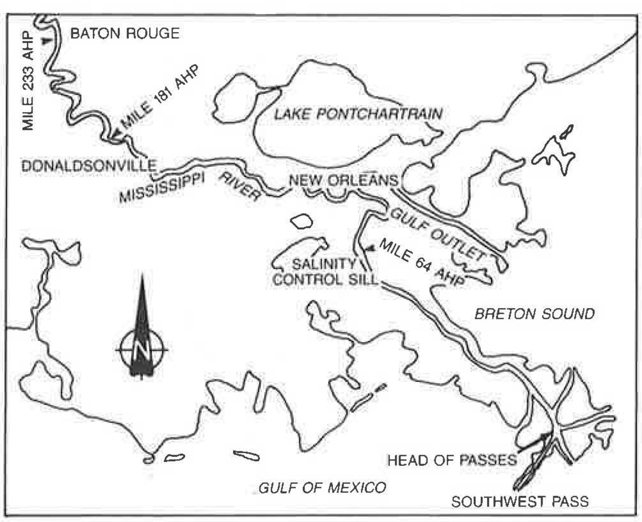

FIGURE 8 Mississippi River Ship Channel, Gulf to Baton Rouge, deepening project.

As in several other ports, the LCAs signed between the state of Louisiana and the Corps of Engineers in 1986 and 1987 provide for only a segment of the authorized project: the so-called Phase I. This consists of a channel 45 ft deep by 500 to 600 ft wide from the Gulf to River Mile 181 AHP near Donaldsonville, Louisiana. Dredging was initiated in July 1987 and completed by the end of 1988 at a total cost of just $39 million, a savings of about $21 million under the original cost estimates for Phase I. Dredged material from construction of the project was used for bank nourishment and the creation of marsh.

Construction beyond Mile 181 AHP and deeper than 45 ft is dependent upon the negotiation of additional LCAs between Louisiana and the Corps of Engineers. The state of Louisiana has requested that the Corps proceed with preparation of the LCA for the extension of the 45-ft channel to Baton Rouge. Construction will most likely proceed in 1991, pending LCA approval and the state's ability to provide its required funds. The deepening of the channel beyond 45 ft remains unscheduled (*2*).

FREEPORT HARBOR, TEXAS

The port of Freeport, Texas, is located just upstream of the mouth of the Old Brazos River and the Gulf of Mexico (see Figure 9). The port has handled an average of over 17 million tons of traffic annually during the last 10 years. Crude petroleum makes up nearly 70 percent of the port's cargo, followed by chemicals and petroleum products (*11*). Major users of the existing project, and hence major beneficiaries of proposed channel improvements, are the bulk vessels serving Freeport's numerous petroleum storage facilities and the massive Dow Chemical Company complex.

Improvements to Freeport Harbor were authorized by the 1970 River and Harbor Act and the 1985 Supplemental Appropriations Act. Plans call for deepening, realigning, and enlarging the 7-mi entrance channel from 38 by 200 ft to 47 by 400 ft and the jetty and main channels from 36 by 200 ft to 45 by 400 ft. Three turning basins would also be deepened to 45 ft. The Brazos Harbor channel and turning basin would be dredged from 30 to 36 ft. Part of the project includes relocating the 3,700-ft north jetty and rehabilitating the south jetty, both of which protect the entrance channel. A U.S. Coast Guard station would also have to be relocated.

Justification for this project was based on transportation cost savings that would result from the use of larger and more fully loaded vessels, primarily oil tankers. The current 36-ft-deep and 200-ft-wide channel is deemed inadequate and unsafe for larger vessels, many of which will not call at Freeport. This problem will only be compounded as the average size of vessels in the world fleet increases. Because of the hazards of narrow channels, sharp curves, and limited maneuvering

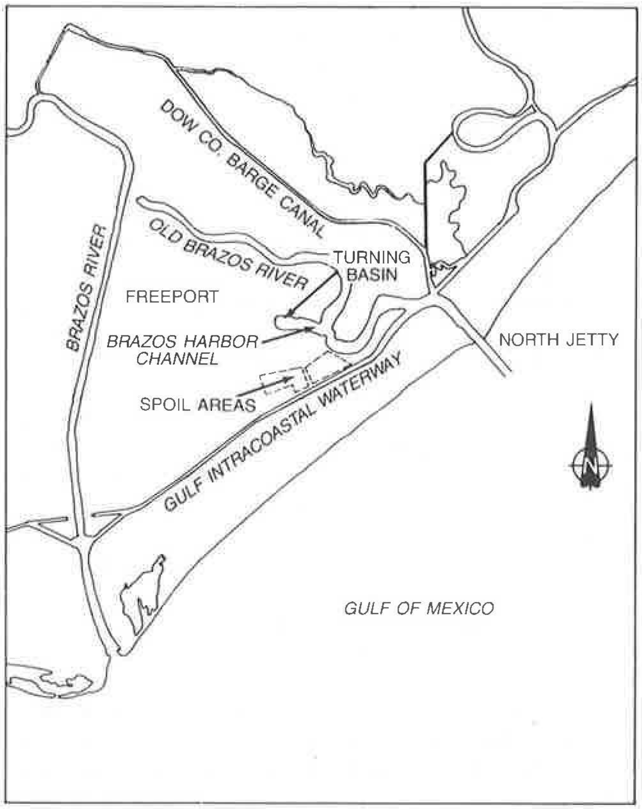

FIGURE 9 Freeport Harbor, Texas, deepening project.

areas in the existing turning basins, deep-draft vessel movements are limited to one-way traffic, with no passing or meeting in the channels inland from the jetty entrance. Strong crosswinds and currents, and periods of fog or other adverse weather may delay or prevent traffic from entering or leaving the jetty channel at all. To minimize these risks, vessels are operated at low or dead-slow speeds, which in turn sometimes leads to loss of effective rudder control. Harbor tugs are necessary to maneuver and assist vessels in the turning basins (*2*).

Because of the perceived necessity of these harbor improvements for economic and safety reasons, the LCAs signed in 1986 and 1987 between the Corps of Engineers and the Brazos River Harbor Navigation District, the local sponsor, provide for full construction of the authorized project. Construction of the new north jetty, relocated 640 ft north of its present alignment, started in May 1987 and is currently 50 percent complete. Progress was unexpectedly halted when a shipwreck site was discovered within the alignment of the jetty. The site was determined to be eligible for inclusion in the National Register of Historic Places. The jetty contractor will leave a gap in the new jetty until the shipwreck recovery operations are complete. Dredging of the first channel deepening, the Brazos Harbor Channel and turning basin, will commence in 1989. The local sponsor is nearing completion of dredged material disposal area levees. The entire authorized project is scheduled and should be completed by 1992 at an estimated cost of $88.2 million (of which $58.5 million is federal).

LOS ANGELES AND LONG BEACH HARBORS, SAN PEDRO BAY, CALIFORNIA

The Los Angeles and Long Beach Harbors complex is one of the most extensive in the world. Commercial cargoes passing through the ports include a wide range of commodities, which totaled more than 90 million tons in 1987. More than half of the total consists of crude petroleum and petroleum products. Other major commodities include chemicals, coke, cement, iron and steel products, automobiles, electrical machinery, miscellaneous manufactured goods, and food products (*11*). Of particular importance to the ports is the phenomenal increase in high-value container traffic through Los Angeles and Long Beach, which grew at an average annual rate of more than 20 percent in the 1980s. The combined volume of more than 3 million container TEUs ranks these ports as the second largest container ports in the world (*16*).

