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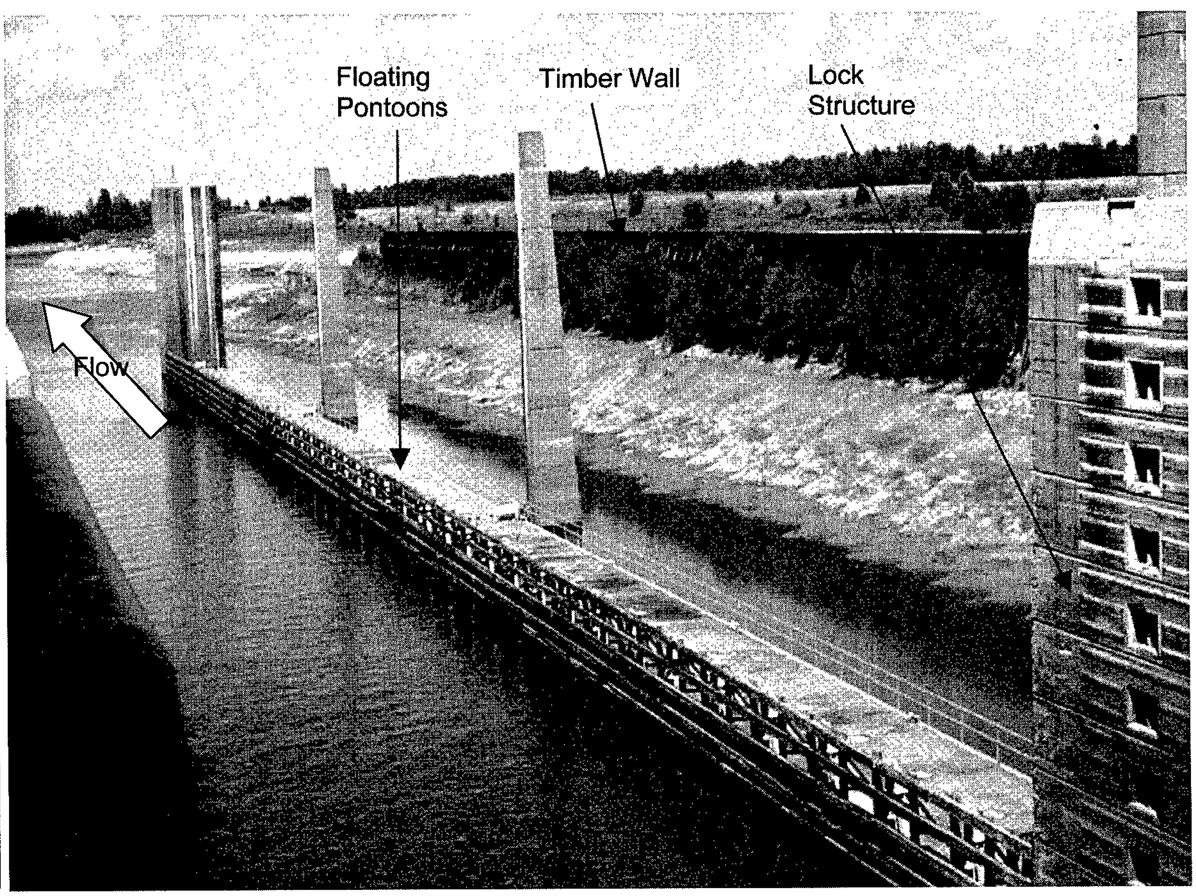
Innovations for Navigation Projects Research Program

Expert-Opinion Elicitation for the Risk Analysis of Design-Improvement Alternatives to the Lindy Claiborne Boggs Lock and Dam

Bilal M. Ayyub, Andrew Nyakaana Blair, and Robert C. Patev

December 2002



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Expert-Opinion Elicitation for the Risk Analysis of Design-Improvement Alternatives to the Lindy Claiborne Boggs Lock and Dam

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Final report

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Contents

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Innovations for Navigation Projects (INP) Research Program. The work was performed under Work Unit 33236, "Quantifying Risks and Uncertainties of Innovative Construction Techniques." Former and current Principal Investigators are Mr. Robert C. Patev and Dr. Joseph A. Padula of the U.S. Army Engineer Research and Development (ERDC) Information Technology Laboratory (ITL).

Dr. Tony C. Liu was the INP Coordinator at the Directorate of Research and Development, HQUSACE; Research Area Manager was Mr. Barry Holliday, HQUSACE; and Program Monitors were Mr. Mike Kidby and Ms. Anjana Chudgar, HQUSACE. Mr. William H. McAnally of the U.S. Army ERDC Coastal and Hydraulics Laboratory was the Lead Technical Director for Navigation Systems. Dr. Stanley C. Woodson, ERDC Geotechnical and Structures Laboratory (GSL), was the INP Program Manager. The research was conducted under the supervision of Dr. David W. Pittman, Acting Director of the ERDC GSL, and Dr. Jeffery P. Holland, Director, ITL.

