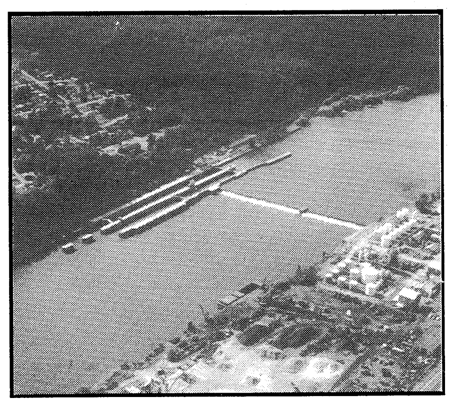
US Army Corps
of Engineers
Pittsburgh District

Lower Monongahela River Navigation System Feasibility Study

Interim Report



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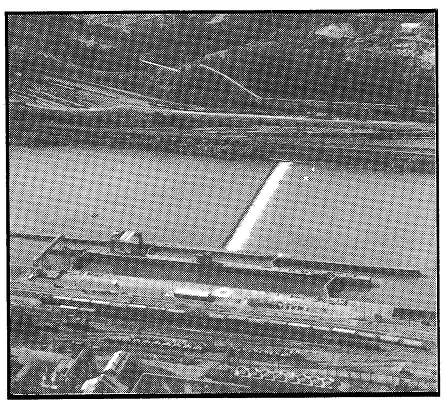

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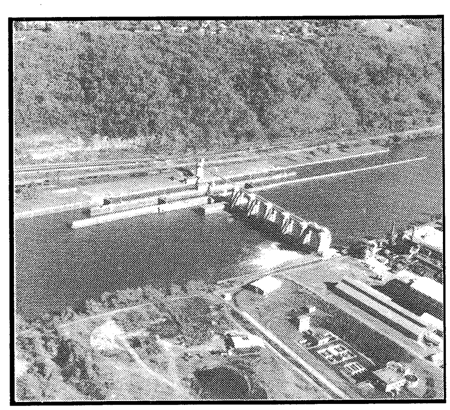

Locks and Dam 4

Volume 5 of 6

Navigation System Analysis

FINAL
December 1991

LOWER MONONGAHELA RIVER
NAVIGATION SYSTEMS ANALYSIS

FEASIBILITY REPORT

VOLUME 5

NAVIGATION SYSTEMS ANALYSIS

LOWER MONONGAHELA RIVER NAVIGATION SYSTEM STUDY

APPENDIX

NAVIGATION SYSTEMS ANALYSIS

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FOR:

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Corps of Engineers
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SECTION 1. INTRODUCTION

1. PURPOSE AND SCOPE

This report was prepared by the Ohio River Division Navigation Planning Center for the Pittsburgh District, U.S. Army Corps of Engineers. The purpose of the report is to document and explain the navigation benefit analysis that was performed for the feasibility study on replacement of Locks and Dam 2, Locks and Dam 3, and Locks and Dam 4 on the Monongahela River.

The report presents an estimation of the National Economic Development (NED) benefits and associated system impacts for continued use of the existing L&D 2, L&D 3 and L&D 4 projects and a number of alternative lock replacement plans. The alternatives evaluated represent the final array of plans that are being given detailed consideration by the Pittsburgh District. The NED benefits and impacts for the replacement plans are measured relative to what is considered to be the most probable future "without" project condition of the navigation system over the period of analysis. The results of this analysis will be used along with other engineering and environmental studies to determine the feasibility and advisability of the alternative navigation improvement plans.

2. REPORT ORGANIZATION

The remainder of this report is organized into the following major topical sections. Section 2 describes the system that was analyzed to determine the extent and magnitude of impacts resulting from improvement of L&D's 2, 3 and 4. Section 3 describes the historic traffic and the projected traffic demands. Section 4 describes the vessel fleet and the performance characteristics of L&D's 2, 3 and 4. Section 5 describes the study methods and procedures including the computer models used, the major model inputs, and the results of model calibration. Section 6 is the evaluation of the without project condition. Section 7 presents the navigation benefits for the alternative location plans. Section 8 presents the project and system impacts associated with the different lock size combinations. Section 9 summarizes the estimated NED navigation benefits for each plan. Section 10 presents the results of the sensitivity analysis.

SECTION 2. DESCRIPTION OF THE NAVIGATION SYSTEM

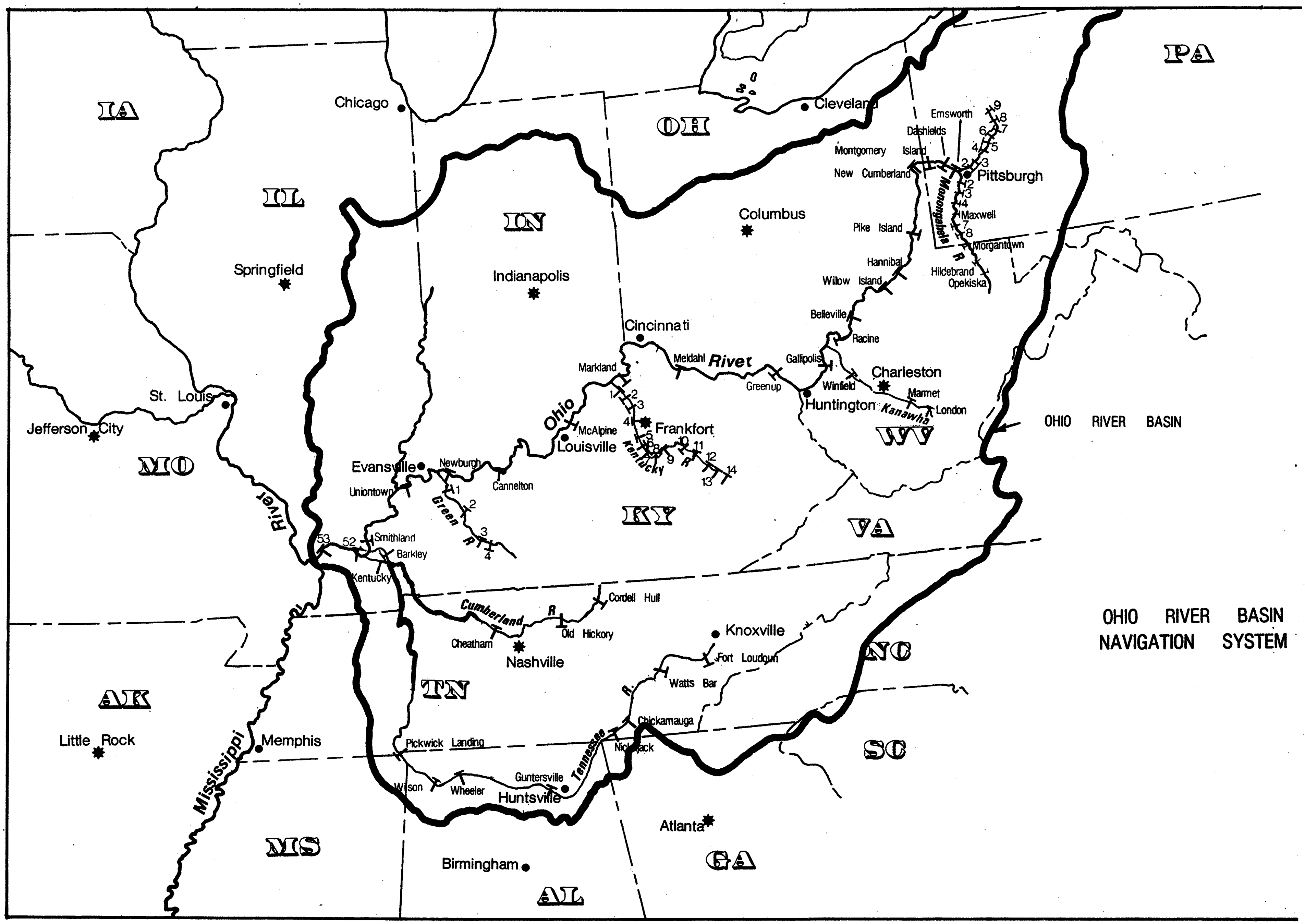
1. GENERAL

The purpose of this section of the report is to define and describe the navigation system that was selected for use in the detailed modeling studies. Also described is the subsystem consisting of the Monongahela River, a section of which is the focus of this study. Background information is provided on the physical and operational characteristics of the system and subsystem.

2. OHIO RIVER NAVIGATION SYSTEM

The Ohio River Navigation System (ORS) is a major portion of the nation's inland navigation system, providing for commercial navigation in the eastern one-third of the country. The ORS consists of more than 2,600 miles of commercially navigable waterways, extending from the Pittsburgh area in the northeast to the junction of the Ohio and Mississippi Rivers near Cairo, Illinois in the midsouth. It includes the Ohio River and the navigable portions of the Allegheny, Monongahela, Kanawha, Big Sandy, Green, Tennessee, Cumberland, and Kentucky Rivers (Figure 1). The Ohio River serves as a collector of system traffic for distribution to points within and outside the Ohio Basin while the tributary streams serve major mining areas and industrial concentrations within the Basin. Through interconnections with the Mississippi River and its tributaries, ORS traffic has direct access to Midwestern states and deep-draft ports on the Great Lakes and Gulf Coast. The principal rivers that comprise the ORS can be categorized into six groups based on annual traffic: (1) the Ohio River with over 195 million tons; (2) the Tennessee River with 40 to 45 million tons; (2) the Monongahela River with 30 to 35 million tons; (4) the Kanawha and Cumberland Rivers with 15 to 20 million tons each; (5) the Big Sandy and Green Rivers with 5 to 10 million tons each; and (6) the Allegheny and Kentucky Rivers, each with less than 5 million tons. The principal commodity involved in river traffic is coal, which accounts for at least one-half of the tonnage on the rivers, with the exceptions of the Allegheny and Kentucky Rivers where the principal commodity is sand and gravel. A listing of the principal commodities and total 1986 tonnage for the major rivers in the ORS is provided in Table 1.

Commercial navigation on the ORS is afforded by a series of interconnected pools created by 60 lock-and-dam projects and by annual maintenance dredging. Twenty of the lock-and-dam projects are situated on the Ohio River, 9 on the Monongahela, 8 on the Allegheny, 4 on the Kentucky, 3 on the Kanawha, 4 on the Cumberland, 9 on the Tennessee, 2 on the Green River and 1 on the Clinch River. The locks at the projects vary in age from 5 to 150 years; in numbers from 1 to 3; in width from 38 to 110 feet; and in length from 145 to 1,200 feet. The navigable pools created by the projects typically provide a minimum navigable depth of nine feet and minimum width of 300 feet.



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Pittsburgh
Monongahela
Maxwell
Morgantown
Hildebrand
Opekiska
Columbus
Pike Island
Hannibal
Willow Island
Belleville
Racine
Springfield
Indianapolis
Cincinnati
Markland
Meldahl
River
Gallipolis
Greenup
Huntington
Winfield
Charleston
Marmet
London
Kanawha
Ohio
McAlpine
Louisville
Frankfort
Kentucky
St. Louis
Jefferson City
Evansville
Newburgh
Cannelton
Uniontown
Green R
Smithland
Barkley
Kentucky
Cumberland R
Cordell Hull
Old Hickory
Cheatham
Nashville
Knoxville
Fort Loudoun
Watts Bar
Chickamauga
Nickajack
Tennessee
Pickwick Landing
Wilson
Wheeler
Guntersville
Huntsville
Little Rock
Memphis
Mississippi
River
Atlanta
Birmingham
OHIO RIVER BASIN
OHIO RIVER BASIN NAVIGATION SYSTEM

Figure 1

TABLE 1

Summary Data Ohio River Navigation System

River	Length (Miles)	Navigable Depth (feet)	Minimum Width (feet)	No. of Operational Locks & Dams	Principal Commodities	1986 Tonnage (Millions)
Ohio	981	9	300	20	coal; aggregates; petroleum products; chemicals	195.8
Monongahela	129	9	300	9	coal; aggregates; petroleum products;	32.4
Allegheny	72	9	200	8	sand & gravel	3.5
Kentucky	259	6	50-150	4	sand & gravel	0.2
Kanawha	91	9	300	3	coal; aggregates; petroleum products	18.2
Cumberland	381	9	125-300	4	coal; aggregates; grain	22.6
Tennessee	652	9	300	9	coal; aggregates; grain, chemicals; petroleum products; ores & minerals; iron & steel	42.1
Green	103	9	100	2	coal	8.6
Big Sandy	9	9	200	0	coal	9.6

3. MONONGAHELA RIVER NAVIGATION SYSTEM

The Monongahela River is formed by the junction of the Tygart and West Fork Rivers at Fairmont, West Virginia and flows in a northerly direction to join with the Allegheny River at Pittsburgh, Pennsylvania in forming the Ohio River. Draining an area of 7,386 square miles, the river falls a total of 147 feet in its 128.7 mile length.

The Monongahela River was first utilized to transport pioneers through the mountains north to Pittsburgh, where they could continue on northward to the Great Lakes or take the Ohio and Mississippi Rivers south to the Gulf of Mexico. This use of the waterway was eventually surpassed by the transport of coal from the rich fields along the upper river to the Pittsburgh area. This remains the primary use of the river.

The Monongahela River was canalized prior to the canalization of the Ohio River, primarily because of the earlier development of the area, the relative ease of canalization, and the opposition of Monongahela River coal boat fleet operators to canalization of the Ohio River. They viewed dams on the Ohio as "obstructions" to the downstream movement of their vessels during periods of high flow. Canalization of the Monongahela was begun in 1839 with the construction of four lock-and-dam structures along the lower river near Pittsburgh. These were completed by 1844. By ~~1866, three~~ 1856 two more locks and dams were completed, extending navigation up-river and from 1874 to 1903 ~~eight~~ nine more were completed, extending navigation to the head of the river.

Rapid traffic growth on the Ohio River System (ORS), combined with decreasing safety and efficiency of the original projects as they aged, led to the replacement of many of the projects. Despite being known as the "Little Giant," federal funding for improvement of the Monongahela River was minimal until 1947. Slack water on the Monongahela in 1947 was essentially a 19th century steamboat project patched up to handle 20th century commerce. Modernization of the Monongahela River system began in the 1940's, but stopped in 1967, only partially finished. Although there have been major rehabilitations of several projects, since that time no replacement projects were authorized until the Water Resources Act of 1986.

Today, commercial navigation on the Monongahela River is provided by a system of nine locks and dams which maintain a minimum navigable depth of nine feet. Descriptive data and a map of the Monongahela River Navigation System are displayed in Table 2 and Figure 2, respectively. Tows are generally able to operate year-round on the river with exceptions occurring only during infrequent periods of high water or heavy ice when navigation becomes hazardous or lock facilities become inoperable. Severe fog conditions also interfere somewhat with the operation of tows.

Projects are currently underway which will improve the system. Lock and dam 7, equipped with a single 360' x 56' chamber, is being replaced with a new structure and L&D 8's single 360' x 56' chamber is being replaced with a 720' x 84' lock chamber. These improvements will allow tows of up to 84' width to traverse the entire length of the river from its headwaters above Morgantown down through Maxwell L&D, which is immediately upstream of L&D 4. In addition to allowing larger tows comprised of either regular, stumbo, or jumbo type barges, it will also eliminate the need for refleeting in this area.

TABLE 2
Monongahela River Navigation System
(Existing)

Lock & Dam	Location (River Mile)	Operational Main	Operational Aux.	Operational Dam	Rehabilitation Main	Rehabilitation Aux.	Rehabilitation Dam	Lock Size (Ft) Main	Lock Size (Ft) Aux.
#2 1/	11.2	1905	1905	1906	1953	1953		110 x 720	56 x 360
#3 2/	23.8	1906	1906	1907	1981	1981	1979	56 x 720	56 x 360
#4 3/	41.5	1932	1932	1933	1964	1964	1967	56 x 720	56 x 360
Maxwell	61.2	1964	1964	1965				84 x 720	84 x 720
#7 4/	85.0	1925		1926				56 x 360	None
#8 5/	90.8	1925		1926			1959	56 x 360	None
Morgantown	102.0	1950		1950				84 x 600	None
Hilderbrand	108.0	1959		1960				84 x 600	None
Opekiska	115.4	1964		1967				84 x 600	None

1/ Original construction of fixed crest dam completed in 1906. Reconstruction of the locks completed in 1953.

2/ Land chamber extended to 720 feet in 1923-1924. Both chambers received major rehabilitation in 1978-1980.

3/ Reconstruction of the dam completed in June 1967.

4/ Replacement of lock and dam authorized by Water Resources Act of 1986. Construction initiated in June 1988, with replacement of 56 x 360 lock with 84 x 720 lock.

5/ Replacement of 56 x 360 lock with 84 x 720 lock authorized by Water Resources Act of 1986. Construction was initiated in May 1990

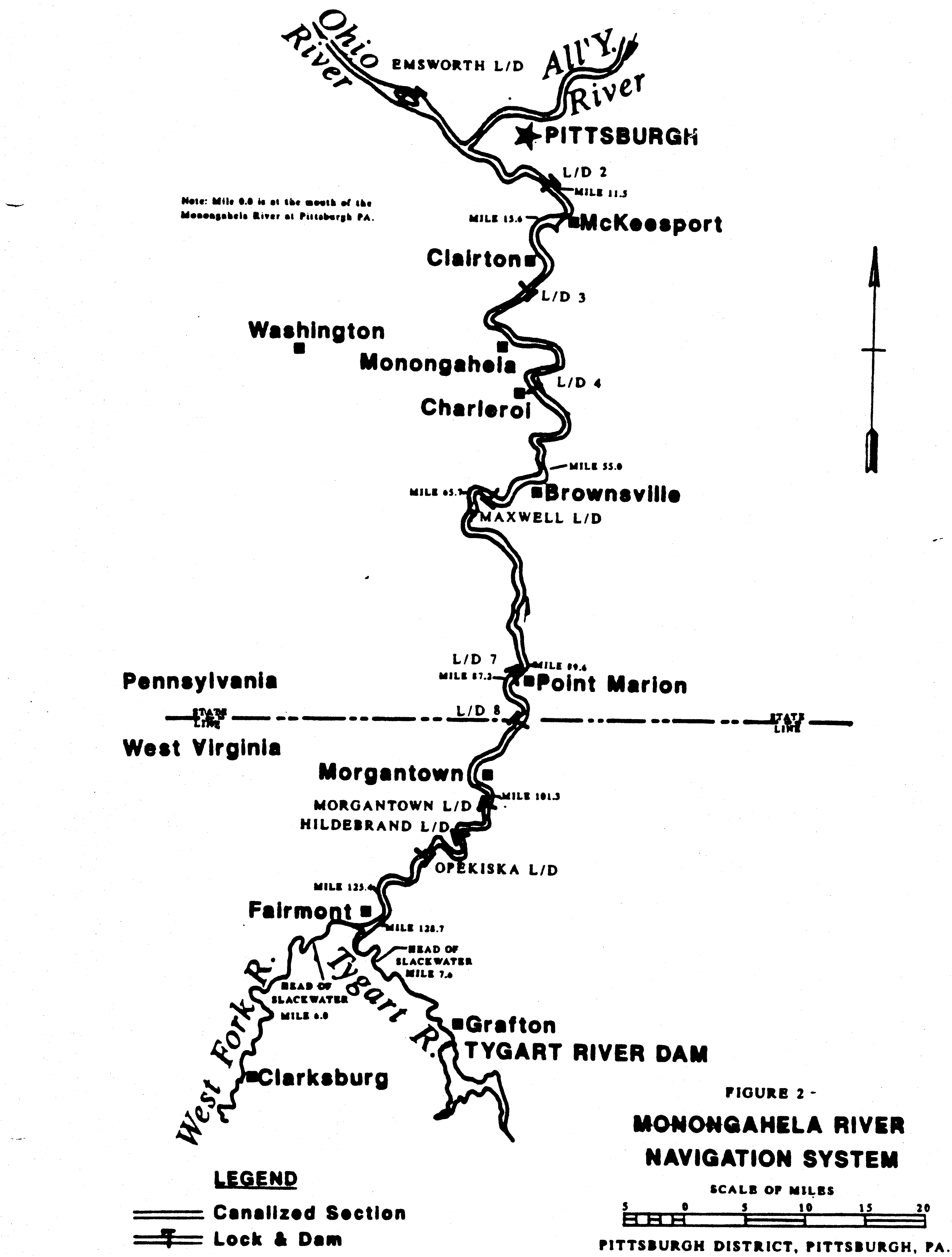


FIGURE 2 -

MONONGAHELA RIVER NAVIGATION SYSTEM

PITTSBURGH DISTRICT, PITTSBURGH, PA.

Revised: 30 September 1978

The Lower Monongahela River consists of three pools formed by the lowermost navigation projects, L&D's 2, 3, and 4, stretching 50 miles between river miles 11.2 and 61.2. L&D 2 is located at river mile 11.2 upstream from Braddock, Pennsylvania. The locks were put in operation in 1905, with the lock chambers being reconstructed in 1953 during the last modernization period.

Locks and dam 3, located at river Monongahela River mile 23.8 near Elizabeth, Pennsylvania, creates a navigation pool that extends upstream 17.7 miles. Constructed in 1907, it is one of the oldest structures in the Ohio River System (84 years old). The project consists of two parallel lock chambers - a main chamber measuring 56 feet by 720 feet and an auxiliary chamber measuring 56 feet by 360 feet. Extensive rehabilitation of the locks was accomplished during the 1977-1980 time period. During the rehabilitation effort the auxiliary lock was converted from a 360' x 56' chamber into a 720' x 56' chamber. This was done to minimize disruptions during closure of the main chamber. However, the emptying system of the extended auxiliary flows into the approach area of the main chamber, preventing safe operation of the main while the extended auxiliary is in use. Therefore, the extended auxiliary is only be used when the main chamber is shut down, otherwise, it is operated as a 360' x 56' lock chamber.

The existing L&D 4 project is located at river mile 41.5 at Charleroi, Pennsylvania. The project consists of two parallel lock chambers, a main chamber measuring 56 feet by 720 feet and an auxiliary chamber measuring 56 feet by 360 feet. The dam at the site was rebuilt and the locks were rehabilitated in the mid 1960's. The navigation pool created by the dam extends upstream 19.7 miles.

Condition studies conducted by the Waterways Experiment Station (WES) and the Pittsburgh District indicate that additional rehabilitation work will be required in the near future to ensure continued operation of the Lower Monongahela River projects. Problems are especially severe at L&D 3 due to its age and deteriorating condition.

Aside from the condition problems, the small size of the locks at L&D's 3 and 4 significantly complicate towing operations on the Monongahela River. These locks provide less width than projects upstream and downstream. While tows of six jumbo barges can single lock through Maxwell Lock (immediately upstream of L&D 4) and tows of nine jumbo barges can single lock through L&D 2, tow size is limited to three jumbo barges at L&D 3 and six jumbo barges at L&D 4. Additional time is required not only for transiting the locks but also for fleeting and refleeting into different tow sizes. This adds to the delivered cost of commodities using the Monongahela River System.

SECTION 3. HISTORIC AND PROJECTED TRAFFIC

1. EXISTING TRAFFIC

a. Commodities

Monongahela River traffic is dominated by the movement of coal. In 1986 the river's 27.8 million tons of coal accounted for 86 percent of total traffic on the Monongahela. Aggregates' 2.2 million tons were a distant second in tonnage followed by petroleum fuels (1.1 million tons) and primary metal products (0.4 million tons). These four commodity groups combined to represent 97 percent of total Monongahela River traffic in 1986. Traffic at the Lower Monongahela's locks shares a very similar mix of commodities, however, aggregates do claim a slightly larger share of traffic on the lower river (see Table 3).

TABLE 3
Lower Monongahela River Traffic by Commodity Group, 1986
(Thousands of Tons)

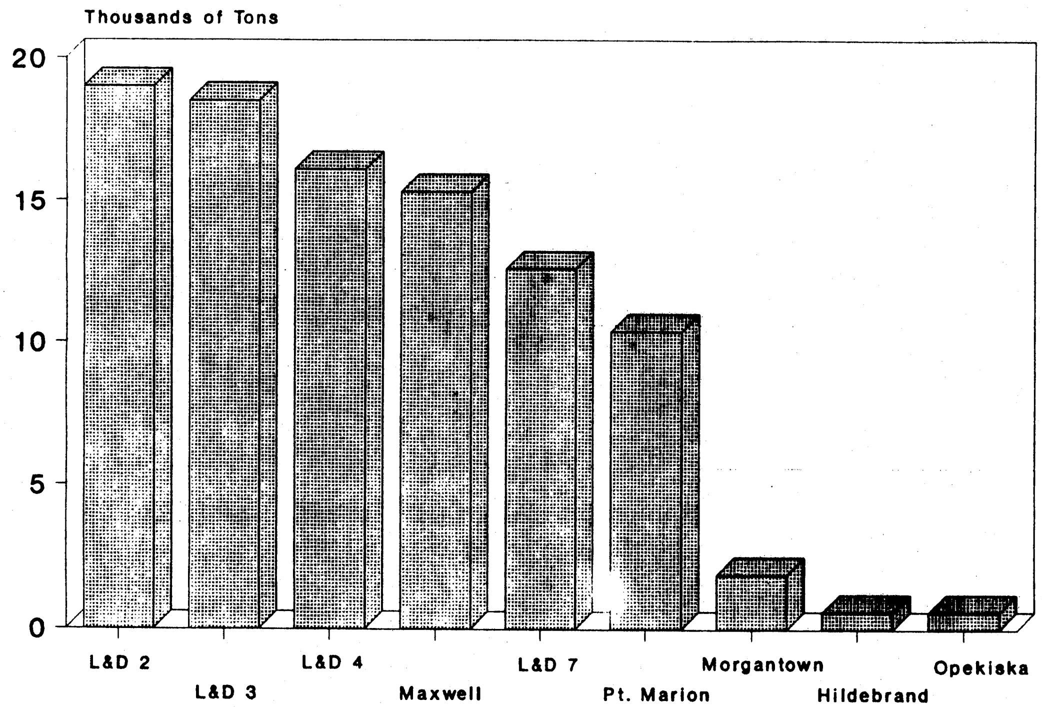
Commodity	L&D 2 Tons	%	L&D 3 Tons	%	L&D 4 Tons	%
Coal	12,389	78	15,109	87	14,271	93
Petroleum Fuels	980	6	721	4	211	1
Crude Petroleum	0	0	0	0	0	0
Aggregates	1,411	9	880	5	808	5
Grains	0	0	0	0	0	0
Chemicals	256	2	174	1	0	0
Ores & Minerals	44	*	15	*	6	*
Iron & Steel	317	2	242	1	92	1
Others	420	3	319	2	7	*
Total	15,817	100	17,460	100	15,396	100

* Less than 0.5 percent.

b. Traffic Density

Traffic densities are greatest on the lower part of the river (see Figure 3) and for the most part, traffic is evenly distributed between the three L&D projects, with each moving 15 to 17 million tons (see Table 3). Downbound traffic is primarily coal moving from mines located along the upper Monongahela to power plants and steel mills on the Monongahela and Upper Ohio rivers. Upbound traffic is more diverse. Significant amounts of petroleum products and aggregates, along with sizable amounts of high quality Big Sandy and Kanawha Basin coking and steam coals move into the lower and middle Monongahela valley.