Improvements to the harbors of Los Angeles and Long Beach (LA/LB) were authorized by Congress in WRDA 86, subject to a favorable report by the Chief of the Army Corps of Engineers and the determination of federal interest in the project. WRDA 86 authorized channel deepening to 70 ft at Los Angeles and 76 ft at Long Beach and the creation of 800 acres of landfill with dredged material. The Water Resources Development Act of 1988, signed into law in November 1988, modified the authorization to the effect that the ports may receive financial credit for advance construction (i.e., in advance of the Corps' final feasibility report, which is scheduled for completion in the summer of 1989).

The comprehensive "2020 Master Plan" for the ports calls for $1.2 billion worth of construction to handle the anticipated doubling of waterborne traffic to 205 million tons by the year 2020 (*2*). (If a federal interest in the project is in fact determined, the federal share would amount to about half of all channel dredging costs, or $183 million.) Together, both ports plan to create some 2,500 acres from dredged material, filling one-fifth of San Pedro Bay (*17*). Construction will be implemented in five phases, the first of which is deepening Long Beach Channel from 62 to 76 ft and widening it to 1,000 to 1,200 ft. The objective of this increment would be to improve access to the existing liquid bulk (petroleum) terminals at Berth 121 and to use the 15.6 million yd^3 of dredged material as landfill for a 146-acre seaward extension of the Pier J container terminal (*18*). Long Beach started work in September 1988 on 2 mi of dike to support the landfill. Completion of Phase I by 1991 is estimated to cost about $145.7 million (of which only $33 million is eligible for reimbursement by the federal government).

As previously mentioned, the project would ultimately consist of five phases, to be constructed through 2010. Subsequent deepening of Los Angeles Channel in phases from 52 to 72 ft, the creation of two new 66-ft channels and one 50- ft channel, and the creation of 650 additional acres for harbor expansion are components of the proposed final federal project (see Figure 10). The federal interest in the LA/LB project would be in dredging the existing navigation channels to realize transportation cost reduction benefits from using larger, more efficient deep-draft vessels, particularly oil tankers. The ports would receive additional benefits from using the dredged material as landfill on which to construct new bulk cargo and container terminals. This in turn would enable the ports to handle additional vessels, reduce congestion, mini-

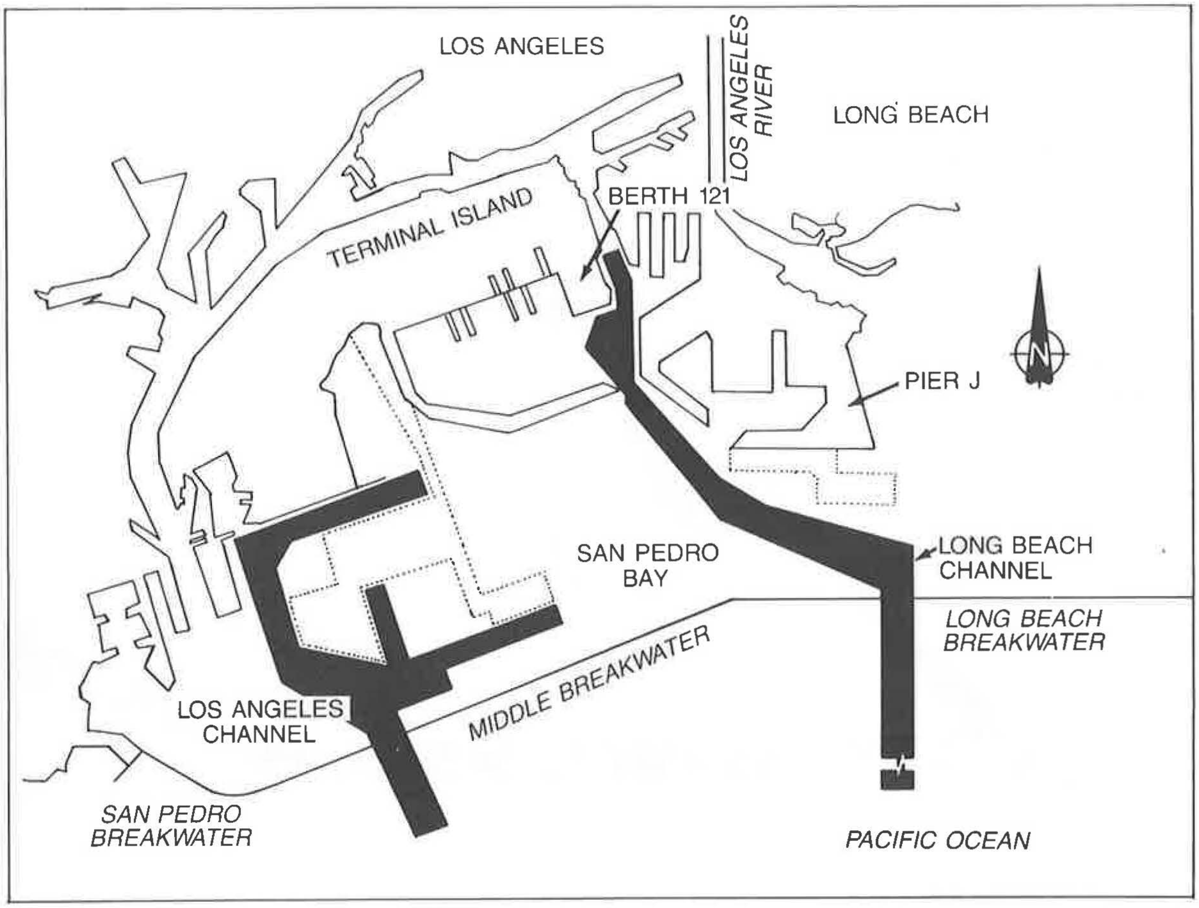

FIGURE 10 Los Angeles and Long Beach harbors deepening project.

mize transportation delay of container shipments, and redivert containers to the LA/LB area that were not able to be accommodated because of capacity constraints on existing lands (*18*).

An additional benefit from this project is the plan by the Port of Los Angeles to construct a 106-acre landfill island as a crude-oil-handling facility. Alaskan crude oil that is currently shipped via the Panama Canal pipeline to the U.S. East and Gulf coasts could be diverted to PacTex Island, as the facility is called, and then transported through the soon-to-be-completed Pacific Texas (PacTex) pipeline to Texas. Benefits are derived from the projected decrease in transportation transit times and costs resulting from the diversion of crude oil from the Panama Canal pipeline to the PacTex pipeline.

OAKLAND HARBOR, CALIFORNIA

Oakland Harbor is the fifth-largest container port in the United States, handling more than 8 million tons of cargo and nearly 1 million container TEUs in 1987 (*16*). The port, which boasts 28 vessel berths and 21 container cranes, services 85 percent of all general cargo moving through San Francisco Bay. Commercial cargo is varied, but the majority consists of iron and steel products, petroleum products, chemicals, plastics, food products, fresh and frozen fruits and vegetables, cotton, and machinery (*11*).