This report was prepared by Drs. Bilal M. Ayyub and Andrew Nyakaana Blair of BMA Engineering, Potomac, MD, and Mr. Patev, currently of the U.S. Army Engineer District (USAED), New England. The work was monitored by Mr. John Burnworth of the USAED, Vicksburg, MS. The authors wish to acknowledge Mr. Burnworth's consistent support and valuable contributions to this research.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

1 Introduction

1.1 Needs

The primary reason for using expert-opinion elicitation is to deal with uncertainty in selected technical issues related to a system of interest. Issues with significant uncertainty, issues that are controversial and/or contentious, issues that are complex, and/or issues that can have a significant effect on risk are most suited for expert-opinion elicitation. The value of the expert-opinion elicitation comes from its initial intended uses as a heuristic tool, not a scientific tool, for exploring vague and unknowable issues that are otherwise inaccessible. It is not a substitute to scientific, rigorous research.

The identification of need and its communication to experts are essential for the success of the expert-opinion elicitation process. The need identification and communication should include the definition of the goal of the study and relevance of issues to this goal. Establishing this relevance would make the experts stakeholders and thereby increase their attention and sincerity levels. Relevance of each issues and/or question to the study needs to be established. This question-to-study relevance is essential to enhancing the reliability of collected data from the experts. Each question or issue needs to be relevant to each expert especially when dealing with subjects with diverse views. It should be preferably performed during a face-to-face meeting of members of an expert panel that is developed specifically for the issues under consideration. Prior to the meeting, several points of information should be communicated to the experts: background information, objectives, list of issues, and anticipated outcome of the meeting.

1.2 Expert-Opinion Elicitation

The expert-opinion elicitation process can be defined as a formal, heuristic process of obtaining information or answers to specific questions about certain quantities, called issues, such as failure rates, unsatisfactory-performance consequences and expected service life. Expert-opinion elicitation as a process is defined in Appendix A. This process should not be used in lieu of rigorous reliability and risk analytical methods, but should be used to supplement them and to prepare for them. It should be preferably performed during a face-to-face meeting of members of an expert panel that is developed specifically for the issues under consideration. The meeting of the expert panel should be conducted after communicating to the experts in advance to the meeting background information, objectives, list of issues, and anticipated outcome from the meeting. The different components of the expert-opinion elicitation process are described by Ayyub (1999).

1.3 Recent USACE Expert-Opinion Elicitation Studies

Expert-opinion elicitation is a technique for using a panel of individuals with various areas of specialized knowledge for estimating parameters or addressing issues of interest based on their expertise. Expert-opinion elicitation has been recently applied by the New Orleans District's study of the Lower Atchafalaya Basin and reevaluation of the Morganza to the Gulf of Mexico feasibility studies, by Vicksburg District's Pearl River study, and by the Sacramento District's Feather River flood damage study. Details on some of these studies are provided by Ayyub (1999).

1.4 Lindy C. Boggs Lock and Dam

The Lindy Claiborne Boggs Lock and Dam is designed to facilitate navigation along the J. Bennett Johnston Waterway between the Mississippi River and Shreveport, LA. Construction of the lock and dam was completed in 1984. A schematic representation of the existing site plan is shown in Figure 1, and annotated photographs of the site are provided as Figure 2.

To accommodate the large fluctuation of water levels, floating guide walls upstream and downstream of the lock were incorporated into the plans. To retain the riverside lock wall backfill, a concrete "T-wall" was constructed for a distance of 130 ft (approximately 40 m) perpendicular from the lock on the downstream end. Anticipating that sediment would deposit in the navigation channel underneath the downstream floating guide wall, provisions were provided in the original plans in the form of an earthen dike and a composite "I-wall" (steel sheetpiling and concrete wall) on top of the dike. The I-wall was connected to the T-wall and continued 130 ft offset from and parallel to the floating guide wall for 1,100 ft (335 m). The purpose of the dike and I-wall was to divert the flow and sediment from the floating guide wall and the navigation channel thus providing a slack water lock approach channel.

After service began in 1984, the T-wall and the I-wall were inundated and sediment began accumulating beneath the downstream floating guide wall, within the concrete lock monoliths, and in the navigation channel and lock approach. As a potential remedy for this problem, the height of the sediment barrier walls was increased from elevation (el) 38.0[1] to el 55.0. An angled timber wall was constructed upstream of the T-wall and the I-wall was modified by constructing a timber wall on top of it. These timber walls were completed in 1986. The angled timber wall extends 30 ft (9 m) from the end of the T-wall upstream and parallel

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[1] All elevations (el) cited herein are in feet referenced to the National Geodetic Vertical Datum.