FIGURE 3
Monongahela River Traffic Density By Project, 1989



c. <u>Shipping Patterns</u>

The waterway segment of greatest interdependence with the Monongahela River is the Ohio River. About 90 percent of all Monongahela River traffic either moves locally on the Monongahela or to/from points on the Ohio River (see Table 4). Most of the traffic moving from the Ohio River to the Monongahela originates within 325 miles of Pittsburgh, while most of the traffic moving from the Monongahela River to the Ohio terminates within 160 miles of Pittsburgh. Of the remaining Monongahela River traffic, significant shipments are made to the Upper and Lower Mississippi, the Allegheny, and the Cumberland Rivers and are received from the Kanawha and Lower Mississippi Rivers.

Lower Monongahela River traffic primarily moves either downbound and through the three projects, or downbound and into one of the three Lower Monongahela River pools (see Table 5). This reflects the movement of coal to utilities and coking facilities located on the LMR and Upper Ohio River. Nearly 86 percent of all LMR coal tonnage was shipped in a downbound direction in 1986. The principal origins of downbound coal are mines located on or near the river in pools created by L/D 8 and Maxwell L/D. The principal destinations for these coal shipments are utilities and coking facilities in the L/D 2 and Upper Ohio River pools. The remaining 14 percent of LMR coal tonnage was shipped from the Huntington/ Charleston areas up the Monongahela River to coking facilities and power plants.

TABLE 4
Monongahela River Traffic by River Segment, 1986
(Thousands of Tons)

River Segment	Shipments Tons	Shipments %	Receipts Tons	Receipts %	Total Tons	Total %
Lower Miss./Gulf Coast	791	4	389	3	1,180	4
Black Warrior/Tombigbee	124	1	11	*	135	*
Arkansas	27	*	0	0	27	*
Upper Miss.	508	3	9	*	517	2
Illinois	18	*	20	*	38	*
Missouri	2	*	0	0	2	*
Ohio	8,003	45	5,752	40	13,755	42
Allegheny	401	2	154	1	555	2
Kanawha	17	*	487	3	504	2
Cumberland	319	2	0	0	319	1
Big Sandy	29	*	136	1	165	*
Tennessee	44	*	4	*	48	*
Subtotal	10,283	58	6,962	48	17,245	53
Monongahela	7,591	42	7,591	52	15,182	47
Total	17,874	100	14,553	100	32,427	100

* Less than .5 percent.

d. Commonality of Traffic

Similarities in Lower Monongahela River traffic, volume and commodity distributions, are primarily a result of the commonality of traffic among the projects, especially at L&D's 3 and 4. At least 80 percent of each project's traffic passes through the other two projects as displayed in Table 6. The commonality of LMR projects, particularly L&D's 3 and 4, with other river projects illustrates the geographic extent of Lower Monongahela River traffic. Only 10 percent of L&D 3 traffic and 8 percent of L&D 4 traffic moves through the Greenup L&D just downstream from Huntington, WV. Relatively little, less than 3 percent, of the Lower Monongahela River projects' traffic moves through other Ohio River tributary projects.

TABLE 5

Lower Monongahela River Projects
River Traffic by Direction and
Commodity Group - 1986
(Thousands)

	Internal			Inbound			Outbound			Through			Total		
	Up	Down	Total	Up	Down	Total	Up	Down	Total	Up	Down	Total	Up	Down	Total
Coal & Coke	7	854	861	1635	5271	6906	4	2100	2104	1028	7626	8654	2675	15851	18526
Petro Fuels	0	0	0	669	0	669	41	150	191	161	1	162	870	151	1022
Crude Petro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aggregates	16	2	18	751	0	751	0	46	46	52	567	619	820	610	1430
Grains	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chemicals	0	1	1	176	0	176	0	80	80	0	0	0	176	81	257
Ores & Minerals	0	0	0	34	0	34	0	3	3	6	0	6	41	3	44
Iron & Steel	0	0	0	21	0	21	0	287	287	8	1	9	29	289	318
All Others	1	0	1	299	0	299	0	117	117	2	2	4	303	119	422

U.S. Army Corps of Engineers, WCSC, 1986

TABLE 6
Commonality of L&D 2, 3 and 4 Traffic With Selected Other Projects - 1986
(Percent)

Project	L&D 2 Traffic Thru	L&D 3 Traffic Thru	L&D 4 Traffic Thru
Morgantown	11	11	12
L&D 8	29	34	43
L&D 7	38	43	53
Maxwell	60	78	96
L&D 4	64	82	100
L&D 3	79	100	93
L&D 2	100	71	65
Emsworth	85	58	53
Montgomery	81	55	50
New Cumberland	58	35	29
Hannibal	48	27	21
Willow Island	40	22	14
Gallipolis	36	20	14
Greenup	18	10	8
L&D 53	10	5	4
L&D 2 (Allegheny)	3	2	3
Winfield	3	*	*
Barkley	2	*	2
Kentucky	1	2	*

* less than 0.5 percent

2. HISTORIC TRAFFIC

a. Historic Traffic Levels

Ohio River System (ORS) traffic grew at an average annual rate of 2.86 percent per year during the 1960-89 time period (see Table 7). The system's relatively high growth rate reflects the continued development of the nation's economy, the construction of coal-fired plants alongside the Ohio River Basin's navigable rivers, and expansion of international trade. Monongahela River traffic grew at a rate of 0.91 percent over the same period. By 1960 waterway commerce was already highly developed along the Monongahela and had strong ties to the long-established local steel industry. This relationship tended to tie waterway traffic to the performance of the steel industry and accounts for the remarkable stability of traffic levels throughout this period.

TABLE 7
Historic Traffic on the Monongahela River, Selected Years, 1960 - 1990
(millions of tons)

Year	Monongahela River Locks			Monongahela River	Ohio River System
	L&D 2	L&D 3	L&D 4		
1960	16.8	20.0	19.2	29.5	105.3
1970	21.6	26.5	22.8	42.3	163.9
1980	19.5	20.1	17.0	34.3	179.3
1981	19.2	18.3	15.5	32.1	181.9
1982	16.0	18.4	16.8	28.8	174.0
1983	12.8	16.0	14.0	26.5	171.2
1984	17.5	19.0	16.6	34.5	202.2
1985	15.3	16.4	14.3	28.8	203.9
1986	15.9	17.5	16.0	32.4	222.2
1987	17.7	19.9	17.8	32.9	226.7
1988	16.1	18.3	16.3	37.2	225.9
1989	15.8	18.6	16.4	38.4	238.4
1990	19.0	18.5	16.1	39.4	n.a.
Ave. Annual Growth Rate 1960 - 1989	(0.21)	(0.25)	(0.54)	0.91	2.86

The electric generating industry, coke producers, the export market, and industries such as cement, paper, and lime manufacturers represent coal's major markets (see Figure 4). The regional importance of the steel industry and its coking operations is reflected by the relatively high share of Monongahela River coal shipments that are destined for coking plants.

Coal shipments have dominated Monongahela River traffic over the past forty years (see Table 8). Moreover, since 1982 coal's dominance of Monongahela River traffic has increased. This increasing share has been due more to the decline of other commodity traffic than to an increase in coal traffic. Shipments of petroleum products have fallen off drastically with the construction of product pipelines. Metal shipments, primarily steel products, have declined from as much as 2.5 million tons to just 300.0 thousand tons as of 1989.

FIGURE 4
End Use Markets for Coal
ORS and Lower Monongahela, 1986

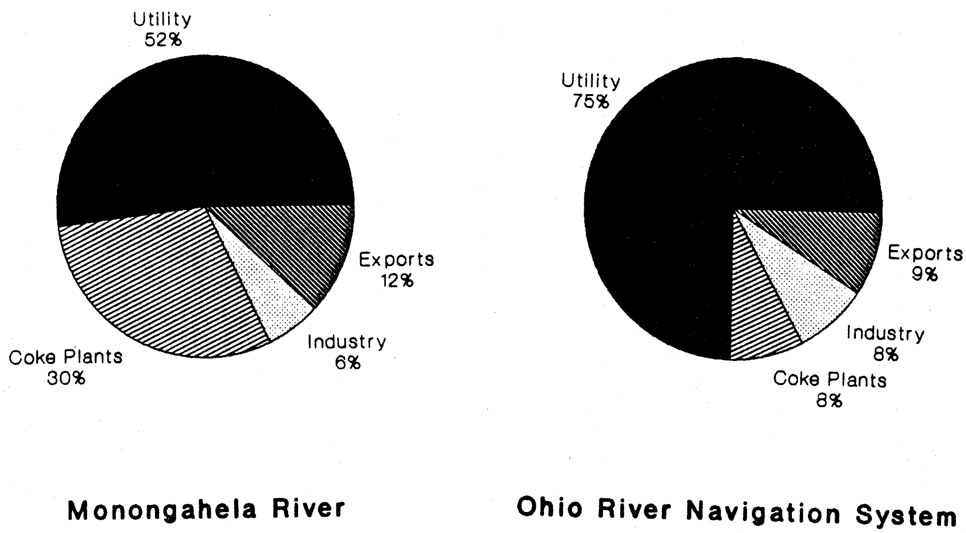


TABLE 8
Historic Monongahela River Traffic
Selected Years and Commodities
(Millions of Tons)

Year	Coal	Primary Petroleum Products	Aggregates	Metal Products	Chemicals	All Others	Total
1951	26.5	0.8	2.8	1.2	0.2	0.5	32.0
1955	30.3	1.2	2.4	2.4	0.2	1.1	37.6
1960	23.7	1.3	1.6	1.8	0.4	0.7	29.5
1965	32.1	1.5	2.3	2.1	0.5	0.3	38.8
1970	34.7	1.6	2.1	2.5	0.6	0.8	42.3
1975	30.3	2.6	1.9	1.3	0.3	0.9	37.3
1980	28.9	1.4	1.7	1.2	0.4	0.7	34.3
1985	24.8	0.9	1.7	0.5	0.2	0.7	28.8
1986	27.8	1.1	2.2	0.4	0.3	0.6	32.4
1987	28.8	0.9	1.9	0.4	0.3	0.6	32.9
1988	32.8	0.8	2.0	0.4	0.3	0.9	37.2
1989	33.7	1.1	1.9	0.3	0.3	1.1	38.4

SOURCE: U.S. Army, Corps of Engineers, Waterborne Commerce Statistical Center, "Waterborne Commerce of the United States" Part 2.

b. <u>Historic Growth Factors</u>

Historically, steel industry activity was the single most important factor in determining the volumes and patterns of traffic on the Monongahela River. The lack of any clear growth trends over the past 40 years reflects the dominance of the regional economy by a mature steel industry. During the 1950's the U.S. produced nearly half of the world's raw steel and Monongahela Valley steel plants accounted for about 26 percent of U.S. raw steel output. Pittsburgh was the world's "steel capital". Steel companies were fully integrated - they not only produced steel, but owned and controlled the raw material inputs which included the metallurgical coal reserves primarily located in the Monongahela, Kanawha, and Big Sandy River basins. The captive metallurgical coal mines of these regions existed and produced for basically one market--the Pittsburgh area's coking operations. Even the region's steam coal demand was driven by the steel industry, the electric utilities' major customer.

Although the U.S. remained the leading steel producer for the next twenty years, its world dominance began to wane. By 1970 the U.S. accounted for only 21 percent of the world's steel production. Since 1977, the integrated mill sector of the U.S. steel industry has closed or liquidated some 200 steel plants. As a result, U.S. raw steel-making capacity was been reduced from 160 million tons in 1977 to 128 million tons by 1986. Overall industry employment fell from 452,000 in 1977 to 175,000 in 1986.

Steel's decline is rooted in several factors, primary among these may be that steel is a less important component of economic growth because of product substitution and changing technologies. Add to this increased import competition and more intense intra-industry competition, particularly from mini-mills, and the industry becomes more susceptible to financial stress during cyclical declines. The recessionary period from 1980-1983, the longest and deepest of the post-war period, precipitated a dramatic decline in demand for domestic steel and led to the industry's "rationalization" in the early 1980's.

This "rationalization", a downsizing and restructuring of the steel industry, was particularly hard on the Monongahela Valley's integrated mills as companies moved to concentrate their operations in the Great Lakes area, placing them closer to both their primary source of iron ore and to their biggest customers - chiefly the motor vehicle and heavy equipment industries. By 1988 the Pittsburgh area contained only 6 percent of U.S. steel-making capacity.

Not surprisingly, this restructuring of the steel industry had a traumatic impact on the Pittsburgh area and weakened the link between the region's steel industry and river traffic. Less coal moved by barge to Monongahela Valley coking plants and steel company demands for electricity declined. Pittsburgh was left with only one integrated raw steel producing facility, the J. Edgar Thompson Works, established by Andrew Carnegie after the 1873 financial panic. In addition to the closure of steel-making and finishing facilities, coking operations, such as J&L Steel's Aliquippa Works were shut down, allowing the steel companies to begin divesting themselves of their coal mines.

Electric utilities serving the Monongahela Valley suffered along with the steel industry during the mid-1980's. Because these utilities' major customer, the steel industry, required much less electricity, much less generating capacity was needed. At the same time, scheduled nuclear capacity additions had just come on line or were due to come on line (i.e. Beaver Valley nuclear Unit 1 in 1976 and Unit 2 in 1987). Steam coal requirements at Monongahela Valley utilities declined as a result.

In 1983 Monongahela River traffic hit its lowest levels in 23 years. However, the restructuring of the economy that occurred at that time created new opportunities for growth. Both new and old owners of the Monongahela Valley's once captive coal reserves began to diversify into other markets, primarily the utility and export markets (see Table 9). For example, coal out of U. S. Steel's Maple Creek and Cumberland mines (at Monongahela River miles 30.3 and 81.5 respectively) is now sold to a Canadian utility. Coal from the mine is barged down the Monongahela River for transloading to rail at U.S. Steel's Duquesne Wharf dock for movement to Conneaut, Ohio, where it is transferred to lake vessel for carriage to Ontario Hydro power stations. Former steel company coal now also moves to TVA plants on the Tennessee and Cumberland Rivers and down the Mississippi River to New Orleans for transshipment to Florida and foreign destinations.

Table 9
Lower Monongahela River
Historic End Use Markets for Coal, Selected Years, 1970-1988
(traffic in millions of tons)

	1970		1980		1986		1988	
Market	Traffic	%	Traffic	%	Traffic	%	Traffic	%
Utility	2.8	10.0	6.4	27.8	8.7	46.8	8.1	38.8
Coke	20.1	72.0	12.3	53.5	4.3	23.1	5.9	28.2
Industrial	2.4	8.1	0.9	3.9	1.9	10.2	2.0	9.6
Export	1.7	6.2	3.3	14.4	3.7	19.9	4.8	22.9
Other	0.9	3.2	0.1	0.4	0.0	0.0	0.1	0.5

The coking market for coal also recovered, despite the permanent closure of many of the area's steel mills due to company decisions to consolidate coking operations in the Monongahela Valley. The proximity of metallurgical grade coal reserves in the Monongahela Valley continues to make coke production feasible. Therefore, after the initial re-adjustments following the closures of the early 1980's, coke production quickly approached pre-closure levels at the remaining coke plants.

However, the greatest impetus to increased coal traffic came from the ability of the area's utilities to sell excess capacity power (coal by wire) to the New Jersey-Washington, D. C. corridor. In general, coal-fired power plants produce electricity at a lower cost than oil and gas-fired plants. This is particularly true of coal-fired power plants in the Pittsburgh area, given their proximity to the large coal reserves of the area and their use of low-cost waterway transportation. Aided by the existence of an extensive transmission line network, Pittsburgh utility companies began marketing electricity to the east coast. These sales quickly became quite significant, accounting for over 15 percent of all the electricity generated in the area. More generation meant more coal consumption, and more coal moving on the river.

c. Summary

The past ten years have been a period of great change for the economy of the lower Monongahela Valley. Steel companies have greatly scaled back their operations in the Pittsburgh area and have sold off much of their coal reserves to coal companies. A brief examination of traffic trends would suggest that waterborne commerce was only temporarily affected by these structural changes. However, an analysis of traffic patterns and markets indicates that these changes led to some very fundamental changes in the waterborne commerce of the area. Coal still dominates river traffic, and metallurgical coal is still important because of coke operation consolidation in the valley, but the biggest end-users are now the utilities - both local and regional, domestic and foreign. The ability of local utilities and coal companies to find new markets led to the recovery of Monongahela River traffic indicated by the average annual rates of growth of 6.4 percent that were experienced between 1983 and 1989.

3. PROJECTED TRAFFIC DEMAND

a. Methodology

(1) General

The traffic demand forecast for the Monongahela River is a subset of the forecasts developed in 1989 for the entire Ohio River Navigation System (ORS) by the Ohio River Division, Navigation Planning Center. In general, future traffic demands for the Ohio River System were projected as a function of future economic growth in the markets served by waterway-using industries. These markets include both end-use/industry markets and geographic markets whether local, broader regional, national, or international. In this context, the traffic demand projections were developed by reference to specific company plans, industry-produced supply/demand forecasts, and to government-produced economic and demographic forecasts.

While the methodologies used in developing traffic demand forecasts were necessarily specific to each individual commodity, two basic methodologies were used - one for utility related commodities and the other for all other commodities. Preliminary steps taken in developing these forecasts were common to both groups, namely: 1) examination and development of base year traffic flows, and 2) development of industry forecasts. Detailed documentation of the study effort is contained in a report entitled "Forecast of Future Ohio River Basin Waterway Traffic, 1986-2050" (May 1990).

(2) Base Level Traffic

Calendar year 1986 was selected as the base year for forecasting purposes. Because actual waterway traffic is a visible component of waterway demands, it serves as the starting point for identifying demands. Establishing base traffic involves insuring that reported traffic for the base year is accurate, that the year chosen is a representative one, and that system constraints are not masking demands.

Traffic data were obtained from two sources: the Waterborne Commerce Statistics Center (WCSC) and the Performance Monitoring System (PMS). The WCSC data were used as the traffic base for the projections since they include the origin and destination of each shipment, whereas the PMS only records the tonnage passing through each navigation project. The WCSC data were verified in several ways. Initially, the WCSC data were run through a computer program to get individual lock tonnages by commodity and direction. The results were compared with the PMS lock data in an effort to verify that all movements had been correctly reported to WCSC. Where discrepancies appeared, the possible shippers involved were identified and contacted so that the reason for the discrepancy could be resolved. Appropriate adjustments were then made to the WCSC data base.

Extensive company contacts were undertaken as a part of the verification effort and as a means of identifying important changes affecting commodity movements that had either taken place in the period subsequent to 1986 or were planned for future years. The information solicited concerned new plant openings and expansions, plant closures, commodity sourcing changes, and changes in transportation mode. This type of information resulted in base year traffic levels and forecasts that reflected the unique circumstances of each company.

In an effort to capture all potential system traffic demands, supplemental traffic surveys were conducted in areas where barge traffic is believed to be limited by the existing navigation system. These surveys were intended to discover if there were potential waterway traffic demands not reflected by existing traffic. The areas surveyed included the Upper Tennessee, the Kanawha and the Monongahela river basins.

In the Monongahela Basin survey, questionnaires were sent to area coal producers. A total of 103 firms were surveyed in the area displayed in Figure 5. Respondents accounting for 73 percent of the area's coal production returned completed forms. Participants in the Monongahela Basin survey indicated that an additional 7.3 million tons of traffic could potentially move on the waterway. In a closer examination of the responses, and in subsequent contacts with the respondents, it was discovered that part of the traffic was already reflected in existing traffic flows. As a result, 2.3 million tons of traffic were eliminated as potential traffic demand. The remaining 5 million tons were considered to represent traffic demands not reflected in existing traffic volumes and this tonnage was included in the traffic forecasts.

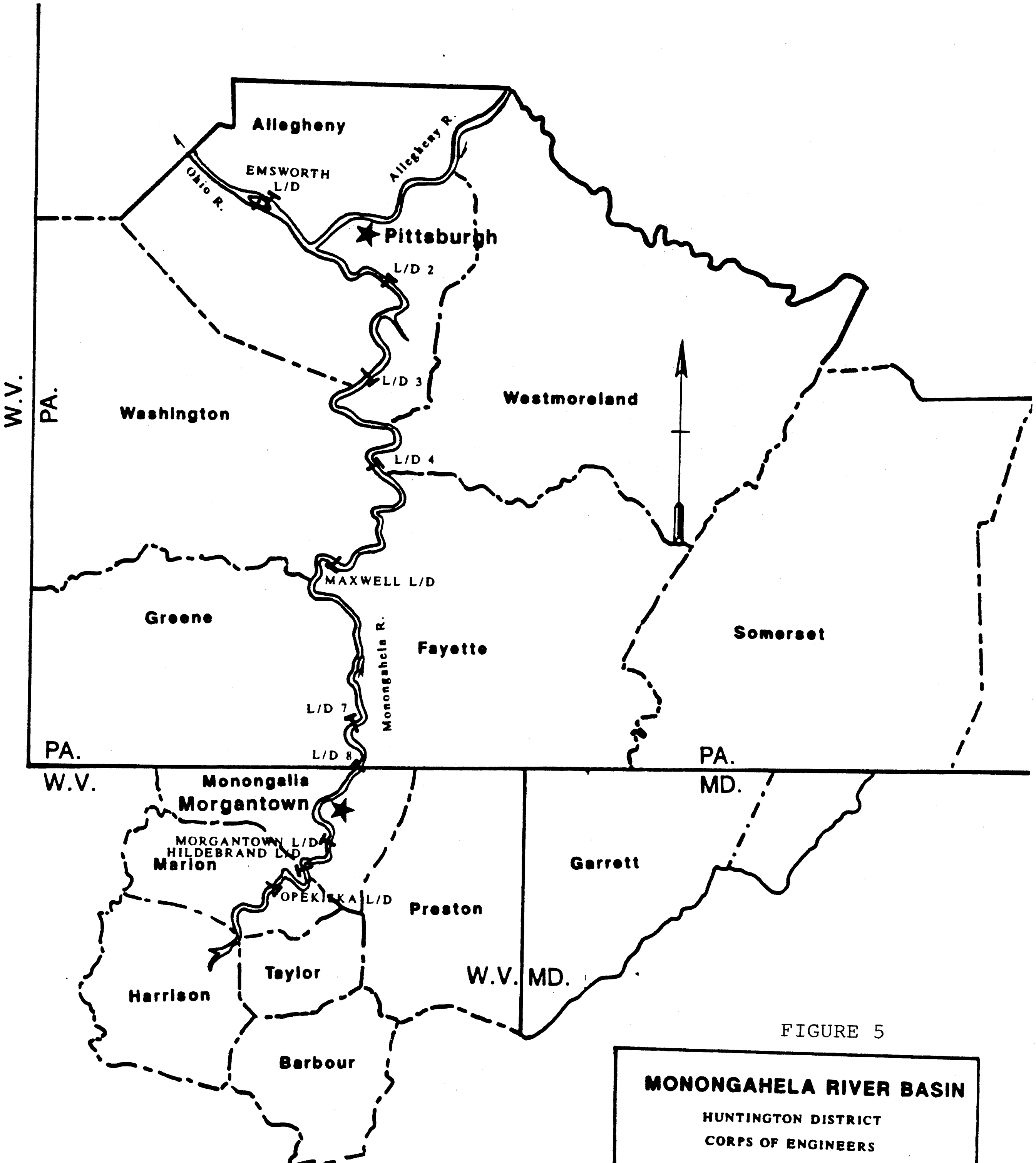


FIGURE 5

MONONGAHELA RIVER BASIN
HUNTINGTON DISTRICT
CORPS OF ENGINEERS

(3) Industry Analysis

Commodity traffic on the inland waterways is comprised of the inputs to and outputs from specific industrial processes. The industry analysis was undertaken to update and expand available information on the Ohio River Basin industries that rely on waterway transportation and to obtain information concerning expected future economic growth in the markets served by those industries. Historic industry development, current operations, and expected future trends that could affect industry requirements for waterway transportation were examined as part of this analysis. Industry and government forecasts were obtained for a number of industries including the electric utility, coal mining, petroleum refining, quarrying, construction, agriculture, chemical, nonferrous metals, steel, and paper industries. These forecasts were the primary source of the growth indices applied to base level traffic.

(4) Utility Commodity Forecasts

Utility coal, and lime and limestone used in coal desulfurization are the waterborne commodities most directly involved in the utility forecasts. These three commodities represented roughly 48 percent of total ORS traffic in 1986, with utility coal alone accounting for about 46 percent of the total. Consequently, the most detailed analysis in the forecasting effort centered around the utility forecasts.

Development of utility commodity forecasts moved through several steps. The first step was to identify all of the electric utility companies that receive Ohio River System coal. Succeeding steps involved forecasting each utility system's demand for electricity, allocating these demands to individual power plants, calculating the amount of coal required to produce this electricity, and finally to determining what proportion of these coal requirements would move by barge.

Moving through this process required the creation of a large data base containing an extensive inventory of all power plants (by fuel type) owned by these companies. In addition, specific data was compiled on the age, capacity, utilization, historic coal burn, mode of fuel transportation, and type of desulfurization equipment, if any, for each plant. This information was obtained for both existing and planned units.

Electricity demand forecasts were developed for each utility receiving ORS coal. Near-term projections were based on demand forecasts obtained from each utility company for their respective service areas. Long-term electricity demand forecasts were based on demographic and economic forecasts prepared by the Bureau of Economic Analysis and published in the report entitled "1985 OBERS BEA Regional Projections".

Each utility's electricity demand forecasts were not allocated uniformly to all plants operated by a company. Electric companies operate their power plants as a system where the least-cost plants are operated first, other plants coming on line in order of their economic efficiency. For most utilities in this region, the efficiency-driven hierarchy of generation is nuclear, hydro, coal, and oil/gas. In developing plant-specific generating requirements, nuclear and hydro capacity was fully utilized before allocating any generating requirements to coal or oil/gas-fired plants. Coal-fired generation was distributed among the coal-fired plants according to their 1986 utilization rates and amount of available capacity. Generation was converted into coal burns based on historic rates of conversion of coal into electricity at the respective plants. Barge receipts and waterside origins were based on historic transportation and sourcing characteristics for each plant.

Other important factors entering into this analysis included electricity sales outside the utilities' service areas, the effects of new plants on system allocations, and capacity limitations at existing plants. As new plants came on line, generation from other plants were reduced until total system generation equaled demand. Generation at each plant was limited to its effective capacity, which is 65 percent of rated capacity for coal-fired plants. Any modifications to the procedures/results described above were based on conversations with company representatives.

The analysis outlined in the preceding paragraphs generated projected coal burns at ORB utility plants as well as utility coal traffic demands. Lime and limestone usage in coal desulfurization was subsequently linked to coal usage. The forecasts were developed while the Revised New Source Performance Standards were still in effect. These regulations required that all new or significantly-modified coal-fired units be equipped with desulfurization equipment. In developing the forecasts, existing units were assumed to be rehabilitated or replaced when they reached 40 years of age, at which time they would install desulfurization equipment. Based on company interviews, all new desulfurization systems were assumed to be limestone rather than lime-based. The waterway's share of the expected traffic to any given plant was based on the location of limestone quarries, the barge share of total coal transported to the plant, and interview responses.