Federal involvement in Oakland Harbor dates back to 1874, when jetties were constructed along the entrance to the Oakland estuary. Although subsequent dredge and fill operations lowered the channel to a depth of 35 ft, the existing federal navigation channel is considered inadequate for efficient shipping operations and vessel safety. The trend toward larger containerships possessing greater economies of scale has made Oakland less accessible to a growing share of the world containership fleet (and therefore less competitive with other ports). Cargo movement by larger, more efficient vessels with lower unit transportation costs is hampered by the need to wait for high tides to avoid grounding hazards. The current plan of improvement is therefore justified on the basis of providing for further development of the harbors, helping to avoid container shipment delays, allowing safe vessel traffic, and providing maximum efficiency of harbor operations (*2*).

The Oakland Inner and Outer Harbor channel improvements were authorized by WRDA 86. The projects were subsequently combined under a single LCA in 1987. The authorized project calls for deepening the Inner and Outer Harbor channels to 42 ft from 35 ft, as well as widening the entrance channel to 1,000 ft, the Outer Harbor turning basin to 1,800 ft, and the Inner Harbor turning basin to 1,200 ft. Approximately 7 million yd^3 of material would be dredged at an originally estimated cost of $74 million (a $47.2 million federal share). Figure 11 shows the layout of the harbor channels.

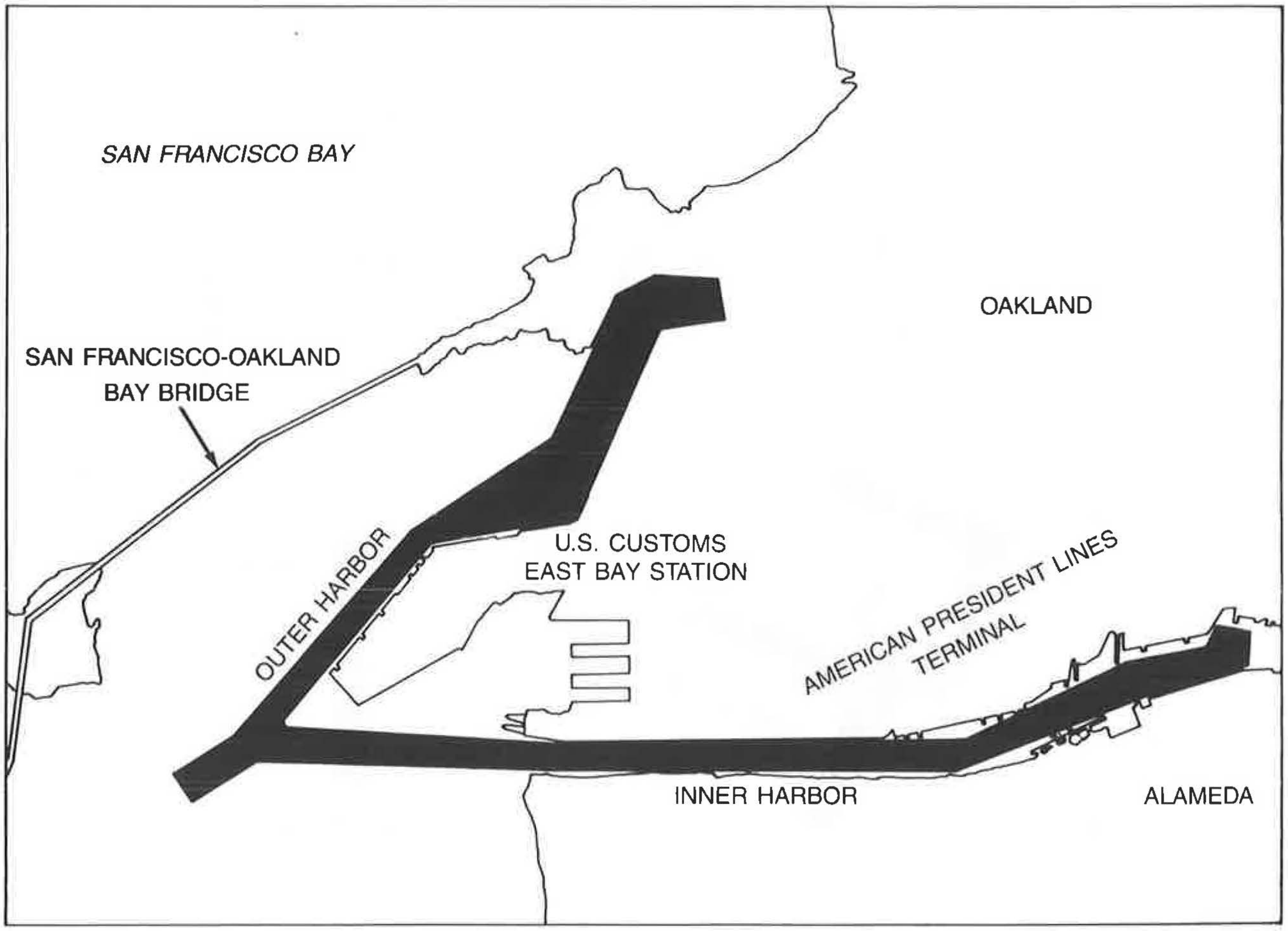

FIGURE 11 Oakland Harbor deepening project.

Phase I of the project, initially scheduled to begin in May 1988, consists of dredging the Inner Harbor channel to 38 ft and constructing a 1,200-ft turning basin to accommodate the new post-Panamax C-10 containerships that began arriving at the American President Line (APL) Oakland terminal in June 1988. Currently, APL's massive vessels must light-load and wait for high tides before docking at Oakland (*19*). Harbor tugs are necessary to maneuver and assist vessels in the turning basins. Phase I involves only 0.5 million yd^3 and would have taken just 90 days to complete.

No sooner had the dredging commenced in May 1988, however, before a local fishermen's association brought a court injunction against the port, halting all dredging. The dredged material disposal site is located outside San Francisco Bay, 11 mi off Pillar Point at Half Moon Bay, in 50 ft of water. The site was selected by the Corps of Engineers with the approval of the Environmental Protection Agency. The local fishermen objected to the site, however, claiming that nearby prime fishing grounds would be endangered. Since then, state and local governments and the California Coastal Commission have joined in the all-out legal battle (*3*). The port is currently awaiting a decision from the California Water Quality Control Board on the quality of the dredged material and its suitability for an upland disposal site in the San Joaquin River delta area. At this time, the legal questions are still undecided and a disposal site has not been selected. Phase I is behind schedule and further deepening (to 42 ft) of both Inner and Outer harbors is dependent on a resolution of the disposal issue.

CONCLUSION

Although this paper has concentrated on only the 12 ports with ongoing construction, the map in Figure 1 highlights several additional authorized deep-draft channel improvement projects. These "next wave" harbor projects are at various stages in the preconstruction process. Some have already gone through lengthy reconnaissance and feasibility studies, negotiation with local sponsors for cost-sharing, and preconstruction engineering and design. (Some have even received federal appropriations but have been delayed for various reasons.) Projects that are likely to begin construction in 1989 or 1990 include Portsmouth, New Hampshire; Savannah, Georgia; Sacramento, California; Port Manatee, Florida; Gulfport, Mississippi; and Grays Harbor, Washington. At the other end of the spectrum, a few projects, although congressionally authorized, might never get off the ground for lack of federal or local interest. Regardless of status, however, all of these projects warrant further monitoring.