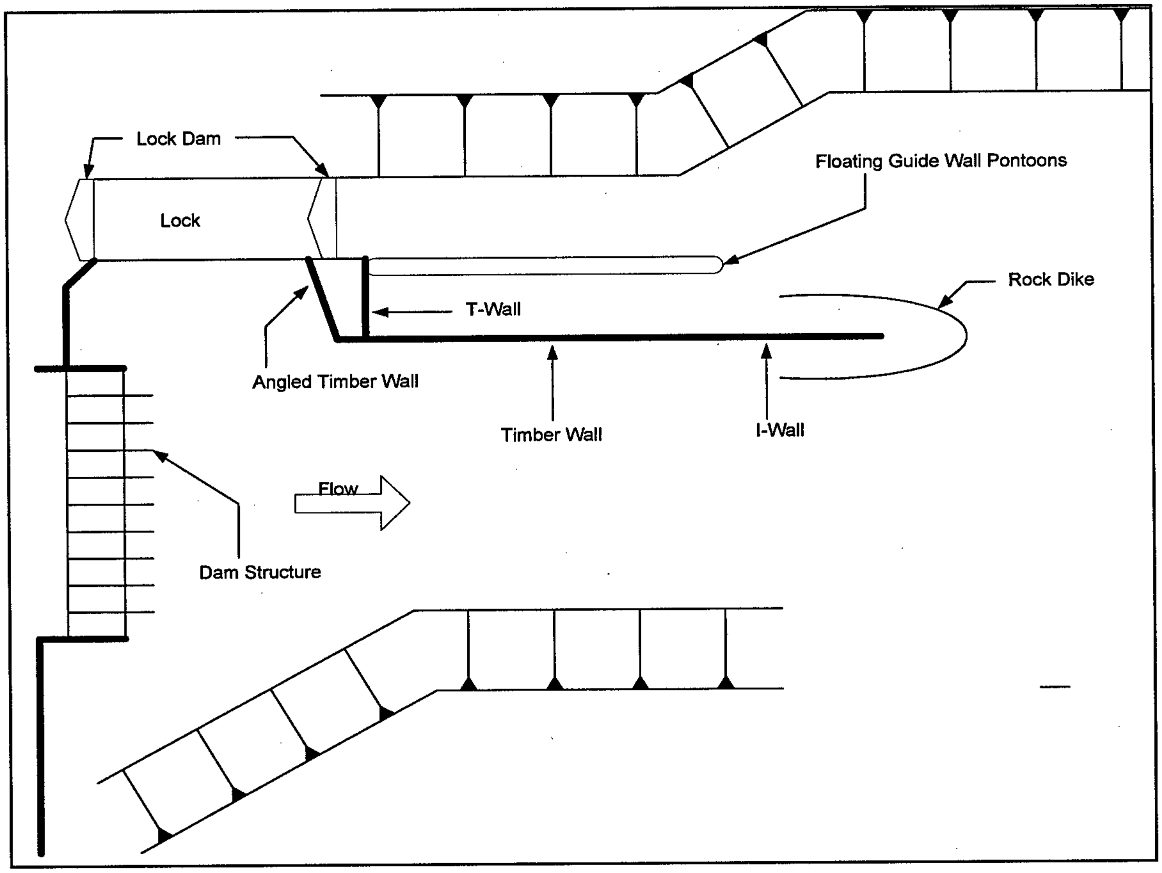

Figure 1. Schematics of the existing site (not to scale)

to the lock wall and then it extends 135 ft (41 m) back to the lock wall on a 24-deg skew angle. The timber curtain wall constructed on top of the I-wall measured 398 ft (121 m) from the intersection with the T-wall. The timber wall is supported by a steel H-pile A-frame structure.

After this measure showed that a timber barrier wall could reduce the amount of deposit of sediment within the lock chamber, beneath the floating guide wall, and within the lock approach channel, the timber wall on top of the I-wall was extended an additional 504 ft (157 m) farther downstream. The extended timber wall (completed in 1988) has proven to be somewhat more effective in reducing the accumulation of sediment although sedimentation continues to be a problem. Dredging has been required on an annual or semi-annual basis to remove sediment from beneath the floating guide wall. The barrier has reduced the amount of sediment deposited in the lower lock approach. However, the lower floating guide wall is still removed yearly or semi-annually for sediment removal from beneath the lower pontoons. Pontoon removal has resulted in minor damage to the pontoons. With the guide wall removed, damage can occur from barge impacts on the end of the lock approach wall adjacent to the location of the guide wall.