(5) Non-Utility Commodity Forecasts

For all non-utility traffic, considerable efforts were made to identify and categorize each of the unique origin-destination commodity movements on the ORS by geographic and end-use markets. This involved identifying the shipper, determining the market it best represented, and in some cases, examining the market(s) the shipper served. The objective was to develop growth indices for each shipment from industry and/or OBERS forecasts. The relevant index was then applied to the base year tonnage of each movement. The indices were based on industry/market forecasts developed by the industry itself, or by the Bureau of Economic Analysis (BEA). The BEA forecasts are presented in the form of industry sector variables referred to as OBERS variables. A summary of the industry forecasts and OBERS variables used in developing the traffic projections in each commodity group are presented in Table 10.

TABLE 10
Summary of Industry Forecasts and OBERS Based Variables
Used in Waterway Projections

Commodity Groups	Short Term Forecasts	Long Term Forecasts
Coal	Utility Industry	Population*
	Coal Industry	Retail Trade Earnings*
	Steel Industry	Manufacturing Earnings*
		Mining Earnings*
		Mining Employment*
		Durable Earnings*
Petroleum Fuels	Population*	Population*
Crude Petroleum	Population*	Population*
Aggregates	Construction Industry	Construction Earnings*
	Steel Industry	Nondurable Earnings*
	Utility Industry	Durable Earnings*
		Population*
		Retail Trade Earnings*
		Manufacturing Earnings*
Grains	US Dept of Agriculture	US Dept of Agriculture
	Population*	Population*
Chemicals	Aluminum Industry	Aluminum Industry
	US Dept of Agriculture	US Dept of Agriculture
	Nondurable Earnings*	Nondurable Earnings*
Ores & Minerals	Nondurable Earnings*	Nondurable Earnings*
	Construction Industry	Construction Earnings*
	Zinc Industry	Zinc Industry
	US Forest Service	US Forest Service
	Population*	Population*
	Steel Industry	
Iron & Steel	Steel Industry	Durable Earnings*
	Manufacturing Earnings*	Manufacturing Earnings*
All Others	US Dept of Agriculture	US Dept of Agriculture
	Population*	Population*
	US Forest Service	US Forest Service
	Construction Industry	Construction Earnings*
	Nondurable Earnings*	Nondurable Earnings*
	Aluminum Industry	Aluminum Industry
	Zinc Industry	Transportation & Public Utility Earnings
	Steel Industry	
	Durable Earnings*	Durable Earnings*

* OBERS Variables

In the short-term (1986-2000), industry forecasts were generally available and the short-term indices relied heavily on these. In some cases, the industry forecasts were regionally specific. Indices used in the long-term projections (2000-2050) were generally tied to a limited set of OBERS variables. These variables relate to broad industrial sectors and small geographic/economic areas - the BEA areas. While only nine OBERS variables were used, they translate into as many indices as there are destination BEA areas for water shipments.

b. Forecast Results

(1) General

A summary of the commodity forecasts for the Ohio River Navigation System is provided in Table 11. Annual growth in traffic is projected to be 1.4 percent, a rate less than half the rate experienced during most of the post World War II period. The principal reason for the projected slowing in the rate of growth is slower population growth. The commodity with the highest projected growth rate is grain (2.1%), primarily because of increased exports. Petroleum products and crude petroleum have the slowest growth rate, mainly because of decreasing per capita consumption (0.2%). The other commodities all grow at about the same rate (1.4% - 1.7%).

(2) Factors Affecting Future Traffic

The decline of the Monongahela Valley's steel industry is barely discernible in an examination of historic traffic trends. However, the industry's decline could have caused long-lasting and dramatic decreases in traffic had it not been for the development of new markets for area electric utilities and formerly captive coal reserves. Traffic only recently dominated by steel industry shipments of coal to coke plants became dominated by shipments of coal to domestic and foreign electric utilities. Both the industry analysis and the shipper surveys conducted as part of the projection study indicated that this trend would continue. Expectations with regard to future markets for Lower Monongahela Valley coal are reflected in Table 12.

While less coke will be needed in the area, modest growth in coke traffic is anticipated in the near future as the remaining coking ovens are refurbished. Modest growth in traffic is anticipated to continue as remaining coking ovens are refurbished and opened for operation in the near future. Among these are ovens at the Clairton works of U.S. Steel, which will increase the plant's coal requirements by over 1.5 million tons a year, all of which is to be barged to the plant. The principal destination of the additional coke produced at Clairton will be the Gary, Indiana, works of U.S. Steel.

TABLE 11
Navigation System Traffic Forecasts
(Millions of Tons)

	Actual	Projected			Annual Percent Growth		
	1986	2000	2030	2050	51-86	86-00	86-50
Ohio	195.8	277.4	379.6	470.2	3.6	2.5	1.4
Tennessee	42.1	54.4	90.1	120.7	7.2	1.8	1.7
Monongahela	**32.4**	**48.1**	**64.6**	**78.7**	**0.1**	**2.9**	**1.4**
Kanawha	18.2	27.7	34.1	40.2	2.7	3.0	1.2
Cumberland1/	22.6	22.1	31.3	42.1	7.5	-0.2	1.0
Big Sandy2/	10.3	12.0	16.6	19.8	16.4	1.1	1.0
Green	8.6	13.1	22.2	28.0	13.6	3.0	1.9
Allegheny	3.5	3.9	10.7	14.0	-0.5	0.8	2.2
ORS	223.9	319.0	442.2	553.9	3.6	2.6	1.4

Table 12
Lower Monongahela River
Historic and Projected End-Use Markets for Coal and Coke, Selected Years

	1986		1988		2000		2050	
Market	Traffic	%	Traffic	%	Traffic	%	Traffic	%
Utility	8.7	46.8	8.1	38.8	15.7	48.3	34.2	62.3
Coke 1/	4.3	23.1	5.9	28.2	8.7	26.8	7.3	13.3
Industrial 2/	1.9	10.2	2.0	9.6	2.5	7.7	2.0	3.6
Export	3.7	19.9	4.8	22.9	5.5	16.9	9.9	18.0
Other	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0

1/ Includes coal to steel plants for the manufacture of coke.
2/ Includes shipments of coal to industrial plants and shipments of coke to steel and other industrial plants.

Coal-by-wire sales are expected to continue to grow. Duquesne Light recently signed an agreement with an eastern utility (General Public Utilities or GPU) for the sale of electricity. As a result of the agreement, Duquesne Light will reopen two of its power plants - Phillips and Brunot Island - and a coal mine - Warwick, as well as construct a new 200-mile transmission line. The venture is expected to create 2,560 construction jobs over the next six years and 1,040 permanent jobs once the plants and transmission line are operating. The coal delivered to the Phillips plant will move by barge in amounts exceeding one million tons annually.

Exports of Monongahela River coal are projected to grow at a modest rate over the next fifty years. These movements had been in jeopardy owing to Canada's strict air emission standards and an initial decision by Ontario Hydro to switch from medium and high sulfur Appalachian to blended coals and low-sulfur Appalachian coals. More recently, however, Ontario Hydro has decided to install scrubbers at its Lambton plant and announced intentions to install scrubbers at Nanticoke plant, allowing the utility to switch back to higher sulfur Appalachian coals and traditional sources in the Monongahela Valley.

Air emission standards are also a concern in the United States as demonstrated by the 1990 Amendments to the Clean Air Act. Power plants are targeted for greatly reduced emissions of sulfurous and nitrous oxides. These compounds are thought to cause acid rain, a phenomena which is linked to the deterioration of forests and lakes in the New England area and Canada. Coking facilities have been targeted because benzene and ammonia emissions from these plants are thought to increase the risk of cancer in the areas around the plants. The effect of such legislation on area industry and mining is uncertain.

Previous Clean Air legislation required all new and substantially refurbished power plants to meet air emission standards that in effect required some sort of desulfurization equipment. Emissions from existing plants could vary, as long as total emissions within an area complied with the allowable limits. In effect, some plants could emit high volumes of sulfur into the air as long as these were offset by low volumes at other power plants.

The Clean Air legislation just passed lowers the allowable amounts of sulfuric and other emissions emitted by power plants into the atmosphere. This will be achieved by allowing the companies to select the least-cost means of attaining the reduction - installing scrubbers or switching to low sulfur coal. Since Monongahela Basin coal is generally classified as medium in sulfur content, allowing power plants to switch to low sulfur coal could result in some loss in market. However, this could be offset by increased shipments to plants that opt to install scrubbers.

Clean Air Legislation affecting the coking industry requires the installation of anti-pollution technology by 1995. The problem here is the escape of gases - primarily benzene and ammonia - when the doors to the coke ovens are opened. The problem worsens as coke ovens age and the seals around the doors wear out. The legislation could result in the closure of some of the smaller coke plants in the area whereas the larger plants, like Clairton, indicate that they will comply. However, any reduction in coke production would be matched by a drop in waterway traffic since nearly all coal delivered to the coke plants moves by barge.

To the extent possible all of the information gathered during the course of the forecasting effort was factored into the forecast of Ohio River Navigation System traffic demands. This included the closure of old plants as well as the opening of new ones. The results of this effort are summarized for the Monongahela River portion of the navigation system in the following sections.

(3) Projected Traffic Demands

A summary of projected traffic demands for the Lower Monongahela, the Monongahela River System, and the three Lower Monongahela River projects are presented in Table 13. Traffic demands on the Lower Monongahela are projected to almost triple over the next 64 years, from 22.0 million tons in 1986 to 61.8 million tons in 2050, which is equivalent to an annual growth rate of 1.6 percent. This is slightly higher than the rate projected for the Monongahela River system (1.4 percent). Traffic demands at L&D's 2, 3, and 4 are projected to grow at nearly equivalent rates due to the commonality of traffic. Monongahela River system lock traffic from 1986 to 2050 is presented graphically in Figure 6.

Between 1986 and 2000 Monongahela River traffic demands are forecast to grow by 15 million tons. This increase resulted from traffic demands identified through a shipper survey, normalization of the strike-affected 1986 traffic and the inclusion of recent, new movements. As noted earlier, 5 million tons, or one-third of the increase, actually represents traffic demands not currently moving on the waterway-traffic identified as part of a shipper survey. A steel strike in 1986 depressed coal receipts at the Clairton coke plant. Accounting for this traffic and for traffic destined for two recently reopened coke ovens accounts for three million of the 15 million tons. The reopening of the Phillips plant by Duquesne Light added another million tons of traffic. The remaining 6 million tons represent demand and population driven growth in traffic due to increased electricity generation by coal-fired plants, small increases in limestone movements for use in desulfurization units, and growth in both the Canadian and Gulf Coast export market and the northeastern utility market.

Post-2000 traffic projections take on a more typical growth pattern and slower rate of growth because population and economic growth is expected to moderate over this time period. It takes nearly 30 years after the year 2000 to equal the 15 million ton increase in traffic shown from 1986 to 2000.

(4) Commodity Mix of Projected Traffic

Coal is projected to remain the predominant commodity shipped on the Monongahela (see Table 14). Nearly nine out of every ten tons of cargo is accounted for by coal. Coal's share of total tonnage will increase from 84 percent in 1986 to 89 percent in 2050, largely because of increases in demands by power plants (see Figure 7).

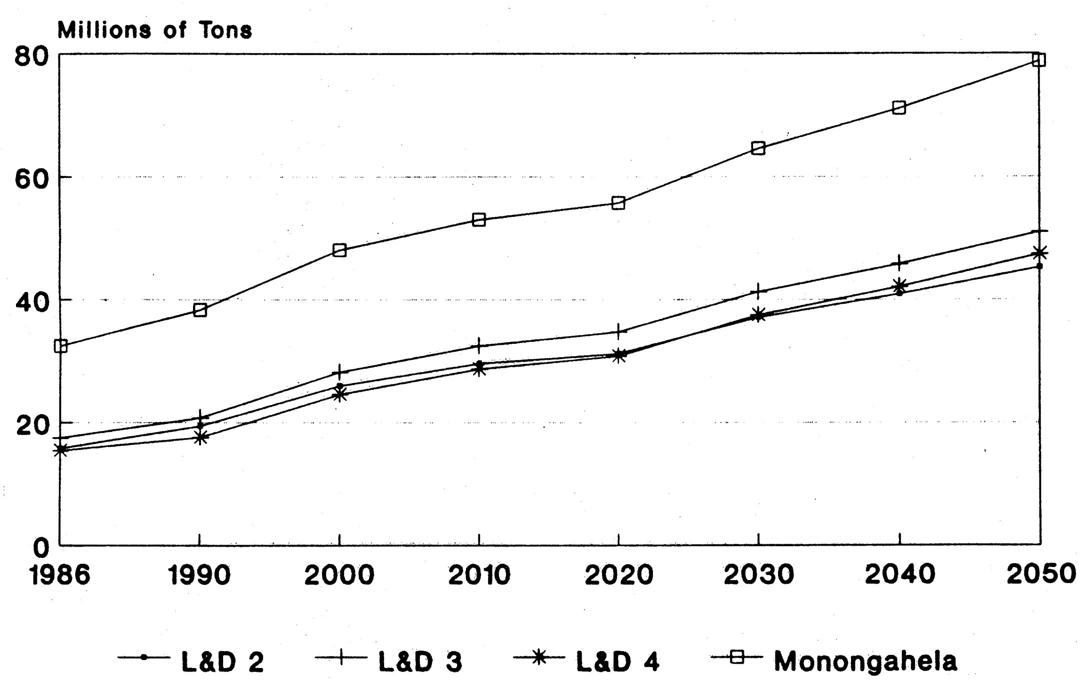
(5) Future Shipping Patterns

Downbound traffic which either moves through or into the lower Monongahela River dominates future traffic flows. The principal destinations are power and coking plants in the Pittsburgh area, and the dock at Duquesne Wharf where coal is off-loaded to rail for delivery to Canadian and East Coast power plants (see Attachment 1).

TABLE 13
Projected Traffic Demands
Monongahela River System
1986-2050
(Thousand Tons)

	L/D 2	L/D 3	L/D 4	Lower Monongahela	Monongahela
1986	15,817	17,460	15,396	22,023	32,444
1990	19,409	20,770	17,589	27,464	38,318
2000	25,943	28,206	24,567	36,773	48,071
2010	29,592	32,495	28,702	41,421	52,993
2020	31,204	34,777	30,858	43,848	55,720
2030	37,112	41,284	37,454	50,929	64,562
2040	40,853	45,765	42,035	55,951	71,055
2050	45,209	50,966	47,375	61,778	78,700
Average Annual Growth Rate (1986 - 2050)	1.7	1.7	1.8	1.6	1.4

FIGURE 6
Monongahela River Lock Traffic
1986 - 2050



Shipping patterns for Lower Monongahela River traffic for each of the major commodity groups are projected to remain stable from 1986 to 2050 (Table 15). Coal traffic will remain predominantly through traffic while petroleum fuel, chemical, and iron and steel traffic will remain predominantly inbound traffic. Only aggregate traffic is projected to change from largely inbound traffic in 1986 to largely through traffic by 2050. The commonality of the Lower Monongahela projects with other projects on the navigation system is projected to display only minor changes. Changes that do occur are a result of increased utility coal shipments to Upper Ohio project power plants and barge-to-rail transfer docks on the Upper Ohio, and to export terminals on the lower Mississippi River.

FIGURE 7
Lower Monongahela Commodity Traffic Mix
1986 vs. 2050

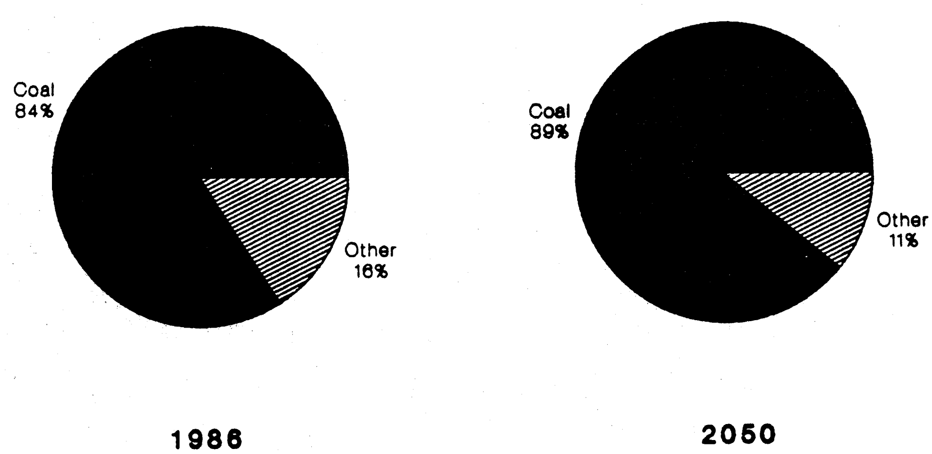


TABLE 14

Commodity Mix of Projected Lower Monongahela River Traffic
1986-2050

	1986		1990		2000		2010		2020		2030		2040		2050	
Commodity	KTONS	%	KTONS	%	KTONS	%	KTONS	%	KTONS	%	KTONS	%	KTONS	%	KTONS	%
Coal	18,526	84	23,740	86	32,514	88	36,667	89	38,080	87	44,840	88	49,498	88	54,942	89
Petro Fuels	1,022	5	1,024	4	1,023	3	1,035	2	1,054	2	1,067	2	1,079	2	1,091	2
Aggregates	1,435	7	1,469	5	1,782	5	2,114	5	2,979	7	3,147	6	3,362	6	3,592	6
Chemicals	257	1	359	1	401	1	437	1	472	1	507	1	542	1	576	1
Ores & Minerals	44	0	45	0	47	0	49	0	50	0	52	0	54	0	55	0
Iron & Steel	317	1	360	1	423	1	485	1	539	1	590	1	642	1	693	1
All Others	421	2	466	2	582	2	634	2	673	2	725	1	775	1	828	1
TOTAL	22,023	100	27,464	100	36,773	100	41,421	100	43,848	100	50,929	100	55,951	100	61,778	100

TABLE 15
Lower Monongahela River Traffic
Projected Shipment and Receipts by BEA Area 1986-2050
Thousands of Tons

BEA No.	BEA NAME	SHIPMENTS Actual 1986	SHIPMENTS Projected 2050	RECEIPTS Actual 1986	RECEIPTS Projected 2050
16	Pittsburgh, PA	16,024.6	30,710.0	22,007.4	48,412.7
47	Mobile, AL	9.9	9.2	90.4	230.3
49	Birmingham, AL	1.4	1.2	N.A.	N.A.
50	Huntsville, AL	1.4	2.5	21.1	53.8
51	Chattanooga, TN	N.A.	N.A.	5.0	10.8
53	Knoxville, TN	N.A.	N.A.	8.6	0
54	Nashville, TN	N.A.	N.A.	320.9	679.3
55	Memphis, TN	N.A.	N.A.	49.2	116.9
56	Paducah, KY	4.5	6.4	4.6	9.3
57	Louisville, KY	17.4	33.1	116.1	247.5
59	Huntington, WV	3,767.7	6,501.2	96.4	148.2
60	Charleston, WV	486.8	442.2	17.5	40.7
61	Morgantown, WV	10,516.7	38,585.6	2,713.6	6,689.5
62	Parkersburg, WV	12.4	12.5	1,414.0	3,696.5
63	Wheeling, WV	1,040.2	1,499.4	3,624.1	9,075.4
64	Youngstown, OH	N.A.	N.A.	127.1	193.6
66	Columbus, OH	39.3	46.1	103.6	127.7
67	Cincinnati, OH	100.6	165.6	372.0	2,861.2
80	Evansville, IN	3.0	3.9	17.4	40.2
83	Chicago, IL	20.4	36.3	17.8	29.5
91	LaCrosse, WI	N.A.	N.A.	469.1	781.9
96	Minneapolis, MN	9.3	14.7	6.0	10.8
98	Dubuque, IA	N.A.	N.A.	15.5	25.8
105	Kansas City, MO	N.A.	N.A.	2.4	4.9
107	St. Louis, MO	N.A	N.A.	17.5	22.3
110	Fort Smith, AR	N.A.	N.A.	23.4	76.0
111	Little Rock, AR	N.A.	N.A.	3.6	9.1
112	Jackson, MS	17.8	33.5	N.A.	N.A.
113	New Orleans, LA	57.9	95.8	538.0	2,415.2
114	Baton Rouge, LA	146.0	313.9	193.3	2,596.0
115	Lafayette, LA	127.2	130.8	2.6	14.3
116	Lake Charles, LA	10.7	17.0	N.A.	N.A.
121	Beaumont, TX	N.A.	N.A.	9.1	16.8
122	Houston, TX	27.5	36.9	35.5	88.8

SECTION 4. VESSEL FLEET AND LOCK UTILIZATION

1. INTRODUCTION

Tows moving on the inland waterway system are configured to operate as efficiently as possible along each waterway segment. While a variety of factors are important in establishing the most efficient tow configuration, lock size and channel dimensions are certainly important. With nine navigation projects and four different lock sizes, towing companies on the Monongahela River are faced with very difficult operating conditions. The industry has responded by adapting their towing equipment and operating patterns to minimize the impact of these constraints. While conditions have gradually improved over time with the enlargement of several projects, tows still must undergo frequent and time consuming changes in configuration in moving from the headwaters of the Monongahela River to Pittsburgh. This section describes the characteristics of the barges and tows using the Monongahela River, the typical operating patterns, and the utilization of the lower Monongahela River locks.

2. VESSEL FLEET

a. Background

Historically, Monongahela River traffic consisted principally of downbound shipments of coal to plants in the Pittsburgh area. While these shipments varied in volume with steel and power plant demands, the pattern itself remained virtually unchanged. Given the stability of shipping patterns and the large volumes involved, the steel and power industries purchased and operated barges that most efficiently utilized the Monongahela River: the regular (175' x 26') barge. Up through the mid 1960's the Monongahela River was basically a 360' x 56' lock system with seven of the ten projects having main chambers of that size. As shown in Table 16, the barge type that best fits a 360' x 56' lock chamber is a regular (standard). Regulars can pack twice the tonnage of jumbos and one-third more tonnage than stumbos into the chamber.

TABLE 16
Lock Dimensions and Tow Size

Lock Size		Regular 175 x 26	Stumbo 195 x 26	Jumbo 195 x 35
360 x 56	Barges:	3	2	1
	Tons:	2,700	2,200	1,500
720 x 56	Barges:	6	6	3
	Tons:	5,400	6,600	4,500
720 x 84	Barges:	9	9	6
	Tons:	8,100	9,900	9,000
720 x 110	Barges	12	12	9
	Tons:	10,800	13,200	13,500

With 720' long lock chambers, stumbo barges (195' x 26') have a significant tonnage-carrying advantage over regulars. With the gradual emergence of a 720' system below L&D 7, the stumbo barge, currently the second largest component of the Monongahela vessel fleet, has become more important. The fewer the number of 360'x56' locks that tows have to pass through, the smaller the advantage of using regular barges.

The third barge type used on the Monongahela is the jumbo (195' x 35') barge. These barges are used less frequently because they do not efficiently utilize the Monongahela navigation system. Jumbo barges are typically used on long-haul movements where the inefficiencies of using jumbos on the Monongahela are offset by the efficiency of using them elsewhere on the navigation system.

The barge fleet currently being operated on the Monongahela River is more a reflection of the navigation system as it existed in the past than of the present or planned system. The system has largely been transformed from a 360' x 56' system into a system of longer and wider locks. The upper most projects measure 600' x 84', the middle system projects are 720' x 84', and the lower projects are 720' x 56', with the exception of L&D2 which measures 720' x 110'. The barge fleet in the future is expected to consist predominately of stumbo and jumbo barges: stumbos for internal Monongahela traffic and jumbos for off-river shipments (regulars remaining only to handle movements between the Allegheny, with its small lock chambers, and the Monongahela rivers). The barge fleet statistics provided in the following sections should be viewed in light of the historic nature of the Monongahela system, rather than as a precursor of the fleet likely to be used on the improved system.

b. Traffic Statistics

Historic data on the number of tons, barges, and tows transiting the Lower Monongahela locks are listed in Table 17. All three locks show slight declines in traffic, and large declines in the number of barges and tows. Operators on the lower Monongahela have been moving to larger barges, which is reflected in the figures which show significantly larger tons per tow despite declining or modest increases in barges per tow.

c. Barge Types

The evolution to larger barges is shown in Table 18, which compares the 1980 and 1990 barge fleets (loaded) at the Lower Monongahela River projects. Though regulars continue to be the dominant barge type, operators have moved away from regular barges, while roughly doubling their reliance on stumbo barges.

TABLE 17
Tons, Barges, and Tows 1980 through 1990

Project/Item	1980	1985	1986	1988	1990	% Change
<u>L&D 2</u>						
Tons (000's)	19,476	15,328	15,894	16,084	18,969	- 3
Barges	33,873	24,586	25,533	23,416	28,270	-16
Tows	6,138	4,659	4,687	4,533	4,690	-24
Barges/Tow	5.5	5.3	5.4	5.4	5.9	7
Tons/Tow	3,173	3,290	3,391	3,548	3,957	25
<u>L&D 3</u>						
Tons (000's)	20,096	16,401	17,516	18,288	18,458	- 8
Barges	40,024	30,507	30,863	33,103	32,058	-20
Tows	8,756	6,766	7,056	7,427	7,632	-13
Barges/Tow	4.7	4.5	4.4	4.5	4.2	-11
Tons/Tow	2,295	2,424	2,482	2,462	2,418	5
<u>L&D 4</u>						
Tons (000's)	16,976	14,344	16,030	16,337	16,062	- 5
Barges	35,488	26,974	28,214	29,305	28,723	-19
Tows	7,002	5,003	5,251	5,300	5,605	-20
Barges/Tow	5.1	5.4	5.4	5.5	5.1	0
Tons/Tow	2,425	2,867	3,052	3,083	2,865	18

SOURCE: PMS.

TABLE 18
Loaded Barges by Type, 1980 and 1990

Project/Barge Type	1980	1990
<u>L&D 2</u>		
Regular	8,202	5,438
Stumbo	1,997	3,776
Jumbo	5,453	4,925
Other 1/	2,531	2,042
<u>L&D 3</u>		
Regular	13,465	8,276
Stumbo	2,633	5,377
Jumbo	2,488	1,833
Other 1/	1,737	1,411
<u>L&D 4</u>		
Regular	13,026	7,621
Stumbo	2,419	4,755
Jumbo	1,403	1,448
Other 1/	1,038	1,082

1/ Other includes sand flats and tanker barges.

While the fleet consists predominantly of regular and stumbo barges, other types move on the river as well. Most numerous among these are jumbo (195' x 35') barges, but also included are sand flats (148' x 27') and various size tankers. Typically, jumbo barges are moved in small tows to fleeting areas for inclusion in larger tows destined for more distant points on the waterway system. Sand flats and tankers are used to haul construction materials, petro-chemicals, and other commodities.

d. Percent Empty

The percentage of empty barges that move on a given waterway segment indicates the level of backhaul opportunities. Fifty percent empty indicates the total absence of backhauls with barges moving loaded one direction, empty in the opposite direction. The percent empties are 44 percent at L&D 2, 47 percent at L&D 3, and 47 percent at L&D 4. This implies that 6 percent of the barges at L&D 2, 3 percent at L&D 3, and 3 percent at L&D 4 are loaded both upbound and downbound through the lock. In other words, there is very limited potential for backhauls on the Monongahela.

e. Tow Size

The most common size tow on the Lower Monongahela is a six-barge tow. Four of every ten tows through L&Ds 3 and 4 and two of every ten through L&D 2 are six-barge tows (Table 19).