In conclusion, it bears repeating that WRDA 86 represented a watershed: 16 years had passed since the last major authorization bill, and 7 years since the last new construction start. The breaking of the logjam with almost 40 projects in WRDA 86 and the reinstitution of the biannual authorization process with WRDA 88 make this a truly significant period in America's port development.

Similarly, the introduction of local cost-sharing of harbor improvements has had a significant impact on the way projects

TABLE 1 SUMMARY OF DEEP-DRAFT HARBOR PROJECTS

	Originally Authorized Project		Phased Project		
Project Name	Scope	Estimated Cost ($ millions)	Scope	Revised Cost ($ millions)	Current Status
Kill Van Kull/Newark Bay	Deepen to 45 ft	342	Deepen to 40 ft	212	Under construction
Delaware River near Camden, NJ	Deepen to 37 ft	2.2	No phasing	—	Completed
Baltimore, MD	Deepen to 50 ft	330	Deepen to 50 ft, reduced channel widths	246	Under construction
Norfolk, VA	Deepen to 55 ft	232	Phase I: Deepen to 50 ft outbound	33	Completed
Charleston, SC	Deepen to 40 ft	125	No phasing	—	Under construction
Ponce, PR	Deepen to 36 ft	10.4	No phasing	3	Completed
Tampa, FL	Deepen four channels to 41 ft	52	Deepen one channel to 41 ft	13	Under construction
Mobile, AL	Deepen to 55 ft	482	Deepen to 45 ft	38	Under construction
Mississippi River Ship Channel	Deepen 55 ft to Baton Rouge	490	Deepen 45 ft to Donaldsonville, La.	39	Completed
Freeport, TX	Deepen to 45 ft	88	No phasing	—	Under construction
Los Angeles/Long Beach, CA	Deepen LA to 70 ft, LB to 76 ft	560	Deepen one channel to 76 ft	146	Under construction; federal interest pending
Oakland, CA	Deepen Inner and Outer channels to 42 ft	74	Deepen one channel to 38 ft	Undetermined	Delayed; in litigation

are conceived, designed, and ultimately built. Local sponsors are playing an active role in project planning and, in many cases, have scaled down their needs in the face of escalating construction costs. Dredging channels to shallower depths than their fully authorized dimensions, at least in the initial construction phases, was a cost-saving method employed by local sponsors in the Kill Van Kull/Newark Bay, Norfolk, Tampa, Mobile, Mississippi River Ship Channel, Los Angeles/Long Beach, and Oakland projects. The state of Maryland opted to dredge Baltimore's shipping channels to the fully authorized depths but minimized costs by scaling back the channel widths. In addition, most of the projects benefited from an exceptionally competitive climate in the private dredging industry, resulting in substantially lower construction costs than had been estimated. Table 1 summarizes the phasing and cost-saving elements for each of the ongoing projects.

In the new world of cost-sharing, the goal has become to maximize the economic benefits while keeping project costs within the reach of local sponsors. It has therefore become increasingly important to develop more sophisticated techniques to evaluate a project's economic impacts and ensure that scarce local dollars are spent more wisely. It will take months or even years to begin to fully assess the impacts of these new harbor-deepening projects. Those now under construction have local and federal support and will most likely be completed. Some, but not all, of those authorized will be constructed. Further updates will be necessary.

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Economic Analysis for Long-Term Operation and Maintenance of a Waterway: The Case of the Monongahela River

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Recent advances in navigation planning emphasize systemwide economic analysis as the appropriate context for estimating benefits of improving a single navigation facility within the system. These planning techniques ensure that the benefits to improving any one navigation project are net of the costs that may be induced by other other system projects. For example, the economic benefits of expanding capacity at one lock are estimated net of delay costs at other navigation facilities induced by the additional traffic drawn to the waterway by improvements to the first lock. Despite these advances, navigation planning continues to emphasize identifying and solving problems at single facilities rather than formulating a plan for continued operation, maintenance, and improvement of the entire system. The results of a study incorporating elements of a systemwide planning approach are presented. Specifically, an economic analysis of the long-term operation and maintenance of the Monongahela River navigation system is described. Consisting of nine locks and dams, this system currently has five facilities that will require major rehabilitation or replacement to continue navigation during the next 50 years. The analysis demonstrates the economic justification for improving two of them (Locks and Dams 7 and 8) as the first component of a 50-year system plan that incorporates operation, rehabilitation, and replacement at the other seven facilities.

During the 1970s, navigation planners in the U.S. Army Corps of Engineers made enormous strides in systems analysis of lock capacity expansion. Based on the pioneering efforts of Howe, Carroll, Bronzini, and others (*1*, *2*), the first pre-authorization planning study to apply systems analysis techniques—the Gallipolis locks and dam study (*3*)—was completed in 1980. This study evaluated alternatives for expanding capacity at Gallipolis using a model of the U.S. waterway system. In 1982 the Upper Mississippi River Basin Commission provided an economic evaluation of capacity expansion within the context of a waterway system model (*4*).

Although capacity expansion continues to be an important Corps planning problem requiring the application of systems analysis methods, aged and decaying navigation facilities are posing new analytic challenges during the 1980s. Within the Ohio River navigation system alone, the average age of 60 navigation projects is 50 years. The age of 31 of these 60 locks and dams is at least 50 years, the design life of navigation facilities. As detailed engineering condition studies of older projects have progressed, long-term, dependable maintenance of the waterway system has become an important feature of the Corps navigation planning program.

For example, in condition studies of Locks and Dams 7 and 8 on the Monongahela River, it was found that major investment will be essential to continued, reliable navigation at these projects (*5*). The Corps' North Central Division has faced similar problems on the Illinois Waterway and the Upper Mississippi River. In 1984 the Rock Island District completed the first of a series of reports documenting the need for rehabilitation of navigation facilities on the Illinois (*6*). In 1985 the Louisville District of the Ohio River Division completed a study of Locks and Dams 52 and 53 on the lower Ohio River (*7*). This study addressed both lock capacity requirements and the consequences and costs of potential component failure at these two critical projects. Risk or "probability of failure" analysis was applied to the two locks and dams within the context of a comprehensive benefit-cost analysis of the Ohio River navigation system.

This paper presents an economic evaluation of the stream of investment in construction and rehabilitation, as well as annual operation and maintenance expenditure, necessary to continue long-term navigation on the entire Monongahela River. Supplementing the Pittsburgh District's feasibility report for Locks and Dams 7 and 8 on this river, the analysis demonstrates that system benefits for continued navigation over the planning horizon significantly exceed the economic costs of this plan.

Projected long-term improvements to the Monongahela River include the recommended improvements for Locks and Dams 7 and 8 as well as major maintenance or replacement at each of the other seven locks and dams on the river. Modernization of Locks and Dams 7 and 8 is shown to be justified not only when analyzed independently from system investment costs but also when considered as the first step in a long-term program for the entire Monongahela system.