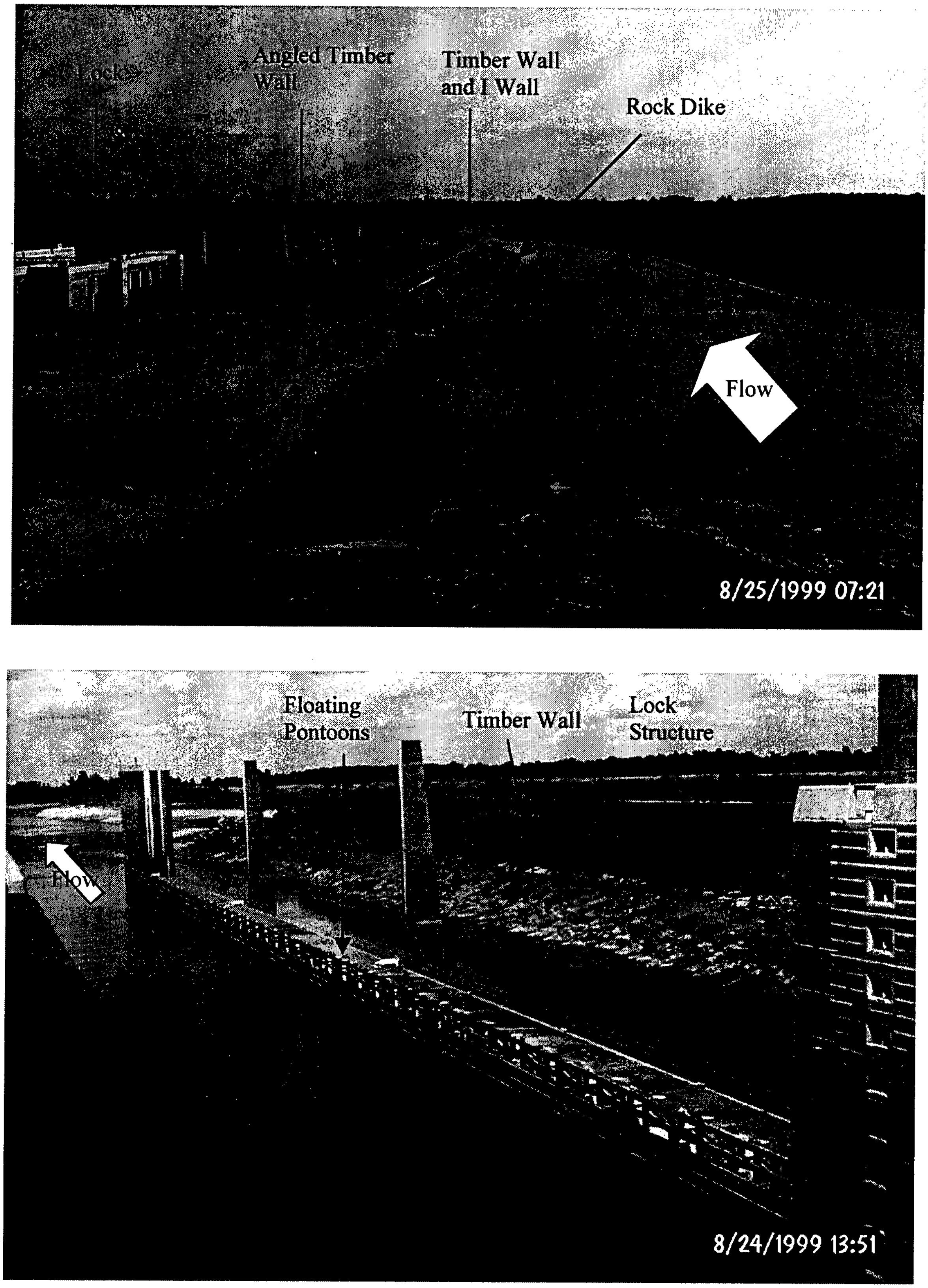

Figure 2. Annotated photographs of existing site

1.5 Objectives and Scope

This study uses expert-opinion elicitation to obtain information related to occurrence probabilities and associated consequences. Three alternative improvements are proposed to control sedimentation in the Lindy C. Boggs Lock and Dam. The Vicksburg District requires the probability of catastrophic failure during the construction and utilization phases of the lock-improvement alternatives including potential catastrophic damage occurring to the floating guide wall pontoons while they are being removed, transported to and from their temporary storage area, and reinstalled. The tasks in every phase of each alternative are assessed for risk by examining initiating events, failure scenarios, occurrence probabilities and associated consequences. Initiating events and failure scenarios are identified and enumerated. Consequences and occurrence probability are determined by expert-opinion elicitation, as documented in this report.