TABLE 19
Barges Per Tow 1986

Barges/Tow	L&D 2	L&D 3	L&D 4
1-2	1,405	1,635	538
3-4	790	1,728	1,101
5-6	1,155	3,181	2,565
7-10	829	512	1,012
11-22	508	0	35
Total	4,687	7,056	5,251

The predominance of six-barge tows reflects the intensive usage of regular and stumbo barges in the area. Six-barge tows of either type can lock through the main (720' x 56') lock at any of the Lower Monongahela projects in a single operation. The largest jumbo barge tow that can do likewise is a three-barge tow, and in fact, the predominant size jumbo tow is a three-barge tow. Tankers generally move in one and two-barge tows because of their size, the limited tonnage required per time period, and the sometimes hazardous nature of their cargo. Sand flats also move in relatively small tows, a reflection of the shuttle nature of the traffic (a listing of the distribution of barges per tow by barge type is provided in Attachment 2).

f. Towing Operations

While six-barge tows are most common, larger tows routinely move on the Monongahela River and the operation involved in getting them to Pittsburgh can be quite complicated. For example, regular barge tows originating above L&D 7 will generally start as six-barge tows, the largest regular barge tow that can pass through L&Ds 7 and 8 in a double lockage operation. Barges can be added in the Maxwell pool (the site of numerous coal mines) before the tow continues down through Maxwell to a point above L&D 4. Here the tow will be reconfigured from 78' in width to 52' in width so it can be double-locked through L&D 4. At a point above L&D 3 the tow will tie off half of its barges before proceeding on through L&D 3 with the other half of the tow. This is done so that the tow can pass through L&D 3 in the required one-cut operation (hazardous approaches limit tows to one-cut lockages in the main chamber). The towboat will tie off the barges below L&D 3, and return light (a towboat with no barges in tow) up through the project to retrieve its barges above the project. After picking up these barges the tow will again move down through L&D 3. Once below L&D 3, the tow will pick up the first set of barges and reconfigure into a large tow. This operation is known as double-tripping and is currently estimated to take 3 to 6 hours, depending on lock delays and river conditions. The operation is illustrated in Figure 8. The time consuming nature of this operation has caused towing companies using the Monongahela River to decidedly favor sizes capable of being moved through L&D 3 in single cuts, that is six-barge regular tows, six-barge stumbo tows, and three-barge jumbo tows.

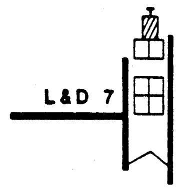
Stumbo and jumbo barge tows can also be handled in similar fashion. That is, a stumbo tow can be increased to nine barges in the Maxwell pool and continue downriver where it would require reconfiguration and double-tripping to pass through L&Ds 3 and 4. Similarly, a jumbo barge tow can be increased to six barges in the Maxwell pool and continue downriver where it would require reconfiguration and double tripping to pass through L&Ds 3 and 4. However, as with regular barge tows, operators prefer to move stumbo and jumbo barges in tows capable of being locked through L&D 3 in single-cuts.

In moving the length of the Monongahela River in single-cut operations, except at L&Ds 7 and 8, the largest regular barge tow can move 5,400 tons, the largest stumbo tow can move 4,400 tons, and the largest jumbo tow can move 3,000 tons. The advantage is clearly with the regular barges. However, stumbos and jumbos show an advantage along the lower river. By adding barges in the Maxwell pool, to take advantage of its larger chambers, the stumbo tow can increase its carrying capacity to 9,900 tons and the jumbo barge tow to 9,000 tons, while the regular barge tow remains at 5,400 tons. The advantage is with the stumbo barge, although that advantage is offset somewhat by the need for refleeting in the Maxwell pool.

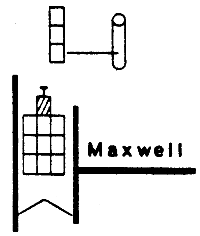
Figure 8
Towing Operations

Operation

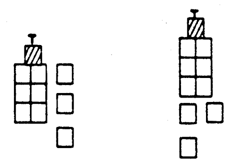
1. Six barge standard (regular) tow loaded on Upper Mon. Double lock thru L&D 7.



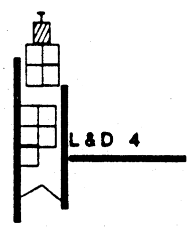
2. Add three barges in Maxwell pool. Single lock thru Maxwell.



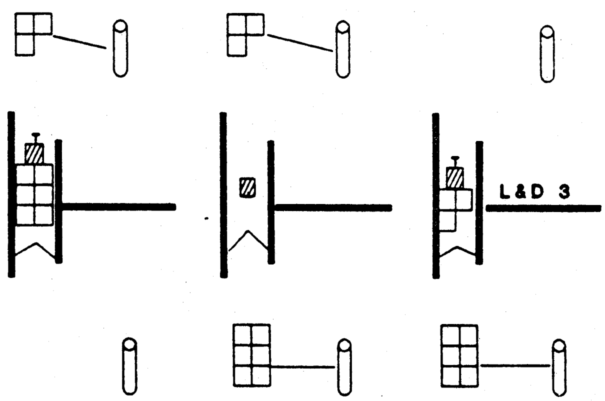
3. Reconfigure in L&D 4 pool.



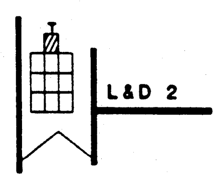
4. Double lock thru L&D 4.



5. Tie off three barges in L&D 3 pool. Lock down with six barges. Tie off six barges in L&D 2 pool. Towboat locks up with no barges. Lock down with three barges.



5. Reconfigure into 9 barge tow in L&D 2 pool and continue trip.



3. LOCK PROCESSING TIMES

a. General

Lock processing time has two components: lockage time and delay time. Lockage time is the amount of time a lock is obligated to serve a particular vessel. Delay time is the amount of time a vessel may have to wait to be served. Lockage and delay times for each of the Lower Monongahela River projects are provided in Table 20. Both times are discussed in more detail in the following paragraphs.

b. Lockage Time

Component lockage times by chamber are displayed in Table 21. The two items of interest are the relatively short times for the auxiliary as compared to the main chambers and the relatively short times through L&D 3 as compared to the other two projects. Lockage times through the auxiliary chambers are 35 to 50 percent lower than through the main chambers at all three projects. The reason for the shorter times at the auxiliaries are their use by recreational and other small craft. These craft can enter and exit the lock much faster than tows.

Lockage time for L&D 3 is 15 to 20 percent lower than the other two projects. The shorter time at L&D 3 relative to L&D 2 reflects the prevalence of large tows and the use of double lockages at L&D 2. Shorter times at L&D 3 relative to L&D 4 arise from two factors: 1) one-cut limitations at L&D 3 and 2) the shorter component lockage times for single cuts at L&D 3. Tows that require more than one-cut take longer to serve and, because approximately 14 percent of L&D 4 lockages were double-cuts in 1989, it is expected that L&D 4 would have longer lockage times than L&D 3. In addition, shorter approaches and lower lifts at L&D 3 allow single-cut lockages to occur in less time than single-cut lockages at L&D 4 (see Table 22).

c. Delay Time

Delays are not a serious problem at the Lower Monongahela River locks under present traffic levels. The time waiting in queue averages around 14 to 16 minutes at each project. However, these statistics mask the true constraint imposed by the small locks. It must be recognized that the total distance between the three projects is only about 30 miles. Therefore, an average of nearly 3 hours is required to process each tow through all three of these closely spaced projects. In addition, the delay measured at the lock does not include the significant time and cost penalty involved in refleeting and adjusting tow size to accommodate the small locks.

TABLE 20
Lower Monongahela Locks Processing Times
(Minutes per Tow)

	1985	1986	1987	1988	1989	1990
L&D2						
Lockage	40	39	39	39	39	43
Delay	18	16	14	15	9	17
Total	58	55	53	54	48	60
L&D3						
Lockage	33	33	33	33	32	31
Delay	15	14	13	19	13	14
Total	48	47	46	52	45	45
L&D4						
Lockage	45	42	46	46	44	43
Delay	39	16	20	23	24	21
Total	84	58	66	69	68	64

TABLE 21
Lockage Component Times, 1989

	Approach	Entry	Chambering	Exit
L&D 3 (Single Cut)				
Main	11.1	6.3	9.1	6.5
Auxiliary	9.3	4.1	7.9	4.1
L&D 4				
Single Cut				
Main	12.6	7.2	10.1	7.4
Auxiliary	11.2	4.6	9.5	5.6
Double Cut				
Main	15.6	12.9	50.7	15.3
Auxiliary	10.2	8.4	46.3	12.4

TABLE 22
Lower Monongahela River Projects
Number of Lockage Cuts per Tow

Project	1980	1982	1984	1986	1988
L&D 2					
Single	7,193	6,224	6,076	6,024	5,973
Double	560	344	538	401	373
>2	21	0	0	65	74
Total	7,774	6,568	6,614	6,490	6,420
L&D 3					
Single	9,705	9,433	9,540	9,591	10,088
Double	8	0	1	0	1
>2	0	0	0	0	0
Total	9,713	9,433	9,541	9,591	10,089
L&D 4					
Single	7,968	7,147	7,121	6,345	6,222
Double	175	263	224	585	852
>2	0	0	0	13	0
Total	8,143	7,410	7,345	6,943	7,074

4. LOCK AVAILABILITY

In the context of navigation system modeling, lock availability refers to the amount of time that locks are available in a normal year to process tows. Normal downtime refers to the amount of time in a normal year that they are unavailable for use. Normal downtime occurs because of weather conditions, high water, and routine maintenance. It does not include the time the locks are closed for scheduled or unscheduled major maintenance. Historic data on lock downtimes were obtained from PMS records. PMS records each downtime event by chamber number, date, duration, and cause of the outage. A list of all outages longer than one day was extracted and analyzed by Operations personnel for more detailed information on the cause of the closure and as a check on missing and/or erroneously entered data. The events were then categorized according to one of four general causes: 1) weather and high water; 2) routine maintenance; 3) unscheduled major maintenance; and 4) accidents and other.

The data was then analyzed both collectively and for each individual lock to determine 'normal' levels of downtime. The lock-level analysis indicated considerable variation in downtimes from year to year, even after unscheduled major maintenance events were factored out. In order to mitigate these statistical distortions, it was decided to use ten year averages to calculate 'normal' levels of downtime (Table 23). On average, only one lock is available at a project for 25.9 days, or 3.5 percent of the time (25.9/365x2).

TABLE 23
Average Project Downtime per Year

Causative Factor	Days	Percent
Weather and High Water	3.7	14
Routine Maintenance	9.5	37
Unscheduled Major Maintenance	11.8	46
Accidents and Other	2.8	3
Total	25.9	100

SECTION 5. BENEFIT EVALUATION PROCEDURES

1. PURPOSE

The purpose of this section is to provide an explanation of the analytic procedures that were employed in estimating the National Economic Development (NED) benefits and system impacts of alternative plans considered for operating and/or replacing the Lower Monongahela River locks. The models and procedures are discussed in a fairly general manner. More detailed explanations can be found in the Tow Cost Model (TCM) and Waterway Analysis (WAM) User Manuals.

2. DESCRIPTION OF THE SYSTEM MODEL

a. General

The model used to keep track of all the traffic interactions and to estimate National Economic Development benefits and navigation system impacts for the Lower Monongahela improvement plans is a package of computer programs collectively referred to as the Tow Cost Model (TCM). The model was originally developed for the Corps of Engineers by CACI, Incorporated, and was selected by the Ohio River Division (ORD) for use in all ORD navigation system studies, including - Gallipolis L&D, Monongahela River L&D's 7 and 8, Olmsted L&D, Winfield L&D, and McAlpine L&D. Over the years the model has undergone extensive modification and refinement.

The TCM uses the changes in barge line-haul costs for each movement (a movement is defined as a unique origin, destination, commodity and route option) over time, along with externally developed estimates of existing waterway rate savings, to compute equilibrium traffic flows. In defining equilibrium system traffic levels, the model assumes that movements will divert off the waterway system when towing costs increase to the point that it becomes cheaper to move via an overland mode. The solution is presented at both macro and micro levels of detail which provides the user with great flexibility in choice of analytical characteristics for the entire system, subregions of the system, locks and reaches, and for all the traffic between selected port pairs. The effects of a system improvement are evaluated by specifying an alternative set of input parameters to reflect the improvement and re-solving the model. This allows incremental system benefits to be computed for virtually any type of system modification.

Two modules within the TCM perform the model's two main tasks - waterway costing and equilibration/optimization. These two modules and the tasks performed are discussed in the text below.

b. The Costing Module

This portion of the TCM completes sophisticated, analytically-based costing routines used to compute the towing costs of each port-to-port movement in the Ohio River System. In making its cost calculations, the costing module uses a set of interlinked computer programs and detailed data that describe: 1) the waterway system being evaluated, 2) the equipment used for towing operations and the costs associated with owning and operating the equipment, and 3) the port-to-port commodity flow demands. Using these inputs, the model calculates the resources required for each port-to-port commodity movement (number of barge and towboat trips, for example) on a least cost basis. For each port-to-port movement, the model calculates the round-trip time from shipping port to receiving port. These times are translated into costs of transport by applying the equipment operating costs per unit of time. The major time and cost elements considered by the model include: 1) time loading/unloading barges, 2) time waiting for access to docks, 3) time loaded barges wait for towboat, 4) time making/breaking tows, 5) tow transit time, 6) lockage time, and 7) lock delay.

The towing costs for each port-to-port commodity movement generated by the costing module are used along with the waterway rate savings for each movement in finding the equilibrium traffic set. This portion of the modeling process is termed equilibration and is discussed in more detail below.

c. Equilibration/Optimization Procedures

The 1986 base condition is the starting point for the equilibration process, being the condition against which the economic impact of future increases in towing costs are measured. The impact of future increases in towing costs, induced by increased traffic demands, on the ability of traffic to move at a savings is measured by adjusting the base year rate savings in line with changes in base year shipping costs. This was accomplished by comparing the future year and the base year towing costs for each port-to-port movement and making corresponding adjustments to base year rate savings.

As traffic demands increase, waterway congestion results in increased barge line-haul costs which cause the complete erosion of the waterway rate savings for many prospective barge shipments. This, of course, means that system traffic demands exceed the capacity of the system. The objective of the equilibrium process is to determine the aggregate system traffic level at which the last increment of tonnage added exhibits sufficient rate savings to just offset the increase in average towing costs. This task is made difficult by the complex interaction of the movements. Since each movement has the potential for affecting the shipping costs and rate savings for virtually every other movement, iterative processing and incremental analysis is required to achieve the correct equilibrium solution.

Iterative processing occurs in the TCM's equilibrium module. This module systematically tests different combinations of movements, each combination having its own set of lock delays and associated tow operating costs. Processing ceases when all movements that could move on the waterway at a rate savings are in the equilibrium solution set.

The equilibrium process determines the amount of traffic that can move on the system at a rate savings. It does not determine the optimum solution. The procedure for determining optimum traffic flows is the same as described above, except that the model is resolved for a sufficiently wide range of congestion fees (dollars/ton) at the lock(s) being examined such that a fee amount can be determined which maximizes total system rate savings.

3. MODEL INPUT DATA AND SOURCES

a. General

The major data requirements of the TCM include descriptions and definitions of: 1) the waterway system being analyzed; 2) the towing equipment (towboats and barges) available for moving the tonnage and their operating costs; 3) existing and projected tonnage demands by commodity group and origin-destination area in the system; and 4) the base-year transportation rate savings for each origin-destination commodity movement. These data bases are discussed in the following paragraphs.

b. System Analyzed

The system used for analyzing the benefits and impacts of improvements at the Lower Monongahela projects is the Ohio River navigation system. This system, which was described in some detail in Section 2, is comprised of 2600 miles of navigable water, afforded by 60 lock and dam projects. Figure 9 schematically represents the system that is modeled. All traffic which currently moves or is projected to move on any part of this system has been considered in the Lower Monongahela study. All segments of this system were modeled in detail with the exception of the Kentucky River which has very little commercial traffic. Segments of the inland navigation system outside of the Ohio River System were included in the model, but in a very aggregated manner. This system definition is more than adequate to account for all significant impacts resulting from potential changes at the Lower Monongahela projects.

The location of each lock and dam project to be considered as a constraint node in the analysis must be described in the TCM network. Required input data for each project includes the average lockage time per tow, physical tonnage capacity and a tonnage-delay function. These values were used by the model to calculate the amount of lockage delay time incurred by each tow in moving from the origin port to the destination port. Lock tonnage capacities for each of the 56 projects included in this analysis were obtained from capacity studies using either the LOCALC or WAM models. The tonnage-delay relationships for the system locks is one of the most important model inputs, since changes in lock delay are the primary determinant of future changes in barge shipping costs. A detailed discussion of capacity work done on the Lower Monongahela is presented in Attachment 2.

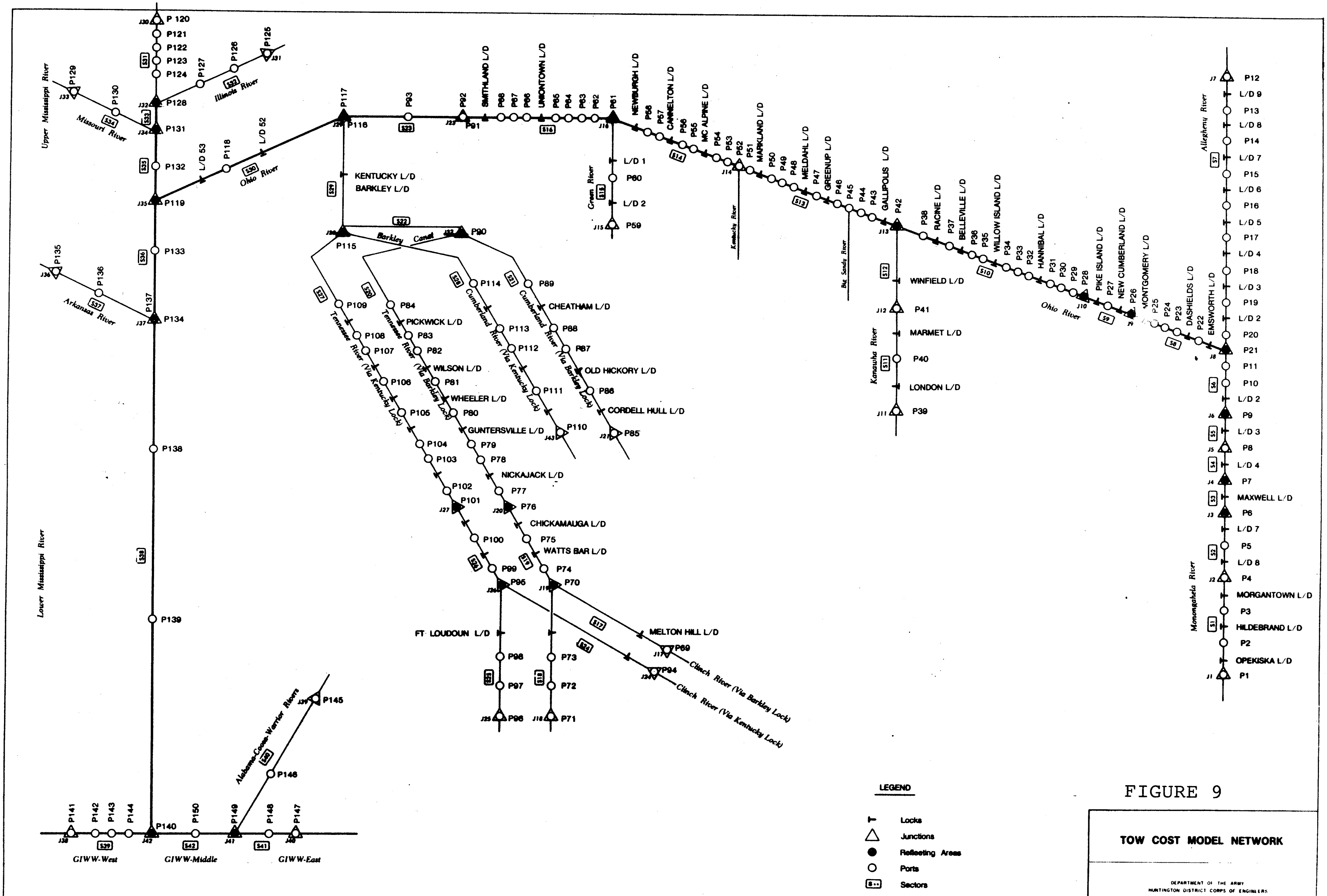


FIGURE 9

TOW COST MODEL NETWORK

DEPARTMENT OF THE ARMY
HUNTINGTON DISTRICT CORPS OF ENGINEERS
HUNTINGTON, W.VA.

c. Towing Equipment Data

These data provide pertinent physical and operating cost information on the towboats and barges to be used by the TCM in computing towing costs. A wide array of barges and towboats are used to transport cargo on the inland waterway system. Since it is not practical to consider all of these variations in a full systems analysis, a set of equipment was selected as being representative of the types encountered on the waterway system, with particular attention to the Ohio River system. Based upon a very detailed analysis of the Corps of Engineer's Performance Monitoring System (PMS) and Waterborne Commerce (WCSC) data bases, nine barge classes and eight towboat classes were selected for use in the Lower Monongahela study. Towboat and barge operating costs were obtained from data collected by the Institute for Water Resources.

d. Commodity Data

The commodity shipment list drives the model in that most model processing is directed toward determining the towing costs for each movement and how much of each movement could move on the waterway system at a savings. Information in the shipment list for each movement includes the origin port, destination port, commodity group, annual tonnage, and barge type.

The information on base year 1986 tonnage flows by origin and destination port for each commodity group and barge type was developed using the detailed point-to-point shipping records reported in the WCSC data. The shipment lists for all future years were developed using the projected origin-to-destination traffic demands for the ORS discussed earlier in Section 3. Traffic demand forecasts are the amounts of traffic expected to use the navigation system in the absence of navigational constraints, such as congested or odd-sized locks.

e. Transportation Rate Data

The ORS transportation rate matrix contains each waterway movement in the system, the rate charged by waterway carriers, and the rate that would be charged by overland carriers (railroads, trucking firms, and pipeline companies, for example) using alternative routings.

The most recent comprehensive rate survey of ORS waterway traffic was completed in 1984 using 1980 movements and 1982 rates. Charles Donley and Associates (Donley) rated a stratified random sample of 1,695 movements selected from the 1980 waterborne traffic base of 8,934 unique dock-to-dock commodity movements. The October 1982 based rates developed by Donley for the sampled movements were extended to the total population of 1980 movements by using predictive equations based on the rates and key characteristics of the sampled movements.

The results of this rate survey were updated in 1989 to October 1987 price levels. This was accomplished by re-rating a sample of movements selected from the original sample that had been provided to Donley. Tennessee Valley Authority (TVA) rate analysts were contractors for the 1989 study. Most of the rates reported by TVA were not published tariff quotes. TVA relied on surveys and costing models for barge rates. Rail rates were based on tariff research, surveys of shippers, and rail costing models. Where no alternative rail route existed, rates were based on rail movements of comparable distance and like commodity. A total of 701 previously rated movements were re-rated by TVA in this fashion. The observed changes in mode-specific rates between 1982 and 1987 were used to update each of the unsampled movements' 1982 rates in order to arrive at a 1987 rate for the entire population of movements.

4. MODEL CALIBRATION AND VERIFICATION

The TCM is essentially a predictive model requiring calibration tests to show the model's capability of replicating known shipper behavior and system operating characteristics before attempts are made to forecast future behavior and system operating characteristics. A base condition is established for the analysis based on traffic levels, towing characteristics, and system performance characteristics that existed in 1986. Considerable effort is expended in ensuring that the fleet and towing conditions used by the model in costing barge movements replicates actual conditions as nearly as possible. The existing system on the Monongahela River includes the small 360'x 56' locks at L&Ds 7 and 8 and refleeting points in the Maxwell, L&D 3, and L&D 2 pools. A more detailed explanation can be found in the 1986 Tow Cost Model Calibration Report available from the Huntington District's Navigation Planning Center.

Once it was determined that the model replicated 1986 shipping characteristics, it was recalibrated for each future condition (as reflected by differing project capacities and fleet assumptions). For the without project condition, the model was recalibrated to reflect the authorized navigation system which includes, among other projects, the replacement of L&Ds 7 and 8 with 720' x 84' locks. The larger locks were input to the model description, along with expected changes in the vessel fleet that occur due to the replacement of L&Ds 7 and 8. Several refleeting points are also affected. The Maxwell refleeting area is no longer needed once the replacements of L&Ds 7 and 8 are complete. The refleeting point in the L&D 3 pool will be removed and replaced with one in the L&D 4 pool because the future without condition allows for larger tows to use L&D 3. The refleeting point in the L&D 2 pool remains, since it allows tows to add or remove barges for shipments moving off or coming on the Monongahela River System.

The replacement alternatives for L&Ds 3 and 4 generally involve replacing the 720' x 56' main locks with either 720' x 84' or 720' x 110' locks. In addition to providing greater capacity, the alternatives provide for larger tow sizes and the elimination of refleeting requirements. The specific effects depend on the replacement lock size. With the 720' x 84' alternative, the tow size increases to a maximum of six jumbo or nine stumbo barge tows. The transition point between the 84' wide system and the 110' wide system is the L&D 2 pool. Therefore, some refleeting is still necessary in the L&D 2 pool. With the 720' x 110' alternative, the maximum tow size increases to nine jumbo and twelve stumbo barges through L&Ds 3 and 4. This eliminates the need to refleet in the L&D 2 pool but requires refleeting in the L&D 4 pool. The model with each alternative was recalibrated to reflect these changes to the system. A summary of the calibration results is provided in Table 24.

TABLE 24

Model Calibration Lower Monongahela River Projects

	Without Project			84' width			110' width		
Project	Target	Model	% Diff	Target	Model	% Diff	Target	Model	% Diff
				Barges/Tow					
L&D 2	5.4	5.4	0.0	5.2	4.9	-6.1	5.4	5.5	1.9
L&D 3	4.7	4.8	2.1	5.5	5.1	-7.8	6.4	5.5	-14.1
L&D 4	4.7	4.8	2.1	5.5	5.4	-1.9	6.4	6.1	-4.7
				Tons/Tow					
L&D 2	3740	3529	-5.6	4,098	3,925	-4.2	4,209	4,372	3.9
L&D 3	3010	2970	-1.3	3,726	3,581	-3.9	4,495	4,194	-6.7
L&D 4	3010	2825	-6.1	3,726	3,608	-3.2	4,495	4,408	-1.9

5. MODEL OUTPUT

A variety of output reports describing the relevant performance statistics for the entire Ohio River navigation system and each key operating component are provided by the TCM. Detailed data are provided for waterway segments, ports and locks and for individual port-to-port shipments. The primary output for purposes of economic analysis is a detailed listing of all the Ohio River system movements that are included in the equilibrium solution for each plan and condition, and the corresponding waterway rates and rate savings per ton. Information is also provided on the tonnage, ton-miles, and rate savings for the Ohio River System. The exact same listing is provided for the subset of movements that transverse the Lower Monongahela River and each of the Lower Monongahela River projects. Incremental system impacts and benefits can be calculated by comparing these outputs for each plan and condition.