This paper differs from most of the previously cited studies of aged, deteriorating projects in that detailed risk assessment techniques were not applied. Instead, preliminary results of detailed engineering studies and the Pittsburgh District's extensive experience with maintenance and rehabilitation were used to develop a forecast of future actions to sustain Monongahela River navigation. Detailed engineering studies, including risk assessment, are currently under way and will

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form the basis for more specific future recommendations at particular projects. As in the previously cited studies, transportation benefits for the forecast maintenance plan are rate savings to commercial navigation traffic on the Monongahela River (*5*).

The next three sections present background information on the Monongahela River navigation system, modernization projects previously undertaken, the Locks and Dams 7 and 8 study, and improvement studies currently under way. The motivation and conceptual framework for the economic analysis of continued navigation on the river is presented, and the remaining sections discuss the development of costs and benefits attributable to a long-term plan of investments and annual operation and maintenance expenditures for continued navigation during the period 1990 to 2040; the benefit-cost analysis; and brief evaluation of the level of confidence inherent in the study's results and the potential role of this methodology in other navigation planning contexts.

MONONGAHELA RIVER NAVIGATION SYSTEM

The Monongahela River rises in northeastern West Virginia and flows north into western Pennsylvania to join the Allegheny River in forming the Ohio River at Pittsburgh. By means of a system of nine locks and dams, the Monongahela River navigation project provides a minimum navigation depth of 9 ft throughout the entire 129-mi length of the river from Pittsburgh, Pennsylvania, to Fairmont, West Virginia (Figure 1). Federal interest in the river was established in 1872 with the construction of two locks and dams on the upper river and was renewed in 1896 when Congress authorized acquisition of the original seven locks and dams constructed on the lower river by the Monongahela Navigation Company, a private enterprise. Summary data on the present system are shown in Table 1. Locks and Dams 2 through 8 are in Pennsylvania; the other three are in West Virginia.

The Monongahela River carries more tonnage than any other Ohio River tributary and is one of the great industrial waterways of the world. Several municipalities have provided terminals along the river. A modern river freight terminal is located on the riverfront in Pittsburgh. A large number of private dock facilities are maintained for the handling of coal and coke, sand and gravel, iron and steel products, petroleum products, and other commodities. In 1984, 34.5 million tons of waterborne commerce used the Monongahela River navigation system. Figure 2 shows the distribution of this tonnage by commodity. Additional information related to historic commodity movements and forecasts of future traffic demand for the Monongahela may be found in the Locks and Dams 7 and 8 interim feasibility report (*5*).

MODERNIZATION EFFORTS

The current modernization program for the Monongahela River navigation system continues work begun with the reconstruction of Locks and Dam 2, started in 1949. Since then, the river above Locks and Dams 7 and 8 has been improved by constructing new navigation facilities: Morgantown Lock and Dam (1950), Hildebrand Lock and Dam (1960) and Opekiska Lock and Dam (1964). Each of these facilities has a single 84-ft by 600-ft lock chamber and a gated dam. On the middle river below Lock and Dam 7, the new Maxwell Locks and Dam was placed in operation in 1964. Maxwell also has a gated dam but, unlike the upper river locks and dams, has twin lock chambers, each 84 ft wide by 720 ft long. The dam at Locks and Dam 2 and Locks and Dams 3, 4, 7, and 8 are now the oldest facilities in the system (see Table 1). At both Locks and Dams 3 and 4, the main chambers are 56 ft wide by 720 ft long, and the auxiliary chambers measure 56 ft wide by 360 ft long. At each of Locks and Dams 7 and 8, the lock chamber is 56 ft wide by 360 ft long with no auxiliary chamber.

The age, physical condition, and stability of these projects present significant potential challenges to maintaining dependable navigation service. In addition, because the chambers were designed to handle standard-size barges (26 ft wide by 175 ft long), these locks pose severe restrictions on the use of jumbo barges (35 ft long by 195 ft long). Jumbo barges are more competitive in today's water transportation markets because they carry larger loads and are efficiently accommodated within the chambers at locks on the mainstem Ohio, Tennessee, and Upper Mississippi rivers.

In response to the problems of age, project condition, and lock size, recent Corps planning studies have concentrated on Locks and Dams 3, 4, 7, and 8 together with Locks and Dam 2 where the age and condition of the dam are expected to warrant near-term investment. Preauthorization planning for the modernization of Locks 2, 3, and 4 is continuing. As previously noted, the Pittsburgh District completed a feasibility study for the improvement of Locks and Dams 7 and 8 in early 1984 (*5*). Because the analysis described in this paper was undertaken to supplement the feasibility study, the Corps' findings and recommendations will be summarized as background for subsequent discussions.

LOCKS AND DAMS 7 AND 8 STUDY

The feasibility study found that severe physical deterioration of Locks and Dams 7 and 8 has resulted from adverse weather conditions, acidity of water due to acid mine drainage, and the age of the structures. Costly operation and maintenance were anticipated, and engineering studies indicated significant risks associated with continued reliance on the structures to maintain navigation service in the future. Damage to the concrete guide, guard, and lock walls at both structures was found to be extensive, and detailed engineering studies demonstrated that components were seriously deficient in their overall structural stability. Valves, miter gates, operating controls, and embedded concrete were deteriorated. In addition, the concrete apron at Dam 7 was found to be undermined for most of its length. The concrete spillway at Dam 7 was also severely eroded over its surface and leakage occurred through the monoliths. Although the structural condition of Dam 8 was found to be generally good, exposed concrete was deteriorated and scouring has occurred downstream of the dam apron. The right abutment was found to have stability problems and to be in poor condition. Condition studies concluded that replacement or rehabilitation of the structures is needed as soon as possible but not later than the early 1990s.

The existing 56-ft by 360-ft locks were found to be incommensurate with the size of barge tows using the waterway.