Succeeding sections of this report provide a description of the improvement alternatives (Chapter 2), details regarding the panel of experts (Chapter 3), a discussion of the expert-opinion elicitation process (summarized in Chapter 4 and detailed in Appendix A), definition of the five sets of issues (Appendix B), discussion of formulas used for calculating percentiles to aggregate the various expert opinions (Appendix C), and a glossary of terms (Appendix D).

2 Improvement Alternatives

2.1 Background

Michael Baker, Inc., conducted a lower lock approach sediment control study consisting of six alternatives for solving the sedimentation problem. The study consisted of performing preliminary engineering design on each of the six different alternatives and obtaining costs and benefits with associated uncertainties and risks. Of the six alternatives, the Corps considered two viable and worthy of further investigation. The two viable alternatives were modified expanded into three alternatives for further investigation and preliminary design. Neel-Schaffer, Inc., examined the three alternatives and performed design analyses on each alternative proposing to solve or reduce the sedimentation. Three alternatives were assessed, based on costs and benefits with associated uncertainties and risks, to select the best design improvement.

The proposed alternatives to the sedimentation problem are listed below.

a. Remove the timber barrier, concrete I-wall, and dike and build a fixed guide wall.

b. Remove the timber barrier and the concrete I-wall and build a fixed guide wall.

c. Extend the existing timber barrier downstream an additional 400 ft (122 m), replace the timber wall with concrete panels, and encase the steel H-pile support frames in concrete.

This section defines and describes the three alternatives.

2.2 Alternative A: New Fixed Guide Wall with Dike Removal

The existing floating guide wall pontoons will be removed and disposed of, and a new cast-in-place guide wall will be constructed. The foundation for this fixed guide wall will consist of a sheet-pile cell and pile-supported cast-in-place concrete footing. The new guide wall will be constructed to the same elevation as that of the lock walls and to the same length as the existing floating guide wall. The existing timber curtain walls, concrete I-wall, earthen dike, and a portion of the T-wall will be removed and disposed of. The backfill on the riverside of the guide wall will match the slope of the lock wall backfill and taper to no backfill at t he downstream end of the guide wall. All excess material from the dike will be relocated to the left descending bank of the downstream lock approach channel to construct a navigation channel width of 115 ft (35 m) through the downstream lock approach, measured from the guide wall to the toe of the left descending bank. This width is consistent with the width at Russell B. Long Lock and Dam (formerly Lock and Dam No. 4) on the J. Bennett Johnston Waterway.

2.3 Alternative B: New Fixed Guide Wall with Retention of Dike

The existing floating guide wall pontoons will be removed and disposed of, and a new cast-in-place guide wall will be constructed. The foundation for this fixed guide wall will consist of a sheet-pile cell and pile-supported cast-in-place concrete footing. The new guide wall will be constructed to the same elevation as that of the lock walls and to the same length as the existing floating guide wall. The existing timber curtain walls, concrete I-wall, and a portion of the T-wall will be removed and disposed of. The existing dike will remain in place. The backfill on the riverside of the guide wall will match the top elevation of the existing dike until the end of the guide wall is reached, where the backfill between the existing dike and the guide wall will taper to no backfill at the downstream end of the guide wall. The left descending bank of the downstream lock approach channel will be filled in with suitable material to construct a navigation channel width of 115 ft (35 m) through the downstream lock approach, measured from the guide wall to the toe of the left descending bank. This width is consistent with the width at Russell B. Long Lock and Dam.

2.4 Alternative C: Barrier Extension and Use of Concrete Panels

The timber barrier wall (including the angled timber wall) will be removed, disposed of, and replaced with solid precast concrete wall panels. This alternative will require constructing a new T-wall along the limits of the existing angled wall. New structural steel framing members will be used to attach the new concrete panels to the existing steel H-pile A-frame structure. The new concrete panels will be built to the same elevation as that of the existing timber walls (el 55.0) and will be extended to the end of the existing I-wall (sta 20+15L). A new section, including new concrete wall panels and supporting H-pile A-frame structures, will be constructed approximately 200 ft (61 m) farther downstream to sta 22+16.65L. The dike will also be built up to el 24.25 for approximately 200 ft downstream. The steel H-piles will be cleaned of any foreign materials (existing piles only), repaired as necessary (existing piles only), and concrete encased. Other items of work to be completed in this alternative include excavating the downstream lock approach channel to el -7.0 and excavating the silt on the dike to its original as-built condition.

3 Selection of Experts

3.1 Requirements

The size of the expert panel should be large enough to achieve a needed diversity of opinion, credibility, and result reliability. In recent expert-opinion elicitation studies, a nomination process was used to establish a list of candidate experts by consulting archival literature, technical societies, governmental organizations, and other knowledgeable experts. Formal nomination and selection processes should establish appropriate criteria for nomination, selection, and removal of experts. The résumés of candidates to fill the panel of expert positions should be submitted and reviewed. The panel members should have comprehensive combined knowledge of the following:

a. Design of locks, dams, dikes, and platoons.

b. Construction of locks, dams, dikes, and platoons.

c. Dredging operations.

d. Operating and maintaining locks and dams.

e. Traffic management during construction and operation of locks and dams.

