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

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

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

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

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

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

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

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

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

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

MONONGAHELA RIVER NAVIGATION SYSTEM

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

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

MODERNIZATION EFFORTS

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

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

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

LOCKS AND DAMS 7 AND 8 STUDY

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

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

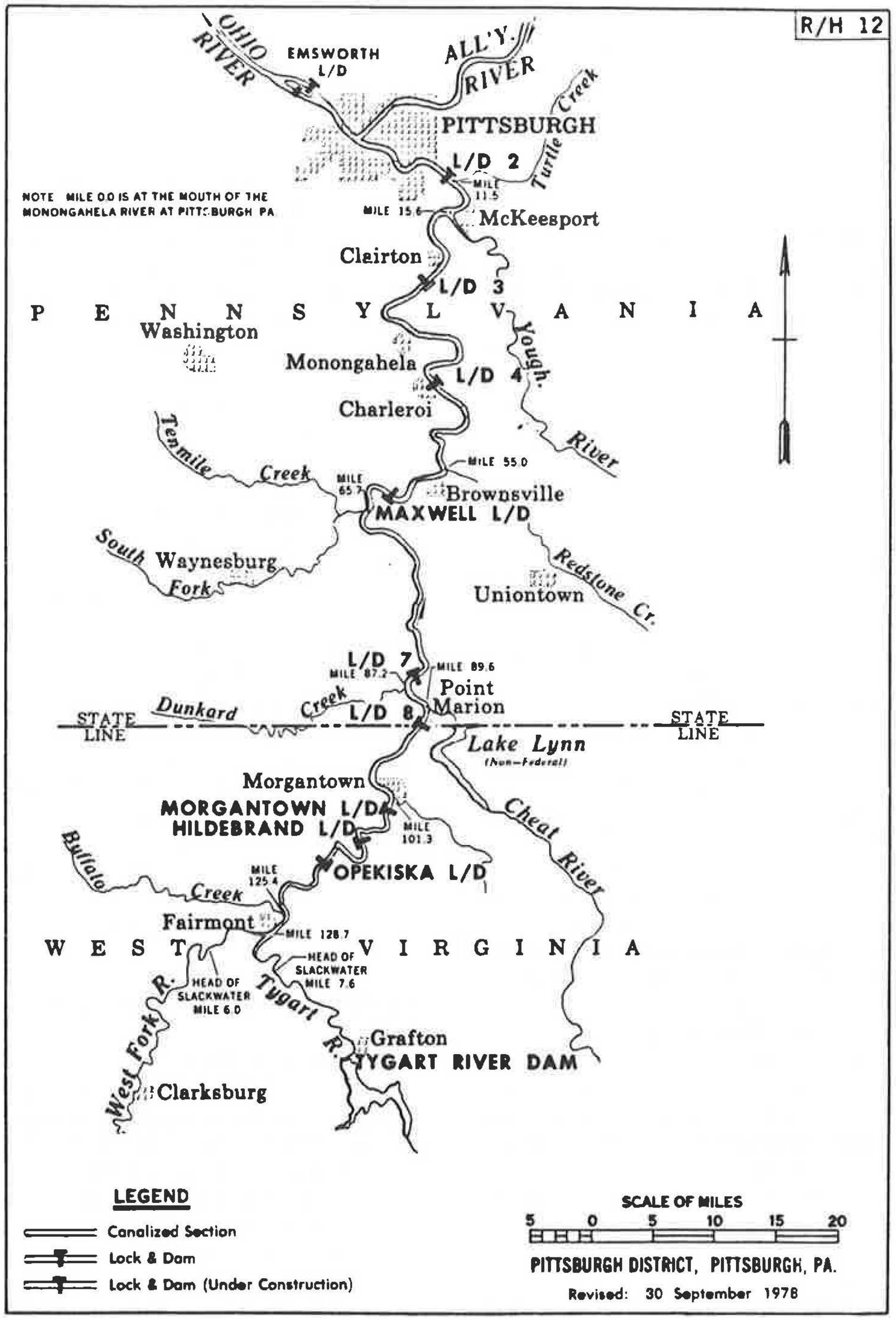

FIGURE 1 Index map of Monongahela River river and harbor project.

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

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

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

TABLE 1 MONONGAHELA RIVER NAVIGATION SYSTEM: PROJECT CHARACTERISTICS

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

a. In feet

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

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

d. Major rehabilitation of locks completed, 1984

e. Dam reconstructed, 1963-1967

f. Dam reconstructed and crest raised, 1958-1959

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

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

CONTINUED OPERATION OF MONONGAHELA RIVER NAVIGATION SYSTEM

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

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

ECONOMIC COSTS OF CONTINUED NAVIGATION

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

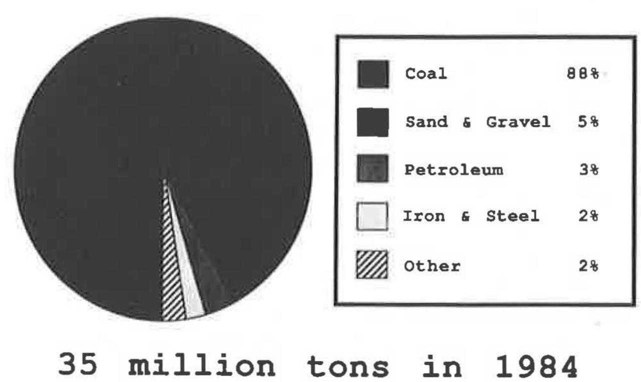

FIGURE 2 Monongahela River commodity traffic.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ANNUAL SYSTEM BENEFITS

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

TABLE 2 MONONGAHELA RIVER NAVIGATION SYSTEM: REHABILITATION AND REPLACEMENT SCHEDULE

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

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

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

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

Note: A dash (-) denotes not applicable.

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

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

c. Salvage value is estimated at 2040.

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

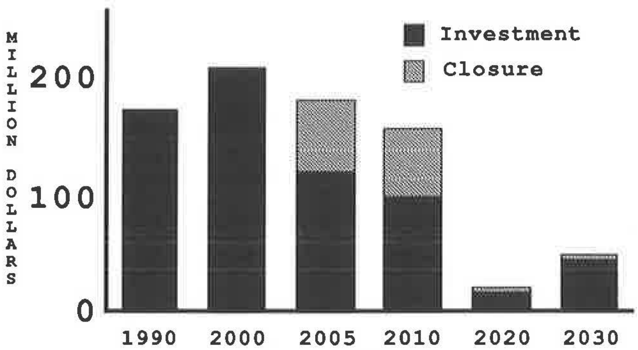

FIGURE 3 Monongahela River economic costs.

COMPARISON OF SYSTEM COSTS AND BENEFITS

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

Total annual system benefits = $330,800,000

Total annual system costs = $42,100,000

Benefit-to-cost ratio (BCR) = 7.9

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

CONCLUSIONS

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

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

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

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

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

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

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

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

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