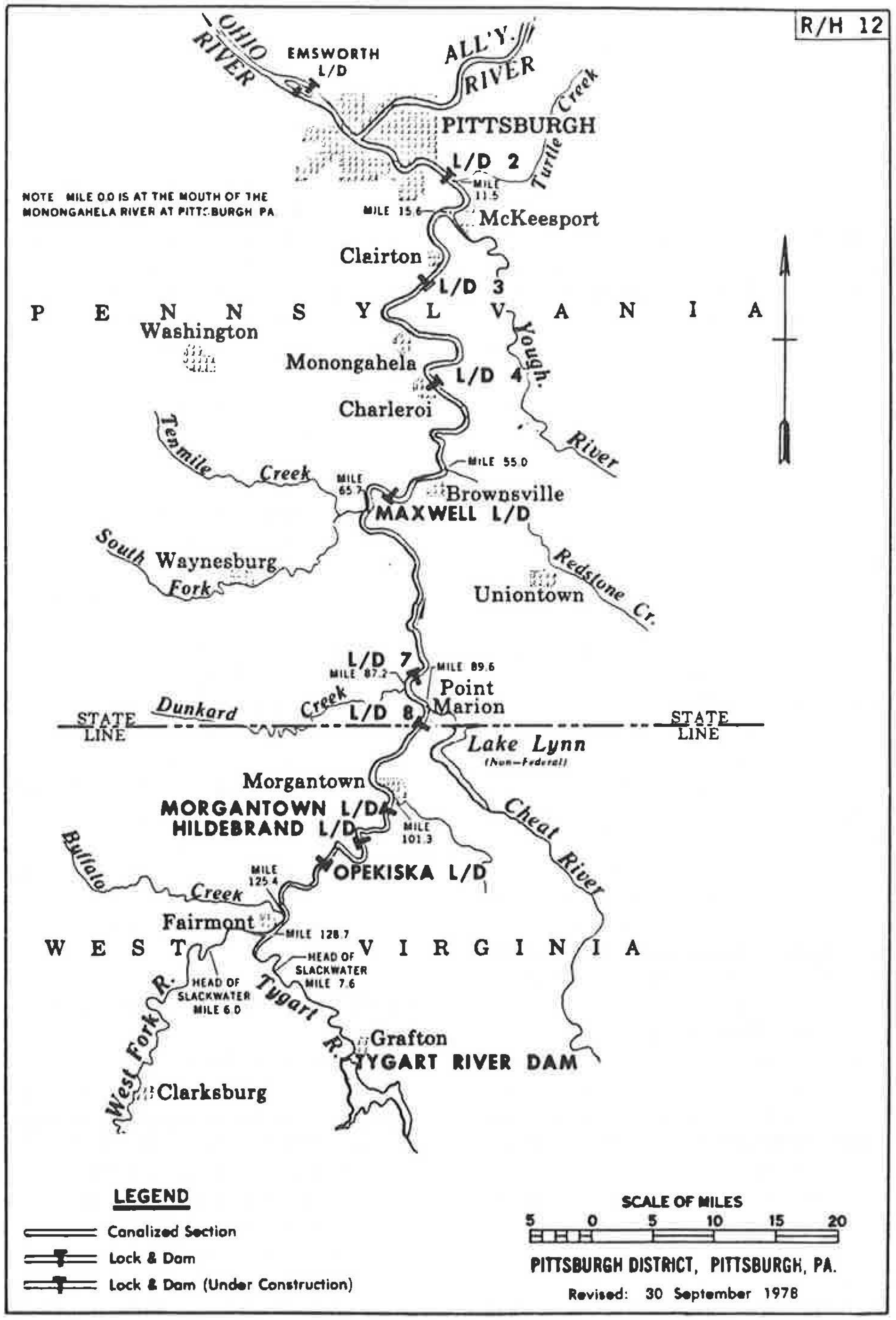

FIGURE 1 Index map of Monongahela River river and harbor project.

Larger locks are needed to facilitate passage of projected traffic and larger tows, to improve operating efficiency by elimination of double lockages, and to reduce existing and future tow delays and related tow operating costs.

The Pittsburgh District considered an extensive array of structural and nonstructural measures to address these problems. These alternatives included several plans for continued rehabilitation, maintenance, and operation of the existing structures and several replacement plans with various lock sizes. The District Commander recommended construction of a new lock and fixed crest dam to replace existing Lock and Dam 7 and a new, replacement lock chamber at Lock and Dam 8 to be built landward of the existing lock. The new lock and dam replacing Lock and Dam 7 would be named Grays Landing Lock and Dam. Lock and Dam 8 would be renamed Point Marion Lock and Dam.

The District's recommended plan was identified as the National Economic Development (NED) plan—the plan that maximizes net benefits. In the feasibility report, total annual benefits of the plan were $61,200,000 and total annual costs

TABLE 1 MONONGAHELA RIVER NAVIGATION SYSTEM: PROJECT CHARACTERISTICS

Locks & Dam	River Mile	Up Pool Elev.	Lock Size Main[a]	Lock Size Aux[a]	Year Opened	Pool Length[b]
No. 2 [c]	11.2	718.7	110 x 720	56 x 360	1906	12.7
No. 3 [d]	23.8	726.9	56 x 720	56 x 360	1907	17.7
No. 4 [e]	41.5	743.5	56 x 720	56 x 360	1932	19.7
Maxwell	61.2	763.0	84 x 720	84 x 720	1964	23.8
No. 7	85.0	778.0	56 x 360	None	1925	5.8
No. 8 [f]	90.8	797.0	56 x 360	None	1925	11.2
Morgantown	102.0	814.0	84 x 600	None	1950	6.0
Hildebrand	108.0	835.0	84 x 600	None	1960	7.4
Opekiska	115.4	857.0	84 x 600	None	1964	13.3

a. In feet

b. Length in miles; pool depth is 9 feet.

c. Locks reconstructed 1949-1953; original dam (1906) remains in service

d. Major rehabilitation of locks completed, 1984

e. Dam reconstructed, 1963-1967

f. Dam reconstructed and crest raised, 1958-1959

were $15,900,000, giving net benefits of $45,300,000 and a benefit/cost ratio of 3.8 based on 8⅛ percent interest and 1983 price levels.

The Division Commander subsequently concurred with the District's report and recommendation, the Board of Engineers for Rivers and Harbors approved in March 1984, the Chief of Engineers concurred in September 1984, and the Assistant Secretary of the Army (Civil Works) forwarded the recommendation to Congress in July 1986. The recommended replacement projects were authorized for construction by the Water Resources Development Act of 1986 (Public Law 99-662). Construction was initiated on the new Grays Landing Lock and Dam in fiscal year 1988 and is scheduled to start at Point Marion in fiscal year 1990.

CONTINUED OPERATION OF MONONGAHELA RIVER NAVIGATION SYSTEM

Replacements for Lock and Dam 7 and Lock 8 will meet only the most immediate needs for continuing navigation on the Monongahela River. Ongoing studies indicate that the age, condition, and lock sizes of Locks and Dams 2, 3, and 4 will require additional investment in the future. Following completion of the Locks and Dams 7 and 8 study, it became clear that the investments recommended at these two projects should be placed in the context of a long-term plan for continued navigation on the entire river. If the benefits to Monongahela River navigation exceed the economic costs of this plan or projected stream of investments and annual operation and maintenance, the recommendations at Locks and Dams 7 and 8 are not only justified under standards applicable to project planning but also warranted under criteria appropriate for long-term systems planning.

The economic costs of a projected schedule of investments and annual operation and maintenance for continued navigation are described next. This forecast was based on preliminary results of ongoing detailed investigations of Locks and Dams 2, 3, and 4; the completed study of Locks and Dams 7 and 8; and the construction, rehabilitation, and maintenance experience of the Pittsburgh District.

ECONOMIC COSTS OF CONTINUED NAVIGATION

The overall age and general condition of each component of the Monongahela River navigation system were reviewed to

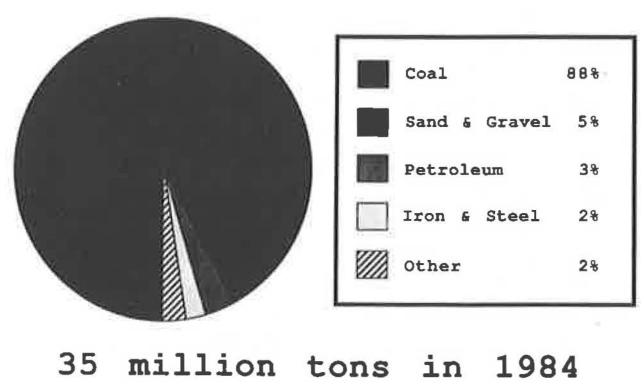

FIGURE 2 Monongahela River commodity traffic.

develop a forecast of future actions for continued safe and reliable operation throughout the analysis period, 1990–2040. This period was chosen to conform with the analysis period for Locks and Dams 7 and 8. In addition to normal operation and maintenance, projected requirements include extraordinary maintenance such as the repair or replacement of major facility components and the rehabilitation or replacement of entire projects as required by sound engineering and maintenance practices.