SECTION 6. SELECTION OF WITHOUT PROJECT CONDITION

1. GENERAL

Federal guidelines for water resource planning studies require that study reports explicitly quantify and describe the conditions that are considered most likely to exist in the study area over the period of analysis in the absence of the proposed project or any change in existing law or public policy. This condition is called the "without project" condition and is used as the baseline for measuring the incremental benefits, costs and other effects of alternative plans of improvement. The guidelines also provide general instructions on the types of elements that are suitable for inclusion in the without project condition. On inland navigation studies such as the Lower Monongahela, where Federal projects currently exist, the existing projects can be included as elements of the without project condition if they are economically justified. The guidelines also require that all reasonably expected nonstructural practices for improving project efficiency, within the discretion of the operating agency, be included in the without project condition.

2. TREATMENT OF EXISTING PROJECTS

a. Benefits

The importance of navigation on the Monongahela River is evidenced by its 150 years of continuous operation. The dollar benefits to the national economy of the low cost transportation provided by the Lower Monongahela River projects are estimated at over $250 million annually. These benefits exceed the costs of all plans designed to continue operation of the projects by a significant amount. Therefore, continued operation of the Lower Monongahela projects was assumed as an element of the without project condition.

b. Structural Requirements

Continued operation of the existing projects will require major reconstruction and/or rehabilitation. Specifically, the without project condition will require the reconstruction of the dam at L&D 2 by the year 2002, the reconstruction of both the locks and dam at L&D 3 by the year 2002, the rehabilitation of the locks at L&D 2 by the year 2022, the rehabilitation of the locks at L&D 4 by 2002, and the reconstruction of the locks at L&D 4 by the year 2027. The sequence and duration of each work item was developed by Pittsburgh District's Engineering Division.

c. Maintenance Requirements and Schedule

In addition to major work items, the locks will need to be closed for thirty days once every five years for inspection and minor maintenance. The frequency and duration were based on Ohio River Division district maintenance schedules. Of course, the cycle may vary depending upon available funds and perceived problems, and the duration may vary depending upon river conditions and the nature of any problems that may require repairs. Since the schedule reflects the periodic inspections necessary to ensure the safety and soundness of the projects, it was considered to represent part of the most probable without project condition (for the complete closures schedule at L & D's 2, 3, and 4 see Attachment 3).

3. NONSTRUCTURAL MEASURES TO IMPROVE LOCK EFFICIENCY

a. General

The necessity of improving navigational efficiency is most acute at L&D's 3 and 4. The capacity of L&D 2 greatly exceeds the peak demands forecast for this project (capacity is estimated at 66.2 million tons while traffic forecasts peak at slightly over 45.0 million tons). The situation at L&D's 3 and 4 is considerably different.

Towing operators on the lower Monongahela contend with small lock chambers at L&D 3 and L&D 4, chambers that will be the smallest on the river in the without project condition. Two important assumptions were made which influenced the development and assessment of nonstructural alternatives for these projects. The first assumption was that the approach at L&D 3 would be improved to allow double lockages. Reconstruction of L&D 3 in the without project condition affords ample opportunity to correct the poor approach which has caused the Corps of Engineers to impose a single-cut lockage policy at the lock. The second assumption involves the composition of the future vessel fleet. With the completion of Gray's Landing and Pt. Marion the Monongahela becomes a bigger system, one which favors stumbo barges over regular barges. Fleet assumptions recognize this, and the general trend to larger vessels and tows, by altering the existing fleet to reflect a future fleet composed of more stumbo and jumbo barges, and fewer regular barges, than are in the current fleet (see Attachment 2 for a discussion of the development of future fleets).

A number of nonstructural measures that offer the possibility of improving lock operating efficiency, and are within the purview of the Corps of Engineers, were considered for inclusion in the without project condition. Three base nonstructural alternatives were evaluated: (1) the use of towhaulage at L&D 3 to allow double-cut tows and decrease lock processing times; (2) the use of switchboats to decrease lock processing times; and (3) the initiation of a lockage policy that would restrict all tows to sizes capable of being processed in single cuts at both L&D 3 and L&D 4. In addition, combinations of these alternatives were considered as a means of optimizing system performance over time.

b. Towhaulage Plan

Towhaulage systems enable tows too large to single cut through the main chamber to complete multiple-cut operations. Towhaulage is currently available at L&D's 2 and 4, but poor approach conditions at L&D 3 prevent tows with dimensions larger than those of the main chamber from using this lock. However, in the without project condition L&D 3 will be reconstructed, offering the opportunity for improving the approach and installing towhaulage equipment, thereby allowing tows requiring double lockages to use this project. By providing towhaulage units at L&D 3, tow operators would be able to reduce the time it takes their large tows to transit both the lock and the lower Monongahela.

c. Switchboat Plans

Initially, two switchboat plans were examined for possible inclusion in the without project condition. The first plan involved the use of two helperboats each at L&D 3 and L&D 4 to assist in pulling cuts out of the lock chambers. Because the first plan offered the same time savings as the towhaulage plan, but at a much greater cost than towhaulage, it was dropped from further consideration. The second plan involved the use of switchboats to power cuts through the locks and move them to remote fleeting areas. This plan would require three towboats each at L&D 3 and L&D 4. It is estimated that this switchboat plan, when compared with the towhaulage plan, would reduce the average lockage time by 5.9 minutes per tow at L&D 3 and 4.3 minutes per tow at L&D 4, and increase the capacities of L&D 3 by 6 percent and of L&D 4 by 11 percent (see Table 25). As with the towhaulage plan, instituting a switchboat plan at L&D 3 implies approach conditions have been improved to allow large tows to safely approach the lock.

TABLE 25
Capacity of Alternative Without Project Conditions
(millions of tons)

Alternative	L&D 3	L&D 4
Towhaulage	40.9	38.4
Switchboat Plan	43.4	42.6
Single Lockage Policy	43.4	42.6

d. Single Lockage Policy

The lockage policy examined would restrict tows transiting L&D 3 and L&D 4 to single-cuts. In terms of processing times and lock capacities this policy has the identical effect as that offered by switchboats.

e. Combination Alternatives

Alternatives combining towhaulage with switchboats and towhaulage with a single lockage policy were also considered. Using combinations allowed capacity additions to be phased-in as warranted by traffic conditions.

4. ASSESSMENT OF NONSTRUCTURAL ALTERNATIVES

a. General

The following compares the performance of the nonstructural alternatives for improving navigation efficiencies in the without project condition. The best navigation plan is then selected based on its ability to maximize system benefits in the without condition. Replacement of the existing structures and improvement of the approaches at L&D 3 and the existing structures at L&D 4 as scheduled by the Pittsburgh District are assumed to be part of the without project condition.

Periodic maintenance and rehabilitation of the locks cause traffic congestion at different points during the without project condition (see Attachment 3 for this schedule). In modeling these closure events, switchboats were found to be economically justified. As a result, switchboats were included when estimating system benefits during periods of closure in the without project condition.

b. Traffic

As indicated in Table 26, the towhaulage system performs as well as the other two alternatives through 2020, but lags well behind for the remainder of the fifty years. The switchboat plan and the single lockage policy demonstrate a superior ability to move traffic, especially as traffic delays become a serious problem at the Lower Monongahela projects.

c. Delays

All of the alternatives handle traffic with modest amounts of delay through 2020 (See Table 27). Congestion becomes a serious problem in the 2030 time frame, especially at L&D 3 because of its higher traffic levels. Switchboats and the single lockage policy do comparable jobs of handling traffic both at L&D 3 and L&D 4. Towhaulage is much less successful, especially in 2040 and 2050, and especially at L&D 4.

TABLE 26
Without Project Alternatives Accommodated Traffic
(Millions of Tons)

Project\Year	Towhaulage	Switchboat Plan	Single Lockage
L&D 2			
2000	25.9	25.9	25.9
2010	25.9	25.9	25.9
2020	31.2	31.2	31.2
2030	34.7	37.1	37.1
2040	37.2	36.7	37.2
2050	37.7	41.7	41.6
L&D 3			
2000	28.2	28.2	28.2
2010	32.5	32.5	32.5
2020	34.8	34.8	34.8
2030	38.8	41.3	41.3
2040	38.8	41.6	41.0
2050	38.7	40.3	40.3
L&D 4			
2000	24.6	24.6	24.6
2010	28.7	28.7	28.7
2020	30.9	30.9	30.9
2030	35.0	37.5	37.5
2040	35.0	37.9	37.3
2050	35.1	37.5	37.4

d. Benefits and Costs

Table 28 displays and compares the benefit streams for the three nonstructural plans discussed above, and for two plans which utilize a combination of plans. Towhaulage proved the best alternative in the early years due to its low cost of implementation and ability to adequately handle the relatively modest levels of traffic demand forecast through 2020. Both the switchboat and the single-lockage policy plans are successful at handling periods of high delay, but implementation costs make them less attractive than towhaulage during the without project condition when delays and traffic are low. Analysis of the combination towhaulage and switchboat plan indicated that switchboats were economically justified by the year 2027. Analysis of the combination towhaulage and single lockage plan indicated that institution of a single lockage policy was economically justified roughly ten years earlier, in 2016. This combination, towhaulage through 2015 followed by a single lockage policy, yielded the highest system benefits in the without condition.

TABLE 27
Without Project Alternatives Delays
(Hours per Tow)

Project\Year	Towhaulage	Switchboat Plan	Single Lockage
L&D 2			
2000	0.83	0.83	0.88
2010	0.97	0.97	0.99
2020	1.04	1.04	1.01
2030	1.17	1.26	1.04
2040	1.27	1.25	1.04
2050	1.28	1.44	1.29
L&D 3			
2000	1.27	1.07	1.04
2010	2.41	1.84	1.87
2020	4.18	2.55	2.48
2030	34.21	36.04	36.92
2040	33.63	41.93	32.53
2050	32.28	16.64	16.09
L&D 4			
2000	1.57	1.37	1.36
2010	1.90	1.68	1.72
2020	2.70	1.84	1.86
2030	25.94	10.66	10.36
2040	27.20	13.47	9.45
2050	28.55	10.64	10.17

TABLE 28
Lower Monongahela Locks and Dam
Comparison of Alternative Without Project Condition System Savings
(Millions of 1991 Dollars, 8-3/4% Discount Rate)

Year	Tow Haulage	Switchboat Plan (3HB/Lock) 1/	Single Lockage Policy	Combination Tow Haulage & Switchboat 2/	Combination Tow Haulage & Single Lockage 3/
2000	$3,185.12	$3,185.70	$3,180.80	$3,185.12	$3,185.12
2010	$3,524.07	$3,525.44	$3,519.16	$3,524.07	$3,524.07
2020	$3,770.77	$3,775.40	$3,774.29	$3,770.77	$3,774.29
2030	$3,993.26	$4,016.44	$4,000.50	$4,016.44	$4,000.50
2040	$4,164.12	$4,180.44	$4,204.33	$4,180.44	$4,204.33
2050	$4,120.66	$4,177.75	$4,192.21	$4,177.75	$4,192.21
Annual Benefits	$3,549.26	$3,553.10	$3,551.03	$3,551.68	$3,553.13
Annual Implementation Costs 4/	$0.16	$6.41	$0.00	$1.02	$0.12
Benefits Less Annual Implementation Costs	$3,549.10	$3,546.69	$3,551.03	$3,550.65	$3,553.01

1/ Switchboats are used to power cuts through the chambers and remove cuts to remote fleeting areas.

2/ Towhaulage units used through 2026, switchboats thereafter.

3/ Towhaulage units used through 2015, single lockage policy thereafter.

4/ Implementation costs are not total system costs, but incremental project costs for implementing the non-structural measures at L&Ds 3 and 4.

e. Conclusion

The alternative selected as representing the most probable without project condition involved a combination of the plans described in the previous subsections. Analysis of the various alternatives indicated that the best plan is to use towhaulage at both L&D 3 and L&D 4 through the year 2015, and from thereafter restrict tows at these two locks to single lockages. Implementation of the without project plan is dependent on the assumption that required structural work at L&D 3 will address the correct problems.

5. OTHER ASSUMPTIONS

Implicit in the foregoing analysis are other assumptions that should be stated explicitly. These assumptions are:

(i) Normal operation and maintenance will be performed on the waterway system over the period of analysis.

(ii) Alternative modes have sufficient capacity to move traffic that cannot be moved on the waterway system at competitive rates.

(iii) The projects under construction at Gallipolis, L&D 7 (Gray's Landing), L&D 8 (Point Marion), and Winfield are completed as scheduled. Also, the authorized project at Olmsted is constructed.

(iv) The fuel tax is $0.20 per gallon in the year 2000 as currently legislated.

6. IMPLICATIONS OF THE WITHOUT PROJECT CONDITION

The most probable without project condition implies only a partial solution to the navigation problems in the area - the correction of the deteriorated condition of the projects. However, the traffic problems as represented by high delays are expected to worsen over time as traffic approaches the capacity of the projects. As shown in Table 29, delays are expected to be minimal through the year 2020. Congestion problems are most severe in 2030 when the combined delays at L&D 3 and L&D 4 reach an average of 47 hours per tow. Because of high delays, some traffic movements divert off the navigation system. Diverted movements total 4.8 million tons in 2040 and 10.7 million tons in 2050. Clearly, the problems currently experienced in navigating the Lower Monongahela will become more severe under the without project condition.

TABLE 29
Performance of L&D 2, L&D 3, and L&D 4 in the Without Project Condition

Project\Year	Tons in Millions Tonnage Demand	Tonnage Moved	Tonnage Diverted	Delay (Hours per Tow)
L&D 2				
2000	25.9	25.9	0.0	0.83
2010	29.6	29.6	0.0	0.97
2020	31.2	31.2	0.0	1.01
2030	37.1	37.1	0.0	1.04
2040	40.8	37.2	3.6	1.04
2050	45.2	41.6	3.6	1.29
L&D 3				
2000	28.2	28.2	0.0	1.27
2010	32.5	32.5	0.0	2.41
2020	34.8	34.8	0.0	2.48
2030	41.3	41.3	0.0	36.92
2040	45.8	41.0	4.8	32.53
2050	51.0	40.3	10.7	16.09
L&D 4				
2000	24.6	24.6	0.0	1.57
2010	28.7	28.7	0.0	1.90
2020	30.9	30.9	0.0	1.86
2030	37.5	37.5	0.0	10.36
2040	42.0	37.3	4.7	9.45
2050	47.4	37.4	10.0	10.17

SECTION 7. PRELIMINARY EVALUATION OF ALTERNATIVES

1. ALTERNATIVES EVALUATED

The first step in the formulation process involved the identification of the best overall concept plan for modernizing the lower Monongahela River. A total of seven alternatives were evaluated involving the provision of either two or three projects at different site locations. Three of the plans involved construction and/or modification of three projects (referred to as three-for-three plans) and the other four involved the construction and/or modification of two projects (referred to two-for-three plans). Table 30 lists the basic location features of the seven alternatives. A detailed description of the plans and the analysis is provided in the PLAN FORMULATION APPENDIX.

TABLE 30
Number and Location of Projects
Under Alternative Plans

Plan	Project Location (Mile Point) L&D 2	L&D 3	L&D 4
Without Condition	11.2	23.8	41.5
Plan 1	11.2	----	41.5
Plan 2	11.2	22.2	41.5
Plan 3	11.2	23.8	41.5
Plan 4	11.2	24.6	41.5
Plan 5	----	22.2	41.5
Plan 6	11.2	34.0	----
Plan 7	11.2	34.0	----

2. SCREENING OF THE LOCATION PLANS

The first level of screening involved an investigation of the possibility of relocating and possibly eliminating one project altogether. The benefits and costs of these alternative plans were all evaluated on the basis of replacement with twin 720' x 84' locks. The estimated incremental system navigation benefits of these plans range from $32.7 to $39.2 million (Table 31). The benefits are $2-7 million higher for the two-for-three plans (#1, 5, 6, 7) than the three-for-three plans (#2, 3, 4) because the two for three plans eliminate the time and cost of a lockage cycle. The highest benefits are for plan 5 which involves the elimination of L&D 2, and therefore the need to lock through its small auxiliary when the main chamber is closed. Plans 6 and 7 provide slightly higher benefits than Plan 1 because of minor differences in processing times. Plans 2, 3, and 4 are all three-for-three plans. Plans 2 and 4 provide the same level of navigation benefits and slightly higher benefits than Plan 3 because construction at these totally new sites causes less interference with navigation.

TABLE 31
Annual Navigation Benefits of Seven Location Plans
(Thousands of $; Oct. 91 Prices; 8-3/4 %)

Plan	System	Increment Over the Without	Lower Monongahela
Without Condition	3,544,946	0	265,751
Plan 1	3,581,663	36,717	302,468
Plan 2	3,579,962	35,016	300,767
Plan 3	3,577,644	32,678	298,449
Plan 4	3,579,962	35,016	300,767
Plan 5	3,584,107	39,161	304,912
Plan 6	3,581,696	36,750	302,501
Plan 7	3,581,696	36,750	302,501

3. SELECTION OF PLANS FOR DETAILED ANALYSIS

Based on a comparison of the benefits and costs of twin 720'x84' locks at each of these sites, two plans were carried forward for further analysis (see the discussions in Section 5 of the MAIN REPORT and in the PLAN FORMULATION APPENDIX). Plan 1 was determined to be the best two-for-three plan and Plan 4 the best three-for-three plan.

With the completion of this screening and the selection of the best location plans, the analysis moved to selection of the best lock size combinations for these sites. The relative navigation impacts of the different lock sizes are discussed and analyzed in Section 8 and the benefits for the final array of plans are presented in Section 9.

4. NONSTRUCTURAL MEASURES

In addition to the nonstructural measures that were evaluated for improving the economic efficiency of the existing Lower Monongahela projects, consideration also was given to a nonstructural alternative to lock replacement. This alternative calls for the management of traffic demand at both L&Ds 3 and 4 through the use of a congestion or lockage fee which is designed to influence the shipper with very marginal savings for barge shipment to shift their traffic to an alternate overland mode, thereby reducing the amount of lock congestion. Thus, it serves as a device for rationing lock use to the movements with the highest marginal savings. The result would be an increase in total rate savings net of delay costs for the shippers which would continue to use the waterway. However, the fee would not address the need to accommodate continued future traffic growth on the Monongahela River. In fact, it would reduce without project traffic levels.

It is estimated that implementation of this nonstructural measure would result in average annual benefits of $11.2 million. Assuming zero costs for imposition and management of the fee, which is obviously unrealistic, the net benefits would be less than any of the final alternative plans. Also, the fee would result in large volumes of future traffic being diverted to other modes of transportation whose capability to handle this additional traffic has not been determined. Compared to the final structural alternatives, it is estimated that the fee would result in waterway traffic diversion of over 3.7 million tons annually beginning in 2030 and increasing to about 5.0 million tons annually by the end of the planning period. Because of these concerns, and the fact that net benefits would be less than the final structural alternatives, the congestion fee was eliminated from further consideration.

SECTION 8. NAVIGATION IMPACTS OF ALTERNATIVE LOCK SIZES

1. INTRODUCTION

This section summarizes the results of the lock size analysis that was performed for Plan 1 (the best two for three plan) and Plan 4 (the best three for three plan). The performance of the various lock sizes is examined in terms of project traffic and delays, and system traffic and rate savings. These performance indicators are displayed only for Plan 4. Project traffic and delays for Plan 1 and Plan 4 are the same, except that in Plan 1 there is no L&D 3. System traffic levels differ only slightly. The navigation benefits for Plan 1 and Plan 4 are presented in Section 9.

The navigation impacts can be categorized as local (project) impacts and system impacts. The distinction illustrates the rationale for doing systems analysis: the positive impacts at the improved projects are offset by negative impacts at other projects. The positive impacts at the improved projects are in the form of reduced delays and increased traffic levels. The negative impacts at other projects are the higher delays that occur if the improvement increases system traffic levels. The net effects in terms of system transportation savings are the benefits attributable to the project.

The navigation impacts presented in this section assume the operation of three projects (as opposed to a two-for-three plan) with improvements only at L&Ds 3 and 4. Results are provided for the six years modeled in detail and do not include adjustments made for closures. This feature of the with (and the without) project condition will be introduced into the analysis in Section 9.

2. ALTERNATIVES EVALUATED

The alternatives evaluated focus solely on the need for larger locks at L&D's 3 and 4. The main chamber at L&D 2 is larger than those at upstream and downstream projects, and is not expected to cause problems to navigation any time in the foreseeable future. While the auxiliary chamber is small (360' x 56'), it is in reasonably good condition. Therefore, improvements at L&D 2 were not considered as part of this analysis. The alternative lock sizes evaluated for L&D's 3 and 4 were selected based on the size of locks at upstream and downstream projects. This led to the consideration of main chambers measuring 720' x 84' and 720' x 110'. A number of auxiliary lock sizes were considered ranging from no auxiliary at all to locks equal in size to the main chambers (see Table 32).

TABLE 32
Lock Size Alternatives

Modeled in Detail:

1. Single 720' x 84'
2. 720' x 84' and 360' x 56'
3. 720' x 84' and 410' x 84'
4. Twin 720' x' 84'
5. Single 720' x 110'
6. 720' x 110' and 360' x 56'
7. 720' x 110' and 410' x 84'
8. 720' x 110' and 410' x 110'
9. Twin 720' x 110'

Others:

10. 720' x 84' and 410' x 110'
11. 720' x 110' and 720' x 84'
12. 720' x 110' and 720' x 56'

3. PROJECT IMPACTS

a. Traffic.

The amounts of traffic that system studies indicate would move through the Lower Monongahela projects under normal conditions for each alternative lock size are shown in Table 33. Without-project traffic is included for comparison purposes. The table shows that the traffic levels for each lock size alternative are about the same as with the without-project condition through the year 2030. After that, the alternatives would allow about 3 to 10 million tons of additional traffic to move, with the amount depending on the year and the project. All lock size combinations would accommodate all of the projected traffic demands with the exception of the single 720' x 84' plan in 2050.

b. Tow Delays.

The average delay per tow for each of the alternatives is listed in Table 34. Again, this does not include increases in delays during lock closures. During normal operations, all of the alternatives are of nearly equal effectiveness in reducing tow delays, with the exception of the single 720' x 84'.

TABLE 33

Lower Monongahela River Projects
Traffic Accommodated by Alternative Lock Size
(Tons in Millions)

Year/ Project	Projected Traffic Demand	Without Project Condition	Single 720x84	720x84 360x56	720x84 410x84	Twin 720x84	Single 720x110	720x110 360x56	720x110 410x84	720x110 410x110	720x110 720x110
2000											
L&D 2	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
L&D 3	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
L&D 4	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6
2010											
L&D 2	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
L&D 3	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5
L&D 4	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7
2020											
L&D 2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2
L&D 3	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8
L&D 4	30.9	30.9	30.9	30.9	30.9	30.9	30.9	30.9	30.9	30.9	30.9
2030											
L&D 2	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1
L&D 3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3	41.3
L&D 4	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
2040											
L&D 2	40.8	37.2	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8	40.8
L&D 3	45.8	41.0	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8
L&D 4	42.0	37.3	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0
2050											
L&D 2	45.2	41.6	42.7	45.2	45.2	45.2	45.2	45.2	45.2	45.2	45.2
L&D 3	51.0	40.2	48.4	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0
L&D 4	47.4	37.4	44.8	47.4	47.4	47.4	47.4	47.4	47.4	47.4	47.4

NOTE: Alternatives involve replacing L&D 3 and L&D 4 with the same size and number of locks. None of the alternatives involve changing the size or number of locks at L&D 2.

TABLE 34

Lower Monongahela River Projects
Tow Delays by Lock Size
(Hours Per Tow)

Year/ Project	Without Project Condition	Single 720x84	720x84 360x56	720x84 410x84	Twin 720x84	Single 720x110	720x110 360x56	720x110 410x84	720x110 410x110	720x110 720x110
2000										
L&D 2	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8
L&D 3	1.3	0.6	0.6	0.6	0.3	0.5	0.5	0.4	0.3	0.2
L&D 4	1.6	0.9	0.7	0.4	0.5	0.5	0.5	0.5	0.4	0.3
2010										
L&D 2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
L&D 3	2.4	1.1	0.7	0.6	0.4	0.5	0.6	0.5	0.4	0.2
L&D 4	1.9	1.1	1.0	1.0	0.4	0.7	0.7	0.6	0.5	0.4
2020										
L&D 2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
L&D 3	2.5	1.4	0.7	0.7	0.4	0.6	0.6	0.5	0.5	0.2
L&D 4	1.9	1.3	1.2	1.1	0.5	0.8	0.8	0.7	0.6	0.4
2030										
L&D 2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
L&D 3	36.9	2.3	1.0	0.8	0.5	1.0	0.7	0.6	0.6	0.3
L&D 4	10.4	2.7	1.5	1.4	0.6	1.0	1.1	1.0	0.9	0.4
2040										
L&D 2	1.0	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1
L&D 3	32.5	4.8	1.4	1.0	0.6	1.4	0.8	0.7	0.6	0.4
L&D 4	9.4	3.8	1.8	1.7	0.8	1.1	1.3	1.2	1.0	0.5
2050										
L&D 2	1.3	1.3	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4
L&D 3	16.1	10.7	2.3	1.6	0.6	1.6	1.0	0.8	0.7	0.5
L&D 4	10.2	8.9	2.2	1.9	1.0	1.4	1.5	1.4	1.2	0.6

4. SYSTEM IMPACTS

The systemic impacts of the alternative lock sizes arise from two factors. First, the additional traffic that would move on the waterway system as a result of the reduction in tow processing times at the Lower Monongahela projects would cause an increase in lock delays at other navigation locks along the shipping route. This would reduce the waterway rate savings for all affected traffic and could cause some non-Lower Monongahela movements to become uneconomic for barge shipment. The magnitude of these effects is a direct function of the amount of additional Lower Monongahela traffic accommodated by each alternative and the level of system congestion. Second, all of the lock size alternatives are expected to result in larger tows. These fleet changes would result in an increase in tow loadings and a reduction in the number of tow trips on the Lower Monongahela River and possibly other segments of the system. The reduction in tow trips would, in turn, tend to reduce tow delays on the rest of the navigation system. The combined effect of these alternatives can cause the incremental system benefits for the alternative plans to be more or less than the benefits measured solely at the project, depending upon which factor is more dominant in the specific time period being evaluated. However, over the 50-year period of analysis, the incremental system benefits would be expected to be less than the localized project benefits.

a. Traffic

System traffic levels under alternative lock sizes are provided in Table 35. The alternatives have no effect on system traffic levels until the year 2040 and 2050 when system traffic levels increase by amounts that range from 5 million to 8 million tons.

b. System Savings

Transportation savings are computed as the cumulative difference in transportation costs between the water routing and least-costly overland routing. Transportation savings are higher for the alternatives than for the without condition because they provide for more efficient navigation operations. The estimated transportation savings for the without condition and the incremental system savings attributable to each alternative are listed in Table 36.

5. SUMMARY

These system runs form the basis for the lock size optimization analysis discussed in the next section. Optimization will consider not only periods of normal operation, but performance of the various lock size combinations during periods of lock closure for periodic maintenance and rehabilitation for both the best two-for-three and three-for-three plans.