It is necessary to personally contact individual experts for the purpose of establishing clear understanding of expectations.

Observers also need to be invited to participate in the elicitation process. The observers can contribute to the discussion, but not to the expert judgment. The observers can include the following:

a. One or two observers with research or administrative-related background from research laboratories or headquarters of the U.S. Army Corps of Engineers with knowledge of civil works facilities or studies.

b. One or two people with expertise in probabilistic analysis, probabilistic computations, consequence computations and assessment, and expert elicitation. This observer can be the technical facilitator or the technical integrator and facilitator.

A list of experts and brief biographical statements for them is presented in Section 3.2.

3.2 Selected Experts, Observers, and Facilitator

3.2.1 Expert Panel

3.2.1.1 Members

NAME	AFFILIATION
Construction	
Joe McCormick	Management and construction - USACE
Robert Coco	Lockmaster and Site Supervisor at Lindy C. Boggs L&D
Jimmy Coldiron	Mechanical design, construction and repair - USACE
Engineering	
John O. Burnworth	Structural design and construction - USACE
Fred Lee, Jr.	Mechanical engineering and design - USACE
Jimmy Coldiron	Mechanical engineering - USACE
Rick Robertson	Hydraulic engineering - USACE
George Sills	Geotechnical engineering - USACE
Cost Estimation (MCACES prepared by Danny McPhearson, Vicksburg District, SACE)	
John O. Burnworth	Structural engineering, USACE
Fred Lee, Jr.	Mechanical engineering, USACE
Safety	
Robert Coco	Lockmaster and Site Supervisor at Lindy C. Boggs L&D
Management	
Joe McCormick	Management – USACE
Robert Coco	Lockmaster and Site Supervisor at Lindy C. Boggs L&D

3.2.1.2 Biographical Information

Joe McCormick – From 1978 to 1981, Mr. McCormick served as Construction Representative for Felsenthal and Calion L&D projects during their construction phase. After that time he continued the same function at Lake Chicot Pumping Plant during construction. Mr. McCormick was the Lockmaster at Overton L&D from 1987 to 1994. He also served as a second operator at Lindy C. Boggs L&D during the cylinder rehabilitation job. Currently, Mr. McCormick is the Facility Manager over all the locks and dams on the Ouachita/Black and J. Bennett Johnston Waterways. Part of his responsibility in navigation is to continuously monitor channel conditions, employ a full-time survey party, and monitor as many as three dredges. This includes all approach channels to the locks and dams on the Ouachita/Black and J. Bennett Johnston Waterways. He also spends as much as 2 months each year at Lindy C. Boggs L&D working on the downstream approach and the downstream guide wall. He is also responsible for many daily managerial tasks required of the facility manager.

Robert Coco – Mr. Coco was the Construction Inspector on Lindy C. Boggs L&D from July 1980 to November 1984. After that time he was equipment mechanic at Lindy C. Boggs L&D during the period November 1984 to March 1986. Currently, Mr. Coco is the lockmaster and site supervisor at Lindy C. Boggs L&D.

John O. Burnworth – Mr. Burnworth has over 25 years structural design experience. His 20 years of structural design experience on navigation locks and dams includes Felsenthal L&D and T.K. Thatcher L&D (Calion L&D) on the Ouachita-Black Navigation Project; and Lindy C. Boggs L&D (Lock & Dam No. 1), Lock & Dam No. 3, Russell B. Long L&D (Lock & Dam No. 4), and Joe D. Waggonner, Jr. L&D (Lock & Dam No. 5) on the J. Bennett Johnston Waterway project (Red River Waterway). Mr. Burnworth has performed feasibility-level designs within the last 2 years on Bayou Boeuf Lock, Englewood Lock, and Amelia Lock for the New Orleans District.

Fred Lee, Jr. – Mr. Lee has over 31 years of design experience with the Corps of Engineers. His experience includes the design and repair of barges, boats, pump stations, and numerous locks and dams. Mr. Lee is the senior mechanical designer for the Vicksburg District.

Jimmy Coldiron – Mr. Coldiron has over 13 years of design and operations experience with the Corps of Engineers on numerous projects, including the Red River Waterway Locks and Dams, Felsenthal L&D, Lake Chicot Pumping Plant, the Central Maintenance Facility, and repairs to both Ouachita/Black and Red River Locks and Dams. Mr. Coldiron is currently with the Operations Division, River Operations, Navigation Branch. His duties include coordination of major repairs to all locks and dams, special projects coordinator for emergency levee and channel repairs, coordinating consolidated maintenance programs for locks and dams, and assisting field personnel in major repairs or problems.