In developing this investment schedule, it was projected that major rehabilitation would be required at or shortly after the 60th year of each project's life. This time frame is consistent with the Pittsburgh District's experience in the ongoing rehabilitation program on the upper Ohio River and has been confirmed by detailed engineering and condition studies conducted to date. The replacement of existing Lock and Dam 7 and Lock 8, as recommended in the 1984 feasibility report, is also included in the projected schedule of investments. In addition, the age and overall condition of three of the existing facilities are forecast to require replacement-in-kind: the fixed crest dam at Locks and Dam 2 (opened in 1906), both the locks and the dam at Locks and Dam 3 (opened in 1907), and the locks at Locks and Dam 4 (opened in 1932).

Rehabilitation and replacement are also expected to require temporary closures of lock chambers, which would delay or interrupt traffic to varying degrees in the future. Additional costs likely to be incurred by river shippers during these lock closures are reflected in this analysis.

The following required work has been forecast at each of the Monongahela facilities:

Locks and Dam 2: A new fixed crest dam (estimated cost, $53,700,000) would be constructed to replace the existing 81-year-old structure and major rehabilitation would be performed on both locks (estimated cost, $19,900,000), both in 2010. During lock rehabilitation, the large, landward lock chamber would be closed for about 6 months, and all river traffic would use the small auxiliary chamber. This would result in navigation delays and an increase in shipping costs estimated at $47,800,000.

Locks and Dam 3: Notwithstanding the rehabilitation work completed in 1980, the present age (80 years) and the overall condition of this facility would require replacement-in-kind at a cost of $187,500,000 in 2000. During construction of the replacement facility, which would be located as close to the existing facility as possible, normal traffic would be maintained with no appreciable delays.

Locks and Dam 4: Considering the present age of this project (54 years) and the overall condition of the locks, replacement-in-kind would be necessary in 2005 at an estimated cost of $108,700,000. The existing gated dam, reconstructed during 1963–1964, would be rehabilitated in 2030 at an estimated cost of $3,000,000. During in-kind replacement of the locks, closure of one or both existing locks would be required periodically. These interruptions and delays to traffic would increase costs to shippers by an estimated $64,800,000 over a 3-year period.

Maxwell Locks and Dam: The Maxwell facility would require major rehabilitation in 2030 at an estimated cost of $24,900,000. During rehabilitation, each lock chamber would be closed to traffic for a successive period of 6 months. Closure of the locks would result in traffic delays, increasing shipping costs by an estimated $2,200,000.

Lock and Dam 7: As recommended in the 1984 feasibility report, this facility would be replaced with a new lock and dam (Grays Landing Lock and Dam) at an estimated cost of $94,300,000.

Lock and Dam 8: Consistent with the feasibility report, the existing lock would be replaced at an estimated cost of $67,400,000. The existing gated dam, constructed in 1959, is currently being rehabilitated. This rehabilitation is considered sufficient to ensure continued operation of the dam throughout the analysis period.

Morgantown Lock and Dam: This facility, constructed in 1950, would require major rehabilitation at a cost of $15,100,000 in 2010. During this work, interruptions and delays to traffic would result in increased costs to shippers, estimated at $13,800,000.

Hildebrand Lock and Dam: Constructed in 1960, this project would be rehabilitated in 2020. The work, estimated to cost $15,500,000, would cause delays and interruptions of traffic, increasing shipper costs by an estimated $5,300,000 during construction.

Opekiska Lock and Dam: The Opekiska facility was completed in 1967 and would be rehabilitated, at an estimated cost of $14,800,000, in 2030. During rehabilitation, delays and traffic interruptions would increase shipper costs by an estimated $3,000,000.

Tygart Dam: The Tygart Dam, constructed in 1938, provides augmentation flows to the Monongahela River for navigation and would require major rehabilitation, estimated to cost $25,000,000 in 2010. Because navigation is only one purpose of this project, a portion of this investment (40 percent) has been allocated to navigation.

The schedule of major investments for continued navigation on the Monongahela River navigation system is shown in Table 2. Estimated average annual costs, including closure costs and operation and maintenance costs, are developed in Table 3. Figure 3 presents a graphic summary of investment and closure costs. Annual costs in Table 3 are based on a period of 50 years (1990–2040), an interest rate of 8⅛ percent, and October 1983 prices to achieve comparability with the economic analysis of the Locks and Dams 7 and 8 feasibility report. To allow comparison of system facilities having service lives that extend beyond the 50-year evaluation period, a salvage value was estimated for each structure at year 2040. This value was based on the relative age and projected value at that time. As shown in Table 3, annual system costs to continue navigation on the Monongahela River from 1990 to 2040 were estimated to be $42,100,000.

ANNUAL SYSTEM BENEFITS

The estimated benefits for continued operation of the Monongahela River navigation system are developed in the Locks and Dams 7 and 8 feasibility report (*5*, Appendix J, pp. 71–77). Estimated annual transportation benefits for continued operation of the Monongahela River navigation system, including replacements at Locks and Dams 7 and 8 as recommended in the feasibility report, total $330,800,000.

TABLE 2 MONONGAHELA RIVER NAVIGATION SYSTEM: REHABILITATION AND REPLACEMENT SCHEDULE

Locks & Dam 2	1953	Rehab. Locks	2010	19,900
	1906	Replace Dam	2010	53,700
Locks & Dam 3	1907	Replace Locks & Dam	2000	187,500
Locks & Dam 4	1932	Replace Locks	2005	108,700
	1967	Rehab. Dam	2030	3,000
Maxwell L/D	1963	Rehab. Locks & Dam	2030	24,900
Lock & Dam 7	1926	Replace Lock & Dam	1990	94,300
Lock & Dam 8	1926	Replace Lock	1990	67,400
Morgantown L/D	1950	Rehab. Lock & Dam	2010	15,100
Hildebrand L/D	1960	Rehab. Lock & Dam	2020	15,500
Opekiska L/D	1967	Rehab. Lock & Dam	2030	14,800
Tygart Lake[a]	1938	Rehab. Dam	2010	10,000

a Total Rehabilitation Cost $25,000,000 (40% allocated to navigation).