TABLE 35

Lower Monongahela River Projects
System Traffic by Lock Size
(Millions of Tons)

Year	System Traffic Demand	Without Projects Condition	Single 720x84	720x84 360x56	720x84 410x84	Twin 720x84	Single 720x110	720x110 360x56	720x110 410x84	720x110 410x110	720x110 720x110
2000	288.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4
2010	321.4	307.9	307.9	307.9	307.9	307.9	307.9	307.9	307.9	307.9	307.9
2020	347.6	329.7	329.7	329.7	329.7	329.7	329.7	329.7	329.7	329.7	329.7
2030	400.0	376.1	376.1	376.1	376.1	376.1	376.1	376.1	376.1	376.0	376.0
2040	447.8	410.5	415.3	415.3	415.3	415.3	415.3	415.3	415.3	415.3	415.3
2050	501.2	439.9	448.1	448.4	448.4	448.4	448.4	448.4	448.4	448.4	448.4

Note: Does not include intra-pool traffic.

TABLE 36

Lower Monongahela River Projects
System Benefits by Lock Size
(Millions of 1991 Dollars)

		Incremental System Benefits								
Year	Without Projects Condition	Single 720x84	720x84 360x56	720x84 410x84	Twin 720x84	Single 720x110	720x110 360x56	720x110 410x84	720x110 410x110	720x110 720x110
2000	3185.1	4.4	4.3	4.0	5.5	5.7	5.8	5.7	6.0	6.3
2010	3524.1	6.3	7.0	6.4	8.4	8.8	8.7	8.7	9.1	9.6
2020	3774.3	12.7	14.1	13.4	15.7	16.0	15.9	15.9	16.3	17.0
2030	4000.5	114.9	119.5	119.0	122.1	122.1	122.6	122.6	158.1	159.2
2040	4204.3	99.9	111.6	111.8	115.6	115.7	116.7	116.7	119.2	119.0
2050	4192.2	30.8	30.8	39.8	45.6	48.5	49.6	41.8	50.7	52.4

SECTION 9. NAVIGATION BENEFITS FOR FINAL ALTERNATIVES

1. INTRODUCTION

Benefits attributable to each of the final set of alternative plans for the improvement of the Lower Monongahela River navigation subsystem are summarized in this section. Navigation benefits for each alternative represent the reduction in transportation costs as compared to the without project condition. The reduction in costs can also be viewed as an increase in the transportation savings for using the navigation system as compared with the overland alternatives. While they are sometimes displayed as Lower Monongahela project benefits, the navigation benefits were based on system traffic performance and not solely on the performance of the Lower Monongahela River projects. The Lower Monongahela project benefits were computed by adding the increment in system benefits to the without project condition benefits provided by the traffic that passes through the Lower Monongahela projects. This was done to facilitate the comparison of the benefits attributable to each project with the costs of constructing the project.

Navigation benefits displayed in this section reflect the closure schedules assumed for both the without and the with project conditions. The with project schedule assumes a 30 day closure of each chamber once every five years. Benefits were annualized using standard discounting techniques, a 50-year project life, and a discount rate of 8-3/4 percent. The first year the projects are expected to be complete and providing benefits is 2002. Therefore, the year 2002 was chosen as the base year of the project life. All benefits are displayed at October 1991 price levels.

2. LOCK SIZE OPTIMIZATION

a. Lock Size Combinations

The navigation benefits of each lock size alternative for Plan 1 and Plan 4 are provided in Table 37. Elimination of L&D 3, the major feature of Plan 1, results in a reduction in trip time for each shipment in terms of both delay time and processing time avoided. As a result, system benefits for Plan 1 are higher than those for Plan 4 when comparing identical lock sizes across plans.

Benefits for the alternate lock size combinations range from $26.0 to $38.0 million. Combinations with a main chamber of 720' x 110' provide $1.3 to $3.3 million more in benefits than the 720' x 84' combinations. While the larger tows that a 110' wide chamber would accommodate are more efficient, the construction of 720' x 110' combinations extends the capability of operators to use 110' wide tows on the Monongahela River by only another 25 to 40 miles.

The increment of benefits attributable to having various size auxiliary locks range from $0.9 to $7.2 million for the 720' x 84' main-lock alternatives and $0.4 to $5.4 million for the 720' x 110' main-lock alternatives. These benefits largely represent the reduction in lockage and delay times during closures of the main chamber.

TABLE 37
Navigation Benefits of Lock Size Alternatives
(Thousand $; Oct. '91 Prices; 8-3/4%)

Lock Size	Plan 1 (Two for Three) System	Plan 1 (Two for Three) Increment	Plan 2 (Three for Three) System	Plan 2 (Three for Three) Increment
W/O Project	3,544,946	0	3,544,946	0
Single 720' x 84'	3,578,600	33,654	3,572,790	27,844
720' x 84' and 360' x 56'	3,579,461	34,515	3,575,272	30,326
720' x 84' and 410' x 84'	3,580,465	35,519	3,576,875	31,929
Twin 720' x 84'	3,581,663	36,717	3,579,962	35,016
Single 720' x 110'	3,580,562	35,617	3,576,135	31,189
720' x 110' and 360' x 56'	3,580,952	36,006	3,577,265	32,319
720' x 110' and 410' x 84'	3,581,723	36,778	3,578,717	33,771
720' x 110' and 410' x 110'	3,582,494	37,548	3,580,576	35,631
Twin 720' x 110'	3,582,959	38,013	3,581,521	36,575
720' x 84' and 410' x 110'	3,581,188	36,242	3,577,791	32,845
410' x 84' and 720' x 110'	3,574,297	29,352	3,570,907	25,962
720' x 110' and 720' x 84'	3,582,461	37,515	3,579,063	34,118
720' x 84' and 720' x 110'	3,582,461	37,515	3,579,063	34,118
720' x 56' and 720' x 110'	3,581,451	36,505	3,578,054	33,108

The table also includes variations in the lock size alternatives with regard to the sequence of lock construction. For example, the 720' x 110' with a 410' x 84' auxiliary is listed twice but with different benefits. The difference reflects the fact that in the first instance the 720' x 110' is constructed first, so that upon completion it can be used while the second chamber is being constructed. In the second instance, the 410' x 84' is constructed first, and it must process all traffic during construction of the second lock. The traffic delays during the 1-3/4 years of Phase Two construction are significantly higher with the 410' x 84' processing all traffic than with the 720' x 110'. The higher delays translate into $6.1 million less in system benefits. When the same lock sizes appear in the table, the sequence of construction is indicated by the order in which the lock sizes are listed.

b. Optimum Lock Size

Twin 720'x 110' locks would provide the maximum total navigation benefits for both Plan 1 and Plan 4. The benefits and costs of the lock size alternatives for the two plans are summarized in the PLAN FORMULATION APPENDIX. Results of this comparison indicate that net benefits are greatest for both Plan 1 and Plan 4 with twin 720'x 84' locks, making this combination the optimum lock size. This lock size combination is included as a feature of the final alternative plans.

3. TIMING OF L&D 4 REPLACEMENT

As discussed in Section 6, and in detail in the PLAN FORMULATION APPENDIX, the without project condition reflects replacement of the locks at L&D 3 in 2002. However, the locks at L&D 4 are not scheduled for replacement until 2027 in the without condition. In the with condition both Plan 1 (the two-for-three plan) and Plan 4 (the three-for-three plan) propose the replacement of L&D 4 in 2002. Timing of the replacement proposed in Plan 1 is based on the need to adjust the sill depth of the locks to accommodate the change in pool elevation caused by the elimination of L&D 3. The proposed 2002 replacement of L&D 4 in Plan 4 is based on the efficiency of providing a completely modernized system comparable to the other improvement plans. Because the net benefits of Plan 1 and Plan 4 are relatively close, it was decided to evaluate the impact on benefits of deferring construction of L&D 4 until 2027. Navigation benefits associated with Plan 4 and Plan 4 with L&D 4 construction deferred are displayed in Table 38.

TABLE 38
Annual Navigation Benefits for Plan 4
(Thousand $; Oct. '91 Prices; 8-3/4%)

Plan	System Total	System Increment	Lower Monongahela
Plan 4	3,579,962	35,016	300,767
Plan 4 Deferred	3,568,227	23,281	289,032

Deferral reduces the benefits of Plan 4 because small locks constrain traffic for an additional 25 years. However, because deferring construction reduces the economic costs of the project to a greater degree than it reduces benefits, net benefits for Plan 4 with the deferral are slightly greater than Plan 4 with the replacement of L&D 4 in the year 2002. Therefore, Plan 4 Deferred was included in the final array of plans (see the PLAN FORMULATION APPENDIX for a complete discussion).

4. NAVIGATION BENEFITS

The navigation benefits attributable to each of the alternative plans represent the incremental increase in total system rate savings over the without project condition. A summary and breakdown of these benefits by cost-reduction for without project traffic, fleet efficiency benefits for all traffic, and shift-of-mode for the additional traffic accommodated by each alternative is presented in Table 39. The incremental benefits for each decadal point over the period of analysis are converted to average annual benefits using standard discounting techniques. A 50 year project life from 2002 through 2051 and an interest rate of 8-3/4 percent were used in calculating average annual benefits. The time phasing of navigation benefits for each of the alternative plans over the period of analysis and the corresponding average annual benefits are presented in Table 40.

TABLE 39
Summary of Navigation Benefits for the Final Alternative Plans
(Thousands of October 1991 Dollars)

Benefit Category	PLAN 1 (2 for 3) Replacement)	PLAN 4 (3 for 3) Replacement)	PLAN 4 Deferred (Replace L&D 4 in 2027)
Cost Reduction			
Normal Operation	$17,579	$15,975	$14,657
Periodic Closure	4,073	3,975	1,772
Major Closure	3,106	3,106	0
Other 1/	5,457	5,457	3,343
Subtotal	$30,215	$28,513	$19,772
Fleet Efficiency	6,564	6,564	3,569
Shift of Mode	(61)	(61)	(61)
Total	$36,718	$35,016	$23,280

1/ In the without project condition there are significant closures related to the reconstruction of the existing locks. Most of the delay costs associated with these closures would be avoided with the final plans.

TABLE 40

TIME PHASING OF BENEFITS BY TYPE FOR FINAL ALTERNATIVE PLANS

(Thousands of Oct. 1991 Dollars)

Alternative Plan	2000	2010	2020	2030	2040	2050	Ave. Annual Benefits Normal Operations	Ave. Annual Benefits With Closures
PLAN 1 (2 for 3)								
Cost Reduction	$1,350	$11,606	$5,857	$109,639	$99,461	$64,889	$17,579	$30,215
Fleet Efficiency	4,118	4,501	9,593	14,755	15,049	15,706	6,564	6,564
Shift of Mode	0	0	0	0	7,056	(25,942)	(61)	(61)
PLAN 4 (3 for 3)								
Cost Reduction	$1,350	$3,913	$4,724	$107,322	$93,467	$55,871	$15,975	$28,513
Fleet Efficiency	4,118	4,501	9,593	14,755	15,049	15,706	6,564	6,564
Shift of Mode	0	0	0	0	7,056	(25,942)	(61)	(61)
PLAN 4 Deferred								
Cost Reduction	$ 1,073	$2,883	$2,258	$107,322	$96,772	$61,752	$14,657	$19,772
Fleet Efficiency	3,273	4,979	5,231	14,755	15,049	15,706	3,569	3,569
Shift of Mode	0	0	0	0	7,056	(25,942)	(61)	(61)

SECTION 10. SENSITIVITY ANALYSIS

1. GENERAL

The alternative plans for improving the existing Federal projects on the Lower Monongahela have been evaluated using what was judged to be the most probable future navigation conditions both with and without the alternatives. In defining these conditions, certain key assumptions and predictions had to be made regarding the future. Since future conditions cannot be predicted with certainty, several tests were performed to describe the sensitivity of the plan selection to changes in key formulation variables. This section of the report identifies the key areas of uncertainty and describes the sensitivity of plan selection to alternative forecasts of the future.

2. ALTERNATIVE TRAFFIC PROJECTIONS

One of the major factors affecting the need for improvements at the Lower Monongahela projects, particularly L&Ds 3 and 4, and also one of the major areas of uncertainty, is the forecast of future traffic demands. The already mature regional economy and its water-related industries kept growth moderate through the 1960's and 1970's. Both the economy and these industries underwent a restructuring away from a base dependent on the local steel industry toward a more service-oriented base. River traffic declined. However, this restructuring created new opportunities for water-related industries forced to seek new markets. Traffic demands on the Lower Monongahela are projected to grow at a modest average annual rate of 1.0 percent in response to new initiatives on the part of regional industry, particularly coal and electric utilities.

Other traffic growth rates, either higher or lower, are possible. In order to show the sensitivity of the project to alternative traffic demand forecasts, the benefits for the alternative plans were re-evaluated using traffic demands 15.0 percent higher and 15.0 percent lower than the most probable forecast.

As expected, the analysis shows that the benefits for the alternative plans are highly sensitive to the level of the future traffic demands. As shown in Table 41, the navigation benefits for all of the alternatives are considerably lower under the low projection and higher under the higher projection.

TABLE 41
Sensitivity of Navigation Benefits to Alternative Traffic Demand Projections

Alternative Plans	Low Projections	Most Probable	High Projections
Plan 1	30.8	36.7	68.2
Plan 2	29.3	35.0	65.9
Plan 3	27.0	32.7	63.6
Plan 4	29.3	35.0	65.9
Plan 5	33.2	39.2	70.8
Plan 6	30.9	36.8	68.3
Plan 7	30.9	36.8	68.3
Plan 4 Deferred	19.1	23.3	43.5

In addition to the above test, the benefits also were evaluated assuming: 1) no growth in traffic levels after the first 20 years of the project-life, and 2) no growth throughout the entire project-life. Benefits for these alternative traffic scenarios, as with all benefit estimates, are estimated over the 2002 through 2051 period, with 2002 representing the base year for computing average annual equivalent benefits. The resulting navigation benefits are summarized in Table 42 along with the comparable values for the most probable condition. The results show a substantial reduction in navigation benefits.

TABLE 42
Sensitivity of Navigation Benefits to No Growth Traffic Demand Projections

Alternative Plans	Most Probable	No Traffic Growth After 20 Years	No Traffic Growth
Plan 1	36.7	25.1	15.3
Plan 2	35.0	23.5	14.0
Plan 3	32.7	21.2	11.7
Plan 4	35.0	23.5	14.0
Plan 5	39.2	27.5	17.6
Plan 6	36.8	25.1	15.3
Plan 7	36.8	25.1	15.3
Plan 4 Deferred	23.3	14.8	8.1

3. CURRENT FLEET CHARACTERISTICS

The economic analysis of the alternative plans is based upon several assumptions regarding the future fleet in the with project condition. The without project fleet is comprised primarily of stumbo barges. In the with project condition the fleet is assumed to move in slightly larger tow sizes and is comprised primarily of jumbo barges. In order to test the sensitivity of the economic analysis to these projected fleet changes, the analysis was completed using the without project fleet in all of the with project alternatives. The results of this analysis, which are summarized in Table 43, show that the fleet assumptions have a substantial impact on with project rate savings.

TABLE 43
Sensitivity of Navigation Benefits to Alternative Fleet Assumptions

Alternative Plans	Without Project Fleet	With Project Fleet
Plan 1	30.2	36.7
Plan 2	28.5	35.0
Plan 3	26.2	32.7
Plan 4	28.5	35.0
Plan 5	32.7	39.2
Plan 6	30.3	36.8
Plan 7	30.3	36.8
Plan 4 Deferred	19.7	23.3

ATTACHMENT 1

LOWER MONONGAHELA RIVER COAL TRAFFIC BY MARKET AND BY DIRECTION

ATTACHMENT 1

LOWER MONONGAHELA RIVER COAL TRAFFIC BY MARKET AND BY DIRECTION

	Historic				Projected			
	1970	1980	1986	1988	1990	2000	2020	2050
DOWNBOUND AND IN								
Utility	1,134,898	1,395,114	1,075,331	1,144,570	1,194,286	4,562,009	5,572,829	8,123,479
Coke	6,468,744	2,263,195	733,849	1,783,950	2,063,368	2,105,012	1,988,663	1,757,394
Industrial	1,043,343	88,455	31,076	31,893	33,704	41,288	47,750	55,598
Export	1,480,552	2,750,328	3,440,599	4,128,468	3,788,094	3,119,292	4,070,458	5,746,694
Unknown	0	0	0	0	0	0	0	0
Total	10,127,537	6,497,092	5,280,855	7,088,881	7,079,452	9,827,601	11,679,700	15,683,165
UPBOUND AND IN								
Utility	0	0	33,172	76,613	38,191	57,042	57,042	78,319
Coke	3,238,420	4,086,248	1,546,931	2,666,544	3,611,612	3,686,549	3,487,369	3,088,838
Industrial	0	0	14,598	14,660	15,833	19,397	22,436	26,140
Export	22,645	1,062	40,232	544,082	43,332	184,745	237,834	329,534
Unknown	0	0	0	0	0	0	0	0
Total	3,261,065	4,087,310	1,634,933	3,301,899	3,708,968	3,947,733	3,804,681	3,522,831
LOCAL								
Utility	0	30,175	0	4,711	0	0	0	0
Coke	2,947,151	1,348,853	827,200	1,308,425	874,505	892,155	842,837	744,807
Industrial	0	0	2,800	0	3,037	3,721	4,305	5,013
Export	170,208	253,305	14,736	95,938	16,226	19,718	25,732	36,327
Unknown	0	30,175	0	4,711	0	0	0	0
Total	3,117,359	1,662,508	844,736	1,413,785	893,768	915,594	872,874	786,147
OUTBOUND AND DOWN								
Utility	446,720	401,740	1,094,152	1,352,720	1,185,483	2,178,610	2,468,462	3,459,110
Coke	272,187	1,087,431	165,998	15,534	976,734	996,928	945,165	839,434
Industrial	151,847	299,412	417,785	664,567	447,473	547,456	661,420	807,705
Export	0	230,532	91,990	23,376	100,819	803,640	1,082,633	1,331,132
Unknown	1,401	1,427	0	47,947	0	0	0	0
Total	872,155	2,020,542	1,769,925	2,104,144	2,710,509	4,526,634	5,157,680	6,437,381
OUTBOUND AND UP								
Utility	0	26,479	0	35,124	0	0	0	0
Coke	129,338	136,655	0	0	0	0	0	0
Industrial	0	0	6,150	110	6,670	8,172	9,452	11,028
Export	0	0	0	0	0	0	0	0
Unknown	0	0	0	0	0	0	0	0
Total	129,338	163,134	6,150	35,234	6,670	8,172	9,452	11,028

ATTACHMENT 1

LOWER MONONGAHELA RIVER COAL TRAFFIC BY MARKET AND BY DIRECTION

	Historic				Projected			
	1970	1980	1986	1988	1990	2000	2020	2050
DOWNBOUND THROUGH								
Utility	1,262,594	3,550,876	5,447,483	4,817,447	5,612,030	7,911,799	10,375,825	20,721,357
Coke	6,989,952	3,409,393	988,417	77,381	1,044,938	1,066,023	1,014,193	903,312
Industrial	1,155,254	518,519	1,400,096	1,226,658	1,518,367	1,859,906	2,194,379	2,622,055
Export	0	27,464	120,086	0	131,101	1,410,954	1,929,054	2,435,645
Unknown	906,674	77,636	0	0	0	0	0	0
Total	10,314,474	7,583,888	7,956,082	6,121,486	8,306,436	12,248,682	15,513,451	26,682,369
UPBOUND THROUGH								
Utility	0	1,021,779	1,022,414	705,878	1,022,714	1,026,823	1,028,198	1,804,246
Coke	0	0	2,304	48,422	2,437	2,497	2,367	2,097
Industrial	0	1,499	3,352	22,760	3,635	4,452	5,152	6,010
Export	0	0	0	0	0	0	0	0
Unknown	0	0	0	0	0	0	0	0
Total	0	1,023,278	1,028,070	777,060	1,028,786	1,033,772	1,035,717	1,812,353
DOWNBOUND AND IN	10,127,537	6,497,092	5,280,855	7,088,881	7,079,452	9,827,601	11,679,700	15,683,165
UPBOUND AND IN	3,261,065	4,087,310	1,634,933	3,301,899	3,708,968	3,947,733	3,804,681	3,522,831
LOCAL	3,117,359	1,662,508	844,736	1,413,785	893,768	915,594	872,874	786,147
OUTBOUND AND DOWN	872,155	2,020,542	1,769,925	2,104,144	2,710,509	4,526,634	5,157,680	6,437,381
OUTBOUND AND UP	129,338	163,134	6,150	35,234	6,670	8,172	9,452	11,028
DOWNBOUND THROUGH	10,314,474	7,583,888	7,956,082	6,121,486	8,306,436	12,248,682	15,513,451	26,682,369
UPBOUND THROUGH	0	1,023,278	1,028,070	777,060	1,028,786	1,033,772	1,035,717	1,812,353
TOTAL	27,821,928	23,037,752	18,520,751	20,842,489	23,734,589	32,508,188	38,073,555	54,935,274

ATTACHMENT 2
CAPACITY ANALYSIS FOR THE LOWER MONONGAHELA RIVER NAVIGATION IMPROVEMENT STUDY

1. INTRODUCTION

The following discussion describes the methods and data employed in evaluating the capacities of the lower Monongahela River locks, the application of these methods and data in formal capacity analysis, and the results of the analysis. A simulation model was used in estimating the capacities and in describing a tonnage-delay relationship for each project. Both capacity values and the functional description of this tonnage-delay relationship are important inputs to the system model used in estimating the benefits derived from improvements to the navigation system.

2. DESCRIPTION OF THE WATERWAY ANALYSIS MODEL

The capacity and tonnage-delay values used in this study were developed using the Waterway Analysis Model (WAM). The WAM is a stochastic simulation model developed by the Corps of Engineers for use in simulating the impact of tow movements on the inland waterways system. Basically, the WAM is used to calculate delays associated with the processing of tows at a lock, based on varying interarrival times, approach times, and chamber entry, filling, emptying and exit times. Individual tow interarrival and lockage times are selected randomly by the WAM from distributions derived from the observation of historical data.

The model consists of three basic units: model configuration, simulation, and statistics collection. Model configuration defines the system analyzed in terms of the network description, the barges and towboats to be used in the simulation, the shipment list and a list of downtime events. The simulation module processes the input data and moves the shipments from origin to destination through the system elements. Throughout the simulation, statistics are tallied for delays, queue lengths, average processing times and other variables.

The primary item of interest from any single WAM run is the resultant delay for a given traffic level. By making a series of runs over a wide range of traffic levels, enough observations can be obtained to develop a curvilinear relationship which represents the traffic-delay characteristics for each set of conditions. For each set of conditions, the rate of tow arrivals is increased until the facility has reached capacity. Capacity is considered to be the traffic level at which an increase in tow arrivals results in a great increase in average delay and very little if any increase in tonnage.

3. MODEL INPUTS

The model requires four major types of input data to perform the simulation - a description of the waterway network being analyzed, a description of the barges and towboats to be used in moving cargo and their characteristics, a list of cargo shipment demands on the system, and a description of the frequency and duration of downtime events. These data bases are discussed in the following paragraphs.

a. Network Description

The network description includes the location, size, and operating characteristics of all the relevant components of the system. The structure is relatively simple in nature. Ports and locks are called nodes, and represent points on the river system. Sectors and river systems serve to organize these lower-level elements into convenient units for processing and analysis. This organization allows the WAM to be used as a system simulator or as a single lock simulator. For this particular study the WAM was used as a single lock simulator.

1) Locks

The most important part of the system network, both in terms of the volume of data and its significance in determining capacities and tonnage-delay relationships, is the lock data. These records define the river-mile location of the lock, its dimensions, and the time required for lockage. Lockage times are defined by a set of random variable distributions for each of the components of lockage time: approach, entry, chambering, and exiting times.

The use of random variable distributions to estimate lockage times is one of the ways in which the WAM model accounts for variability. Approach and exit times are categorized as long or short approaches or exit. A long approach is one in which a vessel begins its approach to the lock chamber after waiting at a safe distance for another vessel to exit the chamber. Approaches and exits without interference from oncoming vessels are short approaches or exits. Six basic types of distributionS are therefore needed to model lockages at the projects being analyzed: long approach, short approach, entry, chambering, long exit, and short exit.

The distributions for lockage times are developed from actual data using UNIFIT (Simulation Modeling and Analysis Company, Tucson, Arizona) computer software. As with all real-world timed processes, most of the components of lockage time are right-skewed, and are closely approximated by a Weibull or Gamma distribution, as was occasionally true for chambering times. Some rare or insignificant events, such as setover lockages and the addition of recreational crafts, are modeled using constants.

2) Commodity, Towboat, and Barge Classification Data

The towboat and barge classifications in the network file describe the attributes of all the types of towboats and barges that will be modeled. Similarly, the commodity groups and classes in the network file describe some attributes of commodities that may affect lock performance. Only three broad classes are defined: hazardous, non-hazardous,and light and recreational craft (no commodities). Multiple vessel lockages are prohibited when one of the tows contains hazardous cargo. It is important to note that the specific tow configurations and overall fleet composition is determined during the development of the shipment list, which is part of the external event data described below. Likewise, specific commodity movements defined by tonnage, commodity type, origin and destination are also contained in the shipment list.

b. External Event Data

External event data consist primarily of the shipment list and the downtime event list. The shipment list drives the simulation in that it contains the time the shipment enters the system, the port of origin and destination, commodity type, tonnage, barge and towboat type, and the number of barges. Important fleet assumptions and operating procedures are built into the shipment list.

c. Downtime List

Downtime is defined as the time a chamber is unavailable for the lockage of vessels. It includes the time a chamber is "down" due to maintenance, hardware malfunction or weather.

d. WAM Output Reports

The statistics that are gathered during the simulation process are used to generate reports on lock utilization and delay, towboat and barge utilization, port activity, and detailed traffic summaries by reach.

4. DEVELOPMENT OF INPUT DATA

a. Data Base

The primary source of data for the lock simulation model is Performance Monitoring System (PMS) data collected by the Corps of Engineers. The data are collected at the projects and include detailed information on all aspects of vessel lockages. The PMS data have been collected since 1976 so that at the time of this analysis a total of thirteen years of data (1976-1988) were available. To minimize possible bias from the use of single year data, multi-year averages were used for many items as almost every year is subject to some unique occurrence. Some items, such as chambering times, vary little from year to year while others, such as towboat arrivals, show significant variation. The items with the widest variation are generally those most sensitive to the weather, (recreation boat arrivals) and to economic cycles (towboat arrivals). In addition to the PMS data, information was also obtained from Waterborne Commerce Statistics, lock personnel and shippers. Generally these data were used to quantify items for which PMS data does not exist.

b. Project Description and Utilization.

The navigation system in the Pittsburgh area encompasses parts of three rivers and includes 12 navigation projects: 3 on the Monongahela, 6 on the Allegheny, and 3 on the Ohio. The three projects on the Monongahela are the focus of this study. The table below provides information on the location, dimensions, and age of the three projects.