Rick Robertson – Mr. Robertson has over 25 years of hydraulic design experience. His experience includes the design and modification of designs to lock approaches on the J. Bennett Johnston Waterway. Mr. Robertson is currently serving as Chief, Hydraulics Section, of the Vicksburg District.

George Sills – Mr. Sills over 25 years of experience in geotechnical design and over 20 years of experience in solving construction-related problems. His design experience includes foundation design of navigation locks and dams including Felsenthal L&D and T.K. Thatcher L&D (Calion L&D) on the Ouachita-Black Navigation Project, as well as Lindy C. Boggs L&D (L&D

No. 1), John H. Overton L&D (L&D No. 2), L&D No. 3, Russell B. Long L&D (L&D No. 4), and the Joe D. Waggonner, Jr., L&D (L&D No. 5) on the J. Bennett Johnston Waterway Project (Red River Waterway). Mr. Sills is the senior geotechnical designer for the Vicksburg District.

3.2.2 Observers

Robert C. Patev is currently a senior geotechnical engineer with the U.S. Army Engineer District, New England, in Concord, MA. He was more recently a research civil engineer at the Corps' Engineer Research and Development Center, Waterways Experiment Station, in Vicksburg, MS. For the past 8 years, Mr. Patev has focused his work in the areas of risk assessment and engineering reliability. He has worked in directing both the risk and reliability research arena for the Corps, as well as working with Corps Districts on the application of time-dependent reliability procedures to many navigation projects. Mr. Patev's background is diverse, with degrees in geology, geotechnical engineering, and structural engineering. He has published a variety of journal and conference papers on risk assessment and engineering reliability and has contributed technical chapters to a variety of textbooks.

Terry Baldridge is the ITR (reviewer). Mr. Baldridge has 7 years experience as an economist with the U.S. Army Corps of Engineers. His experience includes risk-based feasibility and reliability analysis.

3.2.3 Technical Integrator and Facilitator

Bilal M. Ayyub (PhD, PE, Consultant, University of Maryland, College Park) is a Professor of Civil Engineering at the University of Maryland, College Park. He completed his B.S. degree in civil engineering in 1980, and completed both the M.S. (1981) and Ph.D. (1983) in civil engineering at the Georgia Institute of Technology. Dr. Ayyub has an extensive background in risk-based analysis and design, simulation, structural engineering, and uncertainty modeling and analysis. He completed several projects for the U.S. Army Corps of Engineers, U.S. Coast Guard, and U.S. Navy in this area. He is an author of more than 250 books, publications in journals and conferences, and reports. He is engaged in research work involving structural reliability, and mathematical modeling using the theories of probability, statistics, and fuzzy sets.

4 Expert-Opinion Elicitation

4.1 Background

The elicitation process of opinions should be conducted in a systematic manner for all issues according to the following steps:

a. Issue familiarization of experts.

b. Training of experts.

c. Elicitation and collection of opinions.

d. Aggregation and presentation of results.

e. Group interaction, discussion, and revision by experts.

Details of the above steps are provided in Appendix A. This chapter describes the issues, and the issue statements are provided in Appendix B.

The issues consist of groups of questions concerning the tasks that have to be executed in each phase for each alternative. The tasks in every phase for each alternative are assessed for risk by examining initiating events, failure scenarios, occurrence probabilities, and associated consequences. Initiating events and failure scenarios are identified and enumerated by Ayyub, Blair, and Patev (2002). This expert-opinion elicitation process is a formal process of obtaining information or answers to specific questions about the issues, specifically relating to failure rates (or occurrence probabilities) and failure consequences.

Occurrence probabilities and associated consequences are determined from the opinions elicited from experts. These opinions can be given as subjective evaluations in linguistic terms, using linguistic variables given with corresponding numerical values. Possible values of the linguistic variable Consequence include Very low, Low, Medium, High, and Very high. The costs resulting from these consequences are approximated by the values given in Table 1, which are provided as a guide.

The values of the linguistic variable Occurrence Probability can include Very low likelihood, Low likelihood, Moderate likelihood, High likelihood, and Very high likelihood. The probabilities resulting from these likelihoods are approximated by the values given in Table 2, which are provided as a guide.