TABLE 3 MONONGAHELA RIVER NAVIGATION SYSTEM: AVERAGE ANNUAL COST FOR CONTINUED OPERATION AND MAINTENANCE

Structure	Future Action Item	Future Action Year	Total[a] Invest	Closure[b] Cost	Salvage[c] Value	Net Ann Imp[d] Cost	O&M	Total Ann Cost
			(Millions of Dollars)					
Locks & Dam 2	Rehab. Locks	2010	21.5	47.8	2.0	1.20		
	Replace Dam	2010	53.7	-	10.0	.92	1.50	3.62
Locks & Dam 3	Replace L/D	2000	217.4	-	28.1	8.20	1.20	9.40
Locks & Dam 4	Replace Locks	2005	122.5	64.8	21.7	4.77		
	Rehab. Dam	2030	3.0	-	.6	.01	1.96	6.74
Maxwell L/D	Rehab. L/D	2030	26.7	2.2	4.9	.10	1.70	1.80
Lock & Dam 7	Replace L/D	1990	104.1	-	14.1	8.61	.70	9.31
Lock & Dam 8	Replace Lock	1990	76.8	-	10.1	6.35	.90	7.25
Morgantown L/D	Rehab. L/D	2010	16.1	13.8	1.5	.52	.90	1.42
Hildebrand L/D	Rehab. L/D	2020	16.5	5.3	2.3	.17	.90	1.07
Opekiska L/D	Rehab. L/D	2030	15.8	3.0	2.9	.06	.90	.96
Tygart Lake	Rehab. Dam	2010	10.00	-	1.0	.17	.36	.53
Total								42.10

Note: A dash (-) denotes not applicable.

a. Construction cost plus interest during construction based upon appropriate construction period.

b. Closure costs are shipper costs from delays or interruptions to traffic caused by the need to close a lock chamber during construction of a replacement or rehabilitation of the chamber.

c. Salvage value is estimated at 2040.

d. Net Annual Implementation Cost: annual equivalent of the 1990 present value of investment and closure less the 1990 present value of salvage.

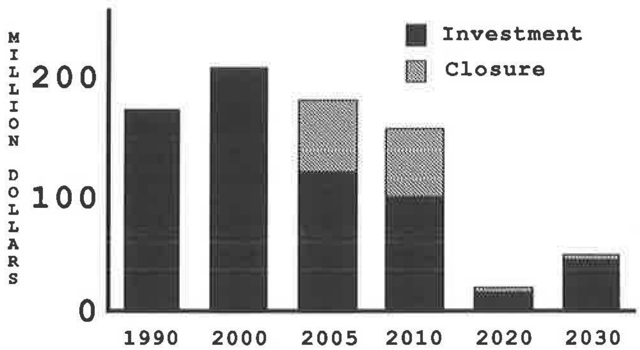

FIGURE 3 Monongahela River economic costs.

COMPARISON OF SYSTEM COSTS AND BENEFITS

Benefits and costs of continued navigation on the entire Monongahela River navigation system are summarized as follows:

Total annual system benefits = $330,800,000

Total annual system costs = $42,100,000

Benefit-to-cost ratio (BCR) = 7.9

Consistent with detailed investigations included in the feasibility report (*5*, Appendix J), this analysis assumes projected traffic growth on the Monongahela River system throughout the 1990–2040 period. An alternative scenario was examined to determine the sensitivity of the benefit-cost analysis to the assumption of constant traffic during this period. The system benefits that would result if the 1980 traffic levels were to continue without additional growth are estimated to be $276,000,000. When this is compared with the previously developed system cost of $42,100,000, the benefit-to-cost ratio is 6.6.

CONCLUSIONS

As the foregoing section indicates, the estimated benefits for continued navigation on the Monongahela River exceed estimated costs by a wide margin. This paper concludes, not with a comprehensive evaluation of the analysis employed here, but with some reasons for the authors' conviction that the results are useful indications of how similar studies might be used in other areas of navigation planning, and an evaluation of the prospects for expanding the methods used here to form a basis for systemwide planning.

First, many of the criticisms that could be made of this study fall under the general rubric of risk and uncertainty, both in engineering and economics. A logical question is, How much confidence should one have in the estimated investment costs used in the study? Fortunately, the mechanics of capitalizing the cost stream (discounting) render annual costs relatively insensitive to very large changes in costs that are farther in the future and about which therefore there is likely to be less certainty. Conversely, annual costs will be very sensitive to changes in the costs of actions that are likely to occur in the near term. In this study, the cost estimates with the greatest certainty are those that were drawn either from a completed feasibility study (Locks and Dams 7 and 8) or from preliminary detailed investigations for an ongoing survey study (Locks and Dams 2, 3, and 4). In other words, the authors' best engineering data are from detailed investigations of navigation projects at which current problems dictate near-term solutions. With regard to system benefits, a dramatic, unprecedented, and permanent decline in Monongahela River traffic would have to occur to upset the overwhelming justification for continued navigation. Given the reasonably high level of confidence in projected near-term actions and the wide margin of net benefits, the previously described analysis shows strong economic justification for undertaking investments in the modernization of Locks and Dams 7 and 8 and for continuing detailed investigations to prepare optimum investment plans at Locks and Dams 2, 3, and 4.

The authors are unaware of other studies that address the long-term navigation planning issues considered in this paper and that also account for projected benefits and costs for an entire major navigation system or subsystem. Although the analysis of this paper is at a lesser level of detail than is characteristic of a full-scale feasibility report, even the abbreviated methodology employed here can be valuable in other contexts. As demonstrated in this paper, such studies can be used to supplement detailed project studies and provide a framework for placing the individual project in the context of a long-term plan for an appropriately defined system or subsystem. Navigation program managers can also use such an analysis to examine project priorities and focus on data needed to reduce uncertainty. In addition, the methodology provides a useful means of summarizing the long-term program envisioned for a waterway and communicating that program and the economic justification for it to navigation program decision makers.

Finally, the authors' experience with this study suggests that current evaluation methods are adequate to support development of a systems planning capability. In this context systems planning may be contrasted with project planning. Traditionally, navigation planning has emphasized identification and formulation of solutions to problems at individual projects within the system. Systems planning stresses identification of the entire collection of existing and future problems (i.e., all projects in the system are evaluated for necessary improvement) and formulates a unified, optimally timed, and scaled investment plan for modernization, rehabilitation, maintenance, and operations.

If implemented in the spirit of long-standing water resources policies, navigation systems planning would identify a program of future investments that are simultaneously optimal in type (e.g., rehabilitation versus replacement, structural versus nonstructural), scale (e.g., lock size or cost), and timing (the implementation date for each component). If conventional criteria were applied, optimality would be defined as achieving maximum system net benefits.

The authors have no intention of thoroughly examining the desirability of implementing a systemwide planning approach. However, their experience with this study suggests that analytic techniques already developed for systems analysis of project benefits are probably adequate to pursue systemwide planning. This conclusion is easier to support in those cases in which future system needs are related to constrained lock

capacity and associated delays. Modern systems analysis methods have been designed with emphasis on congestion problems.

On the other hand, the application of risk analysis techniques to aging and deteriorating projects is still in its infancy. For the most part, these techniques have been applied to outage risks at a single project, not an entire waterway or navigation system. If a dominant concern for future navigation is aged and deteriorating projects, as is the case in the Ohio Valley, much additional development and refinement of risk analysis techniques are essential to a viable systems planning discipline.

In addition to analytic tractability, institutional features currently pose an important limitation on applying a systemwide planning approach. The existing framework of navigation development is structured around projects, not the system. Consideration of the institutional changes necessary for systems planning is beyond the scope of this paper, but clearly significant change would be required to separate study authorization, programming, and funding from individual projects. It also seems reasonable that effective systemwide planning would be dependent on broader and longer-lived congressional authority for Corps navigation modernization actions than is currently available under project-specific planning and construction authorizations.

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