TABLE 2
Lower Monongahela Projects

Project	River	Mile Point	Pool Length	Lift	Chamber Main	Aux
L&D 2	Mon	11.2	12.6	8.7	720x110	360x56
L&D 3	Mon	23.8	17.7	8.2	720x 56	360x56
L&D 4	Mon	41.5	19.7	16.6	720x 56	360x56

The Lower Monongahela projects are used extensively for both commercial and recreational purposes. Commercial vessels account for nearly 75 percent of traffic, with towboats arriving at the projects at rates ranging from 14 to 23 per day or one every one-to-two hours (see Table 3). The highest arrival rate is at L&D 3 and the lowest is at L&D 2.

TABLE 3
Average Arrivals per Day, 1986

Project	Towboats*	Recreational Craft	Total
L&D 2	14	6	20
L&D 3	23	5	28
L&D 4	16	5	21

* Includes towboats without barges (lightboats).

The other 25 percent of the vessels are mainly recreational craft, but also include government repair boats and other miscellaneous craft. The number of these non-commercial craft is unusually high when compared with other projects in the navigation system, a reflection of these projects' location in the immediate Pittsburgh area. On an annual basis, the recreational craft arrival rates range from 3 to 11 a day. However, these craft appear predominantly in the summer months with arrival rates on August weekends averaging nearly 40 per hour.

The main chambers are used predominantly by tows, and the auxiliaries by recreational craft, lightboats and other small vessels (see Table 4). In 1986 over 83 percent of all tows used the main chambers and 93 percent of all small craft used the auxiliaries. Tows are usually configured to take advantage of the largest lock at a project: if they use the smaller lock it is inefficient and time consuming since it may require multiple lockages. Recreational craft can easily fit into the auxiliary chambers, leaving the main available for commercial vessels. Tows normally use the auxiliary chamber only if it is a small tow or if the main lock is unavailable for use.

TABLE 4
Use of Chambers by Vessel Type, 1986
(percentages)

Project	Main		Auxiliary		Total	
	Tows	Others	Tows	Others	Tows	Others
L&D 2	76	2	24	98	62	38
L&D 3	86	4	14	96	68	62
L&D 4	92	2	8	98	70	30

c. Processing Time

Processing time is calculated as the time a lock is devoted to serving a particular vessel. It does not include the time a vessel must wait in queue while the lock is devoted to other vessels. The average processing times in 1986 for the projects under analysis are listed in Table 5. The lowest average time is 29 minutes at L&D 3 and the highest is 38 minutes at L&D 4. Average processing times can vary considerably from year to year depending upon a number of factors. Most important among these are 1) the number of recreation boats relative to the number of tows; 2) the size of the tows; and 3) the availability of the locks. The greater the number of recreation boats vis-a-vis the number of tows, the lower the average processing time since recreation boats can be processed faster than tows. The larger the tows, the higher the average processing time since larger tows may require more lockages and therefore more time for processing. Outages of a lock, particularly the main lock, means more tows at the auxiliary lock which requires more lockages and longer processing times.

TABLE 5
Processing Time, 1986
(Minutes per Vessel)

Project	Main Lock	Auxiliary Lock	Both Locks
L&D 2	43	22	33
L&D 3	33	21	29
L&D 4	46	26	38

1) Component Times

Processing time is the summation of four more detailed times collected for each lockage event: the approach, entry, chambers, and exit times. Variations in these times are largely a result of differences in tow sizes and the number of vessels using the lock. The larger the tow, the more difficult it is to maneuver and, therefore, the longer the times. The greater the numbers of vessels, the shorter the aproach/exit times credited to the vessels since other vessels are likely to be in a position to begin the lockage process. Therefore as traffic increases, average processing times decrease. Average processing time by component are shown in Table 6.

TABLE 6
Lockage Component Times, 1986

Project/Chamber	Approach	Entry	Chamber	Exit	Total
Main Lock:					
L&D 2	14.0	6.1	15.4	7.1	42.6
L&D 3	11.4	6.1	9.4	6.5	33.4
L&D 4	12.4	7.5	14.6	8.8	43.4
Auxiliary:					
L&D 2	7.8	2.8	8.5	2.8	21.9
L&D 3	7.0	2.9	7.8	2.8	20.5
L&D 4	9.0	2.6	10.4	3.6	25.5

2) Delay Times

With delay times of 30 minutes or less, congestion does not appear to be a problem at the projects. However, considering the commonality of traffic, total average delays for the area are about 3 hours per tow. Moreover, the fact that traffic peaks at certain times of the year means that the delays vary accordingly.

d. Vessel Fleet Characteristics

The important characteristics of the vessel fleet are the dimensions of the barges, the number of barges per tow, the average load per barge, and the percent of barges that are empty. As shown in Table 7, the predominant barge type at all the projects is the regular, which measures 175'x 26'. Tows range in size from 4.4 to 5.5 barges, the average load from 570 to 623 tons, and percent empty from 44 to 48. Each of these items is discussed in greater detail in the following paragraphs.

TABLE 7
General Characteristics of the Vessel Fleet, 1986

Item	L&D 2	L&D 3	L&D 4
Tons/barge	623	568	569
Barges/tow	5.5	4.4	5.4
% Empty barges	44	47	47
Predominant barge:			
type	reg	reg	reg
% of total	43	55	56

1) <u>Barge Types</u>

Most of the barges operated on the Monongahela were built specifically for the Monongahela River. These barges, called regulars and stumbos, measure 26 feet in width and 175 or 195 feet in length, respectively. Table 8 is a listing of the barge fleet (loaded) at the Lower Monongahela River projects for the year 1986.

TABLE 8
Loaded Barges by Type, 1986

Barge Type	L&D 2	L&D 3	L&D 4
175' x 26'	5,932	8,837	8,212
195' x 35'	4,143	1,815	1,185
195' x 26'	2,449	4,638	4,860
148' x 27'	776	389	326
155' x 50'	535	464	199
200' x 50'	148	111	4
240' x 50'	101	59	9
300' x 50'	74	52	2
Total	14,158	16,365	14,797

While the fleet consists predominantly of regular and stumbo barges, other types move on the river as well. Most numerous among these are jumbo (195' x 35') barges, but also included are sand flats (148' x 27') and various size tankers. Typically, jumbo barges are used to shuttle cargo to fleeting areas for inclusion in larger tows destined for more distant points on the waterway system. Sand flats and tankers are used to haul construction materials, petro-chemicals, and other commodities. A more detailed listing of the barge fleet by commodity group is provided in Table 9. As shown, each commodity generally moves in a limited number of barge types. As the commodity mix changes, the number of barges by type also changes.

TABLE 9
Loaded Barges by Commodity Group, 1986

Project	Coal	Petro & Chem	Aggregates	Iron & Steel	Others	Total
<u>L&D 2</u>						
175' x 26'	5,138	0	794	0	0	5,932
195' x 35'	3,167	261	104	318	293	4,143
195' x 26'	2,449	0	0	0	0	2,449
148' x 27'	0	0	776	0	0	776
Tankers	0	520	0	0	338	858
Total	10,754	781	1,674	318	631	14,158
<u>L&D 3</u>						
175' x 26'	8,124	0	713	0	0	8,837
195' x 35'	1,424	78	21	207	85	1,815
195' x 26'	4,638	0	0	0	0	4,638
148' x 27'	0	0	389	0	0	389
Tankers	0	447	0	0	239	686
Total	14,186	525	1,123	207	324	16,365
<u>L&D 4</u>						
175' x 26'	7,571	0	641	0	0	8,212
195' x 35'	1,074	7	19	75	10	1,185
195' x 26'	4,860	0	0	0	0	4,860
148' x 27'	0	0	326	0	0	326
Tankers	0	166	0	0	48	214
Total	13,505	173	986	75	58	14,797

2) <u>Barges per Tow</u>

The most common size tow on the Lower Monongahela is a six-barge tow. Four of every ten tows through L&Ds 3 and 4 and two of every ten through L&D 2 are six barge tows. About half of all tows through the locks are six-barge tows or larger (Table 10).

TABLE 10
Barges Per Tow 1986

Barges/Tow	L&D 2	L&D 3	L&D 4
1	656	676	190
2	749	959	348
3	388	913	559
4	402	815	542
5	262	459	409
6	893	2,725	2,156
7	236	492	471
8	182	17	251
9	181	0	125
10	230	0	165
11	164	0	29
12	69	0	6
13	33	0	0
14	56	0	0
15	79	0	0
16	28	0	0
17	22	0	0
18	29	0	0
19	14	0	0
20	14	0	0
Total	4,687	7,056	5,251

The predominance of six-barge tows reflects the intensive usage of regular and stumbo barges in the area. Six-barge tows of either type can lock through the

main (720' x 56') lock at any of the Lower Monongahela projects in a single operation. The largest jumbo barge tow that can do likewise is a three-barge tow, and in fact, the predominant size jumbo tow is a three-barge tow. Tankers generally move in one and two-barge tows because of their size, the limited tonnage required per time period, and the sometimes hazardous nature of their cargo. Sand flats also move in relatively small tows, a reflection of the shuttle nature of the traffic. A listing of the distribution of barges per tow by barge type is provided in Table 11.

TABLE 11
Tow Size Distribution by Barge Type, 1986
(Percentages)

Barges per Tow	1	2	3	4	5	6	7	8	9	10	>10
L&D 2											
175' x 26'	2	4	4	11	5	37	8	5	5	10	8
195' x 35'	28	17	10	6	6	9	3	3	2	1	15
195' x 26'	7	14	5	7	4	17	3	5	7	7	24
148' x 27'	18	42	10	7	6	5	4	4	3	1	0
Tankers	16	24	15	10	6	9	5	2	3	3	7
All	14	16	8	9	6	19	5	4	4	5	10
L&D 3											
175' x 26'	2	5	5	14	6	53	14	1	0	0	0
195' x 35'	29	26	41	1	2	1	0	0	0	0	0
195' x 26'	2	7	3	17	10	61	0	0	0	0	0
148' x 27'	9	17	17	14	15	13	7	7	1	0	0
Tankers	29	57	9	5	0	0	0	0	0	0	0
All	9	14	13	12	6	39	7	0	0	0	0
L&D 4											
175' x 26'	1	3	5	10	7	46	15	5	1	4	3
195' x 35'	12	15	50	9	8	5	0	0	0	1	0
195' x 26'	1	5	2	10	6	61	2	6	3	3	1
148' x 27'	10	13	15	15	16	7	9	2	11	1	1
Tankers	29	50	12	4	1	4	0	0	0	0	0
All	4	7	11	10	8	41	9	5	2	3	0

3) Tons per Barge

The average loading for each type of barge passing through the Lower Monongahela locks is provided in Table 12. To some extent the average loadings reflect the commodity mix transported in each type of barge. For example, at L&D 2 more steel scrap is transported in jumbo barges than at the other two locks. Since scrap cannot be loaded as densely as coal and other commodities, the loadings are less and so the average is lower.

4) Percent Empty

Percent empty indicates the level of backhaul opportunities. Fifty percent empty indicates the absence of backhauls: barges moving loaded through the lock in one direction return empty in the opposite direction. The percent empties are 44 percent at L&D 2, 47 percent at L&D 3, and 47 percent at L&D 4. This implies that 6 percent of the barges at L&D 2, 3 percent at L&D 3, and 3 percent at L&D 4 are loaded both upbound and downbound.

TABLE 12
Tons Per Loaded Barge, 1986

Barge Type	L&D 2	L&D 3	L&D 4
175' x 26'	956	957	998
195' x 35'	1,370	1,401	1,427
195' x 26'	1,124	1,124	1,169
148' x 27'	578	636	643
155' x 50'	1,088	1,040	1,147
200' x 50'	1,921	1,859	2,000
240' x 50'	2,095	2,066	2,000
300' x 50'	2,352	2,784	2,329
Average	1,120	1,070	1,084

SOURCE: PMS.

5) Operating Policies

The most important operating policy in effect in the area is that only one-cut lockages are allowed at L&D 3. This rule was implemented because of the hazardousness of the approach areas at the lock - a result of the intensiveness of barge fleeting in the area and the existence of a developed site that extends into the approach area upstream of the lock. The effect of this policy is to limit multi-lockage operations throughout the area (see Table 13).

TABLE 13
Single and Multi-Cut Lockages

Project	Single	Multi-Cut
L&D 2	90	10
L&D 3	100	0
L&D 4	90	10

The multitude of odd-sized locks in the area and particularly on the Monongahela leads some towing companies to operate in ways that are difficult to discern from a routine review of the data. To learn more about towing operations, a survey was conducted of the major tow operators in the Pittsburgh area. The replies indicated a complexity of operations not found elsewhere on the navigation system. In effect, the companies fleet/refleet at nearly every point where lock size changes.

e. Downtime

Lock downtime was based on data on downtime events recorded in the PMS data, supplemented by information provided by Operations Division. Downtime for purposes of capacity modeling is defined as the "normal" amount and duration of outages expected at a lock in any given year. It does not include downtime for major rehabilitation efforts. Because "normal" downtime can vary considerably from year to year, it was calculated on the basis of ten years of data for six projects in the Pittsburgh area; the three on the Lower Monongahela and the three on the Upper Ohio. The data were compiled by month of occurrence, cause of the outage, and duration of the outage. These data were converted into statistical probabilities which were in turn used to generate a list of downtime events by date, lock, and duration. The sum total of lock downtimes is equivalent to 2.6 percent of the year. The same downtime list was used in the analysis of all three Lower Monongahela projects.

Downtime due to major rehabilitation efforts was excluded from the analysis at this point in order to reflect only "normal" levels of operating efficiency. Major maintenance downtime is addressed as part of the system economic analysis (discussed in Section 6 and Section 9 of this appendix). The remaining downtime totaled 14 days, or 1.9 percent of the year (14/365x2 locks). These downtime observations were stratified by causative factor, month of occurrence, and duration, and converted into statistical probabilities. The probabilities were then used to generate a list of downtime events for use in the simulation model. The events add up to 19.1 days, or 2.6 percent of the year. The modeled list totals more than the actual events because of adjustments made to expected downtime at the auxiliary locks. In many cases, downtime is recorded at the projects only for the main lock even though the auxiliary lock is equally affected by the event. The adjustments increased expected downtime at the auxiliary, but to an amount still 20 percent less than total downtime at the main chamber. Table 14 summarizes downtime data by lock chamber and causative factor.

TABLE 14
Annual Downtime

Lock	Days
Main	
weather	2.4
accidents	1.2
O&M	7.1
subtotal	10.7
Auxiliary	
weather	2.7
accidents	0.1
O&M	5.6
subtotal	8.4
Both	
weather	5.1
accidents	1.3
O&M	12.7
subtotal	19.1

4. SIMULATION MODEL INPUTS

a. Existing Projects

Vessel fleets, lock processing times, and lock downtimes used to estimate the capacities of each of the existing projects were developed from the data discussed in the preceding section. Table 15 summarizes the fleet that was used in estimating the existing project capacities.

TABLE 15
Existing Vessel Fleet

	L&D 2	L&D 3	L&D 4
Barge Distribution (in percents)			
Regular	43	55	56
Stumbo	19	29	33
Jumbo	23	9	8
Tow Size Distribution			
Barges/Tow	5.5	4.4	5.4
Tons/Tow	3,391	2,482	3,052

1/ Barge distributions do not add to 100%. Tanker, sand flat, and other barge types are not displayed in this table.

Estimating the capacity of existing projects is an important exercise in that it allows the analyst to determine if the model is capable of replicating observed operations at a lock. A summary comparison of the actual and modeled data is provided in Table 16. The tonnages and tow data are input to the model and reflect the effort to approximate the actual fleet. The principal difference between the modeled fleet and the actual fleet is that tows in the modeled fleet are comprised of tows of homogeneous barge-type and commodity. In other words, there is a tow-type for each relevant commodity and barge-type combination. The effort to create uniform tows resulted in some deviation from the actual fleet characteristics. In all important areas the deviations were minimal. Delays generated by the model are close to the actual delay levels, indicating the model is calibrated.

TABLE 16
Actual and Modeled Fleet Statistics

	L&D 2 Actual	Modeled	L&D 3 Actual	Modeled	L&D 4 Actual	Modeled
Tons (000's)	15,894	15,659	17,516	17,411	16,030	15,968
Tows	4,687	4,709	7,056	7,137	5,251	5,253
Delays (Hrs)	0.3	0.5	0.2	0.4	0.3	0.5

Times are computed for each lock separately and are provided for single-cut through 15-cut lockage operations. The times are provided by direction for each component of the lockage operation: approach, entry, chamber, and exit. Further distinctions are made for fly and turnback entry/exit operations. The times are described as statistical distributions: gamma, weibull, exponential, normal, or constant. The distribution that best describes each lockage time component was generated separately by fitting the actual PMS data to each possible type of distribution and selecting the distribution that provided the best fit. Distributions for lockage time operations not available from PMS were estimated based on the observed data. For example, a 4-cut lockage operation might be computed based on the time for a 3-cut lockage operation by adding in the time for an additional lockage cycle. A summary of the modeled and actual lockage times is provided in Table 17.

TABLE 17
Actual and Modeled Lockage Times (Minutes)

	L&D 2 Actual	L&D 2 Modeled	L&D 3 Actual	L&D 3 Modeled	L&D 4 Actual	L&D 4 Modeled
Main						
- single	35.0	36.0	34.0	35.0	36.0	37.0
- total	43.0	41.0	33.0	34.0	43.0	44.0
Aux						
- single	24.0	24.0	27.0	26.0	31.0	32.0
- total	22.0	25.0	20.0	30.0	26.0	37.0

b. Without Project Condition

1) General

Capacities for the without project condition were based on existing data and expected changes in the vessel fleet. The vessel fleet is expected to change over time because replacement of L&Ds 7 and 8 will encourage the use of a larger fleet on the Monongahela. These fleet changes increased the average processing times by changing the distribution of single and multi-cut lockages. However, the differences in processing times are less than five minutes per tow. The effects of these factors on the capacity of the projects are described in the following paragraphs.

2) Vessel Fleet

Replacement of L&D's 7 and 8 will have two major effects of the existing fleet: 1) a shift to stumbo and jumbo barges and 2) a shift to larger tows. The fleet currently using the Lower Monongahela projects consists predominately of regular barges, barges which were originally designed for use in lock chambers measuring 360' x 56'. With the replacement of L&D's 7 and 8, no more Monongahela River locks will have main chambers with these dimensions. Therefore, waterway users expect the use of regular barges to decline over time as the operators move their fleet composition toward stumbos and jumbos. Replacement of L&D's 7 and 8 will also allow operators to make economical use of larger tows on the river. Tows are restricted to double lockages at the existing projects, limiting tow size to two jumbo, four stumbo, or six regular barges. The replacement projects at L&Ds 7 and 8 will allow larger tows to move on the river.

Summary statistics showing the effects of expected fleet changes on the vessel at the lower river projects are provided in Table 18. It is expected that stumbo barges will replace regular barges on all movements internal to the Monongahela River, jumbos will replace regulars for off Ohio River movements, with regulars remaining only for those movements originating on the Allegheny River. At L&D 4, the percentage of jumbo barges increases from 8 percent to

25 percent, the percent of stumbo barges from 33 percent to 57 percent, and the percentage of regular barges decrease from 56 percent to 24 percent. Similar changes occur at L&Ds 2 and 3.

TABLE 18
Vessel Fleets - Existing and Future Conditions
(Barge Distribution in Percents)

Alternative	L&D 2			L&D 3			L&D 4		
	Reg	Stumbo	Jumbo	Reg	Stumbo	Jumbo	Reg	Stumbo	Jumbo
Existing	43	19	23	55	29	9	56	33	8
Without Condition	16	31	38	14	52	26	14	57	25

Note: Barge distributions do not add to 100%. Tanker, sand flat, and other barge types are not displayed in this table.

c. <u>With Project Condition</u>

1) <u>General</u>

A number of lock size combinations were evaluated as alternatives on the lower river. The alternatives varied in terms of numbers of locks, size of locks, and number of projects. The number of locks ranged from one to two (existing number), the size from the existing sized locks to 720' x 110' and 720' x 84', and the number of projects from two to three (existing number).

2) <u>Vessel Fleet</u>

Two fleets were developed for the alternatives keyed to lock widths of 84-feet and 110-feet. Both fleets will allow for the use of larger tows, with the 110' fleet being larger than the 84' fleet. The 110' lock will also facilitate the use of more jumbo barges since jumbos become more economic than stumbo barges for certain shipments. The expected changes to the fleet resulting from wider locks are displayed in Table 19. The 84' width alternatives result in a 50 percent increase in the number of barges per tow at L&D's 3 and 4 and a 60 percent increase in the tons per tow. The 110' width alternatives result in a 75 percent increase in the number of barges per tow, a doubling of the tons per tow, and an increase in the percent of jumbo barges from 26 percent to 56 percent. Similar changes are experienced at L&D 2.

TABLE 19
Vessel Fleets for Alternative Projects

Alternative	L&D 2 Reg	L&D 2 Stumbo	L&D 2 Jumbo	L&D 3 Reg	L&D 3 Stumbo	L&D 3 Jumbo	L&D 4 Reg	L&D 4 Stumbo	L&D 4 Jumbo
Without Project	16	31	38	14	52	26	14	57	25
*720'x84'	18	0	66	17	28	52	17	28	52
*720'x110'	18	0	66	17	20	56	17	20	56

Alternative	L&D 2 Barges/Tow	L&D 2 Tons/Tow	L&D 3 Barges/Tow	L&D 3 Tons/Tow	L&D 4 Barges/Tow	L&D 4 Tons/Tow
Without Project	5.40	3,740	3.64	2,294	3.92	2,480
*720'x84'	5.22	4,098	5.49	3,726	5.49	3,726
*720'x110'	5.44	4,209	6.39	4,495	6.39	4,495

* Lock replacement at L&D 3 and L&D 4; L&D 2 existing main chamber is a 720'x 110'.

Note: Barge distributions do not add up to 100%. Tanker, sand flat, and other barge types are not displayed.

5. CAPACITY

a. Introduction

Because efforts to improve navigation efficiency on the Lower Monongahela River focus on L&Ds 3 and 4, this capacity analysis was directed primarily at alternatives for these two projects. Capacities were estimated for the various location plans and lock size combinations by simulating their expected performance at different levels of traffic. The traffic level at which no additional traffic could be processed was deemed the capacity. Simulation also produces a curve (the tonnage-delay curve) describing the expected delays at each traffic level.

b. Existing Project

The estimated capacities of the existing projects are 66.2 million tons for L&D 2, 43.4 million tons for L&D 3, and 35.0 million tons for L&D 4. The high capacity at L&D 2 reflects the availability of the large (720'x110') main chamber. Several factors are at work that give L&D 3 a significantly higher capacity than that for L&D 4. First, L&D 3 has a shorter processing time due, in part, to its location and to the one-cut lockage policy in effect at the project, and secondly to the higher utilization of its auxiliary at high traffic levels. The one-cut lockage policy requires a downsizing of tow sizes prior to use of the main chamber at L&D 3.

While the auxiliaries are infrequently used at current levels of traffic, the difference in operating procedures at the two locks does limits the use of the auxiliary lock at L&D 4 relative to L&D 3. For example, a nine-barge stumbo tow can double lock through the 720' x 56' main chamber at L&D 4, but it cannot use the 360' x 56' auxiliary where it would require a five-cut lockage. Because of the length of the guidewalls and the potential for congestion, tows are limited to two-cuts through the auxiliary when the main lock is operational. The only time the nine-barge tow could use the auxiliary is when the main is down for repairs and maintenance. It is ineffective in processing traffic in a normal situation.

At L&D 3 the towboat makes a double-trip, the nine-barge stumbo tow is effectively disassembled and reconstructed as two separate and smaller tows: one six-barge tow and one three-barge tow. While the six-barge tow could not use the auxiliary if the main was operational, the three-barge tow could use the auxiliary since it would require only a two-cut lockage for passage. This is important not only in increasing utilization of the auxiliary lock, but also in decreasing the queue waiting to use the main chamber. The overall affect of the difference in operating policies is to increase the capacity of L&D 3 to process traffic above that of L&D 4.

c. <u>Without Project Alternatives</u>

The without project condition assumes continued operation of the Lower Monongahela projects with the existing-sized lock chambers. Two key features of the without project condition are: 1) the existence of a slightly larger fleet and 2) an improved approach at L&D 3 that allows larger tows to double-lock at this project. Two nonstructural alternatives were simulated, one which requires the use of towhaulage, the other which requires the use of switchboats. Capacities estimated through the simulation are displayed in Table 20. No nonstructural plans for improving navigation efficiencies are proposed for L&D 2.

When operated without its auxiliary chamber L&D 3 has an estimated capacity of 33.5 million tons, L&D 4 an estimated capacity of 30.6 million tons. The auxiliaries when operated without the main chambers have a capacity of 31.3 million tons at L&D 3 (its auxiliary can be extended to 720'x 56' when the main is closed) and 13.3 million tons at L&D 4's (a 360'x 56' chamber).

d. <u>With Project Alternatives</u>

Two separate sets of with project simulations were completed, one corresponding to the analysis of various lock size combinations with a vessel fleet suited to 84' wide chambers, and the other corresponding to the analysis of lock sizes with a vessel fleet suited to 110' wide chambers. The results of these simulations are also presented in Table 20. As in the without condition, no structural changes are proposed to improve navigation at L&D 2. Differences in capacity values are caused by variations in the vessel fleets between the without and the with condition, and between the 84' and 110' lock-width, project alternatives.

TABLE 20
Lock Capacities for Alternative Lower Monongahela River Projects
(Million Tons)

Lock Size	L&D 2	L&D 3	L&D 4
<u>Without Project</u>	66.2	---	---
Existing Chambers, Towhaulage	---	40.9	38.4
Existing Chambers, Single-cuts	---	43.4	42.6
<u>With Project Alternatives</u>			
a. **Combinations with 84' Wide Chamber**	67.6	---	---
Single 720'x 84'	---	55.8	52.5
720'x 84' and 360' x 56'	---	60.0	55.6
720'x 84' and 410' x 84'	---	70.5	63.2
Twin 720'x 84'	---	107.3	104.4
b. **Combinations with 110' Wide Chamber**	70.6	---	---
Single 720'x 110'	---	72.7	69.3
720'x 110' and 360' x 56'	---	80.4	77.3
720'x 110' and 410' x 84'	---	88.1	80.7
720'x 110' and 410' x 110'	---	97.9	88.5
Twin 720'x 110'	---	138.6	133.4
c. **Existing Size Chambers**	67.6	---	---
Towhaulage and 84' Fleet	---	---	32.6
Switchboat with 84' Fleet	---	---	42.6

Comparing capacities between L&Ds 3 and 4 indicates that the pattern established in the existing condition is still evident. That is, capacities at L&D 3 are slightly larger than those at L&D 4, primarily because the approach to L&D 3 is shorter and chambering times are faster. Comparing capacities between the 84' and 110' chamber widths indicates that, not surprisingly, the larger, 110' chambers have more capacity than the 84' chambers.

Table 20 also gives capacities for a towhaulage plan and a switchboat plan at L&D 4 with an 84' fleet and existing lock chamber sizes. These simulations were completed in order to allow a systems analysis of deferring the replacement of L&D 4 as part of a with project plan. Simulations were also made to estimate capacities for single lock chambers at L&Ds 3 and 4 (see Table 21). Switchboats are employed at the small chambers when the main chamber is not in operation.

TABLE 21
Capacities for Single Lock Sizes

Lock Size/Plan	L&D 3	L&D 4
Without Project		
Main Only	33.5	30.6
Auxiliary Only	31.3 *	13.3
With Project		
Single 720'x 84'	55.8	52.5
Single 360'x 56', w/ Switchboat	15.5	13.3
Single 410'x 84', w/ Switchboat	29.1	25.0
Single 410'x 110', w/ Switchboat	38.9	33.8
Single 720'x 110'	72.7	69.3

* L&D 3's auxiliary can be extended to a 720'x 56' chamber when the main is not in service. The ability of the lock to do this does not exist in the with condition.

e. Traffic-Delay Curves

In addition to providing an estimate of lock capacity, the simulation model was used to generate traffic-delay relationships. The key factor affecting the shape of these curves is the size of the auxiliary lock. With no auxiliary lock, delays at all traffic levels are higher than with a two lock project since lock outages completely stall traffic during the outage period. If the auxiliary is too small to double lock the tows that can pass through the main chamber in a one-cut operation, delays increase as the project becomes, in effect, a one lock project. Utilization of the auxiliary lock is limited, in this case, as it is restricted to recreation boat traffic and small tows. Figures 1 through 6 present a graphical depiction of the traffic-delay relationships for the various lock size combinations. The figures are organized by lock and by lock width for comparison purposes.

FIGURE 1

Existing Chamber Size
Monongahela L&D 3

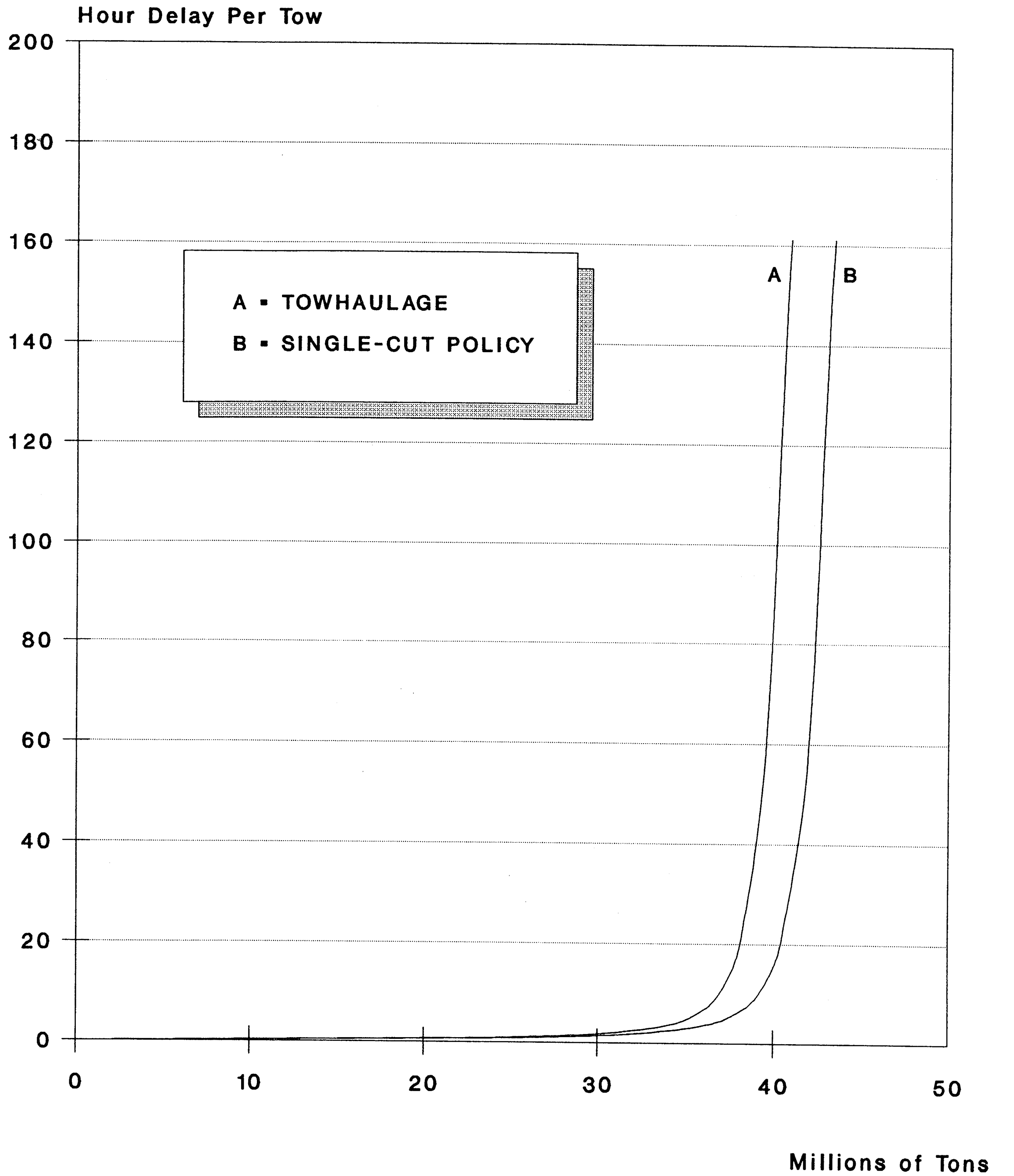


FIGURE 2

Existing Chamber Size
Lower Monongahela L&D 4

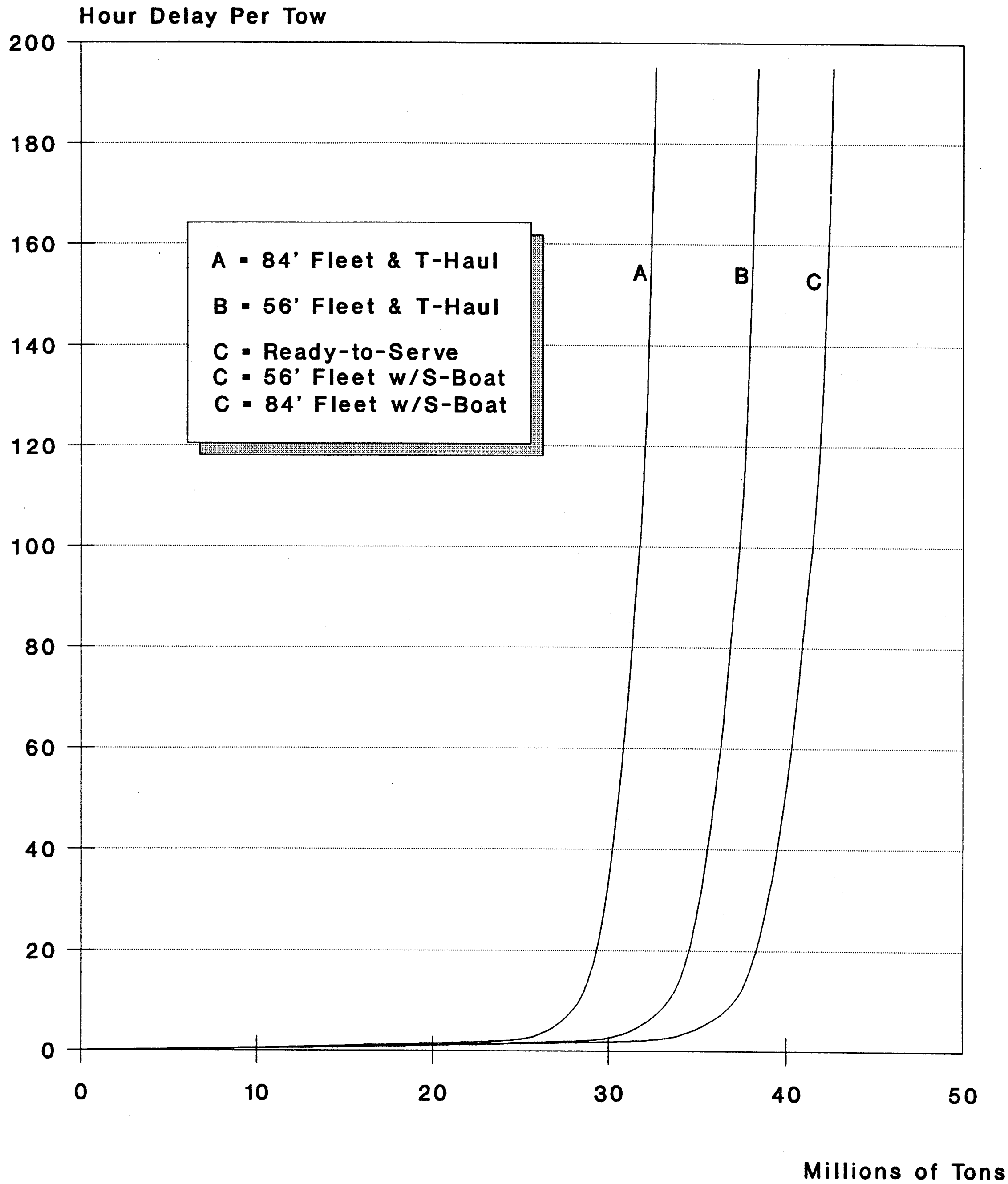


FIGURE 3

84' Width Chamber Size
Monongahela L&D 3

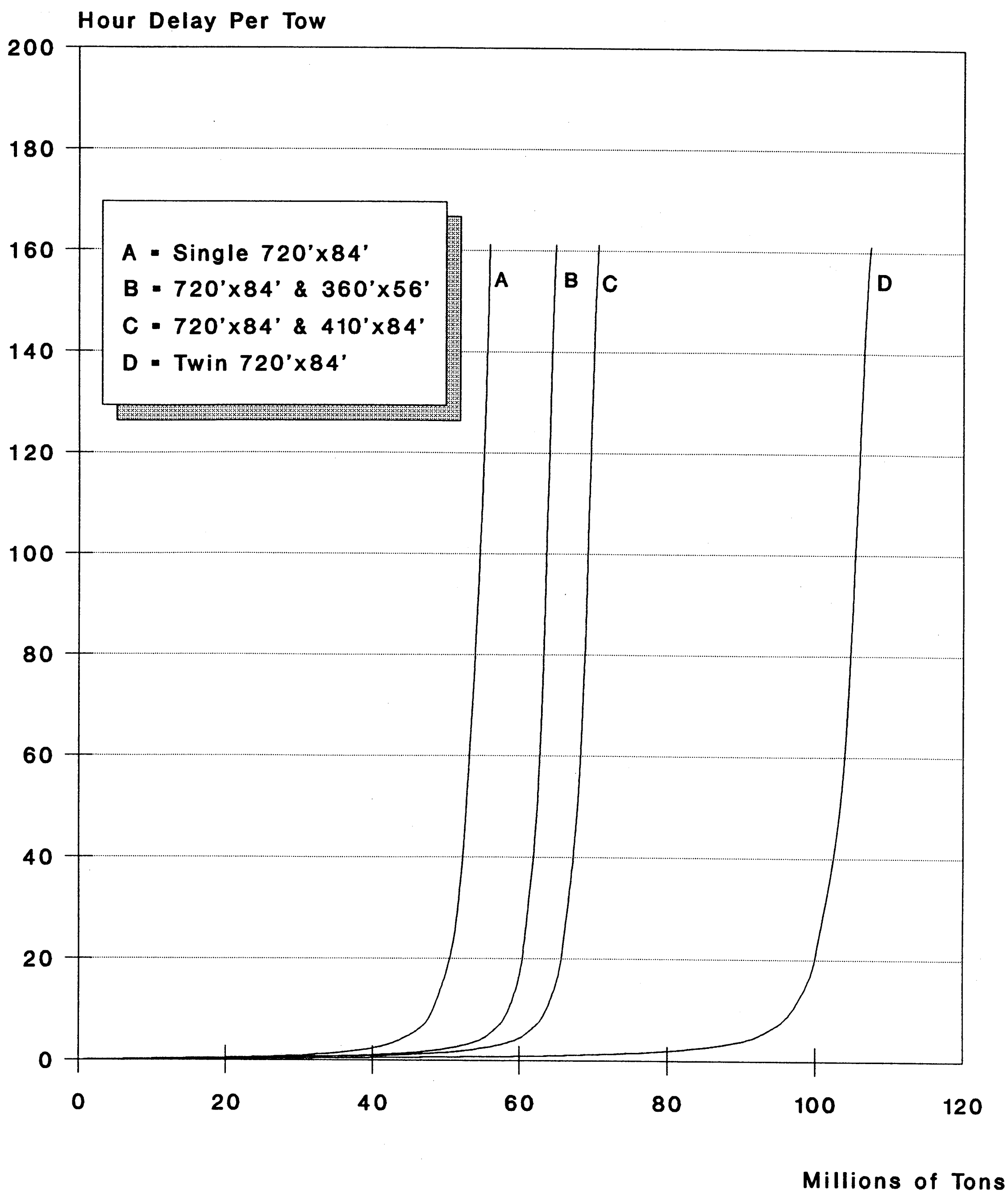


FIGURE 4
84' Width Chamber Size
Monongahela L&D 4

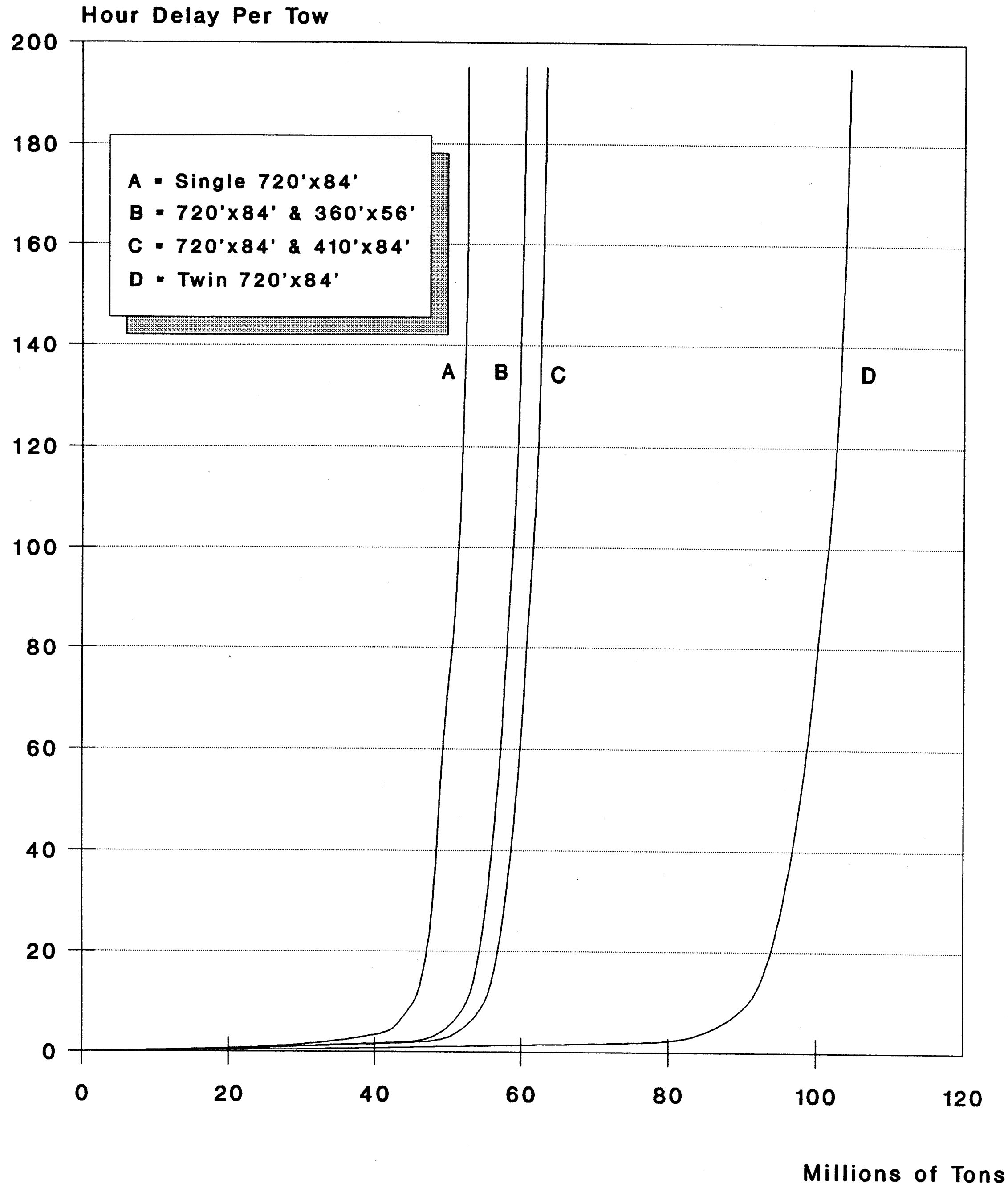


FIGURE 5

110' Width Chamber Size
Monongahela L&D 3

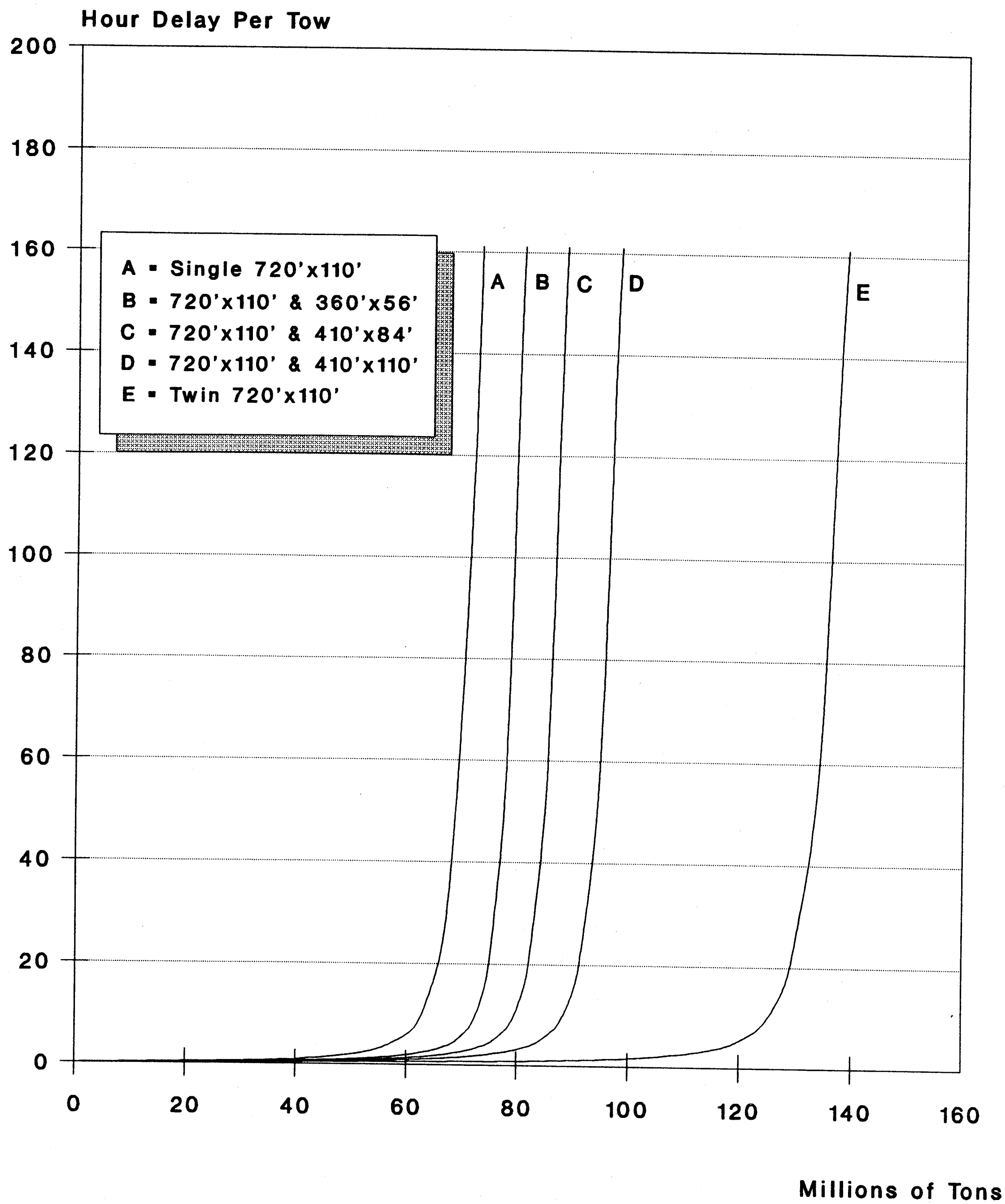
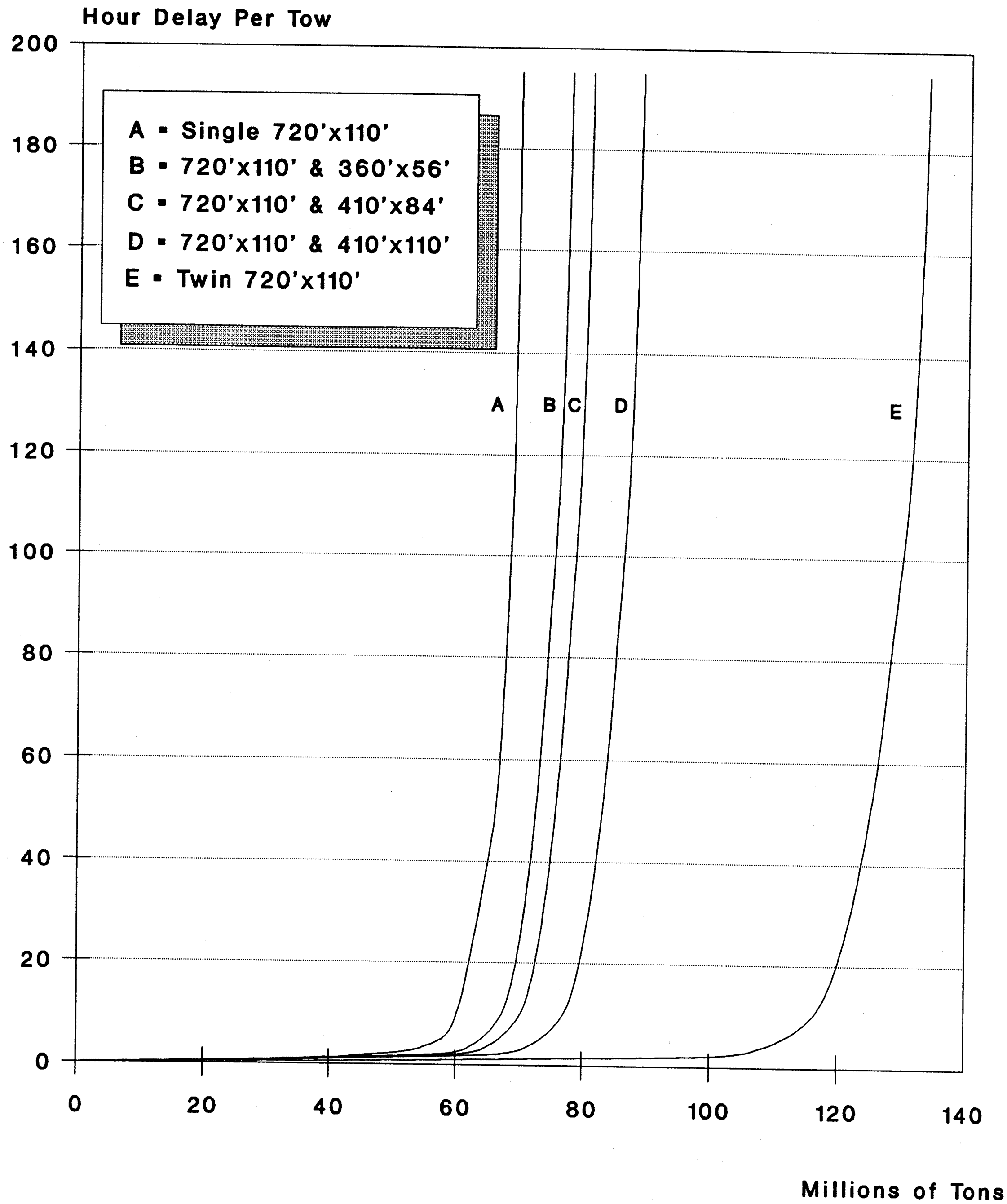


FIGURE 6

110' Width Chamber Size
Monongahela L&D 4



ATTACHMENT 3
Closure Schedule for the Without Project Condition
(in days)

Year	L/D 2 Main	L/D 2 Aux	L/D 3 Main	L/D 3 Aux	L/D 4 Main	L/D 4 Aux
1993	--	60	--	--	--	--
1994	--	--	--	--	--	--
1995	--	--	--	--	--	--
1996	--	--	--	--	--	--
1997	--	--	--	--	--	--
1998	--	--	--	365	--	--
1999	--	--	--	365	45	--
2000	--	--	--	365	45	--
2001	--	--	--	365	--	240
2002	--	--	--	--	--	--
2003	--	--	--	--	--	--
2004	30	--	--	--	--	--
2005	--	30	--	--	--	30
2006	--	--	--	--	30	--
2007	--	--	--	30	--	--
2008	--	--	30	--	--	--
2009	30	--	--	--	--	--
2010	--	30	--	--	--	30
2011	--	--	--	--	30	--
2012	--	--	--	30	--	--
2013	--	--	30	--	--	--
2014	30	--	--	--	--	--
2015	--	30	--	--	--	30
2016	--	--	--	--	30	--
2017	--	--	--	30	--	--
2018	--	--	30	--	--	--
2019	45	--	--	--	--	--
2020	45	--	--	--	--	--
2021	--	240	--	--	30	--
2022	--	--	--	30	--	182
2023	--	--	30	--	--	365
2024	30	--	--	--	--	365
2025	--	--	--	--	--	365
2026	--	--	--	--	--	365
2027	--	--	--	30	30	--

ATTACHMENT 3 (Continued)
Closure Schedule for the Without Project Condition
(in days)

	L/D 2		L/D 3		L/D 4	
Year	Main	Aux	Main	Aux	Main	Aux
2028	30	--	30	--	--	--
2029	--	30	--	--	--	--
2030	--	--	--	--	--	--
2031	--	--	--	--	--	30
2032	--	--	--	30	30	--
2033	--	--	30	--	--	--
2034	30	--	--	--	--	--
2035	--	30	--	--	--	--
2036	--	--	--	--	--	30
2037	--	--	--	30	30	--
2038	--	--	30	--	--	--
2039	30	--	--	--	--	--
2040	--	30	--	--	--	--
2041	--	--	--	--	--	30
2042	--	--	--	30	30	--
2043	--	--	30	--	--	--
2044	30	--	--	--	--	--
2045	--	30	--	--	--	--
2046	--	--	--	--	--	30
2047	--	--	--	30	30	--
2048	--	--	30	--	--	--
2049	30	--	--	--	--	--
2050	--	30	--	--	--	--
2051	--	--	--	--	--	30

Notes:

1/ Closure of L&D 2 in 1993 is due to construction of an emergency bulkhead.

2/ Closure at L&D 3 from 1998 to 2001 is due to construction of replacement locks. During construction of new 720'x56', the old 720'x56' will be used. Upon completion, a new 360'x56' will be constructed and the new 720'x56' will be used.

3/ Closure of L&D 4 in 2021 to 2025 is due to construction of replacement locks according to same sequence at L&D 3.

4/ Major rehabilitation at L&D 2 requires two 45 day closures of the main lock and one eight month closure of the auxiliary.