Table 1
Cost Approximations of Consequence Linguistic Variable (Present Value)

Consequence Linguistic Variable	Cost Approximation
Very low	Less than $50,000
Low	$ 100,000
Medium	$ 500,000
High	$ 1 million
Very high	Over $10 million

Table 2
Probability Approximations of Likelihood Linguistic Variable

Likelihood Linguistic Variable	Probability Approximation
Very low	10^{-3}
Low	2.5×10^{-2}
Medium	5×10^{-2}
High	7.5×10^{-2}
Very high	0.1

4.2 Selected Issues

The three alternatives involve sets of similar tasks and issues. Also, each alternative requires specific tasks that are unique to the alternative. Five sets of issues are identified:

a. Specialty construction issues.

b. Conventional construction issues.

c. Dredging issues.

d. Traffic maintenance issues.

e. Inspection, maintenance, and repair issues.

Opinions on occurrence probabilities and associated consequences for events of interest are elicited from experts with respect to the entire task and all related quantities. Details of the issues are described below, while the issue statements are provided in Appendix B.

4.2.1 Specialty Construction Issues

The specialty construction issue consists of questions relating to tasks during the construction phase that are specific to lock and dam construction. These tasks are:

a. Removal of pontoons.

b. Reinstallation of pontoons.

c. Removal of I-wall and sheet pile.

d. Removal of T-wall.

e. Removal of timber curtain wall.

f. Attachment of precast concrete panels.

Removal of pontoons involves the activities required to remove and dispose of the existing lower floating guide wall pontoons. The activities are as detailed below:

a. Utilize a work crew consisting of approximately eight people to accomplish the task.

b. Shut lock chamber to all lockages for approximately 4 to 6 hr.

c. Utilize two skiffs and one mule barge and/or towboat to move pontoon out of its location and into lock chamber.

d. Remove and secure all three sections (pontoons) in chamber after they are taken loose from guide beams. The pontoons should be removed in order as pontoon 3, then 2, and finally 1. Pontoon 3 is farthest downstream pontoon. This process takes approximately 3 to 4 hr. Once this process begins, it cannot be stopped until all three pontoons are disconnected, moved, and secured in the chamber.

e. Remove the pontoons from the chamber and float them to the upstream guide wall location and secure them. This process requires approximately 3 to 4 hr if weather conditions are favorable. High winds can hamper this operation.

Reinstallation of pontoons is required for one of the three alternatives (Alternative C). This involves storage of the downstream floating guide wall behind the upstream floating guide wall and reinstallation of the downstream floating guide wall, as described below.

a. Approximately once a week, pontoons are inspected for loose ropes or lines and to ensure that they are not in contact with any other concrete surfaces. Rubber tires are placed between each section (pontoon) to keep the sections from touching any other concrete surfaces.

b. Pontoons may be moved out and secured behind the upstream guide wall anywhere from 3 to 6 months, depending on the downstream river elevation.

Reinstallation of the downstream floating guide wall is described below.

a. Requires a towboat and two skiffs.

b. Same crew size needed as required to remove pontoons.

c. Pontoons are floated out of their stored location and into lock chamber. They are secured off in opposite order they are to be installed, with No. 1 being next to the lock. This process requires approximately 3 to 4 hr, during which the lock chamber is shut down to traffic.

d. Remove from chamber and push into place one pontoon at a time. Attach pontoon to guide beams (pontoon 1 first, then No. 2, and finally 3. The lock chamber still shuts down during this process, which requires approximately 4 to 6 hr.

Removal of I-wall and sheet pile involves the removal and disposal of the existing concrete I-wall. The purpose of the I-wall [dimensions: 1,100 ft (335 m) long, 18.25 ft (5.6 m) high, 2 ft (0.6 m) thick] is to divert the flow and sediment from the floating guide wall and the navigation channel. The wall base is set in 2 ft of riprap.

Removal of the T-wall involves removal and disposal of the existing concrete T-type retaining wall. The existing T-wall is approximately 130 ft (40 m) long, 18.25 ft high, and 2 ft thick

The next issue involves removal of the timber curtain wall, which is constructed on top of the I-wall and measures 900 ft (274 m) long and 17 ft (5 m) high. The timber wall is supported by steel H-pile A-frame structures.

Attachment of precast concrete panels is required for all three alternatives. This process involves attaching new solid precast concrete panels to the front of the sheet-pile cells for the fixed wall or attaching new solid precast concrete panels to the existing and new structural steel frames. The precast concrete panels are attached to replace the existing timber wall and are approximately 900 ft long and 17 ft high.

Issue statements and a questionnaire for the specialty construction issues are provided in Appendix B (section B.1).

4.2.2 Conventional Construction Issues

A number of tasks and initiating events for each alternative and phase are conventional construction activities. These activities have risks similar to conventional construction risk. In assessing risks for each alternative and phase, these activities are considered as initiating events and failure scenarios and, therefore, occurrence probabilities and associated consequences are assessed for the task as a whole.

The tasks involved in the conventional construction are as follows:

a. Construction of guide walls.

b. Construction of concrete panels.

c. Removal of earth dike.

d. Construct new T-wall.

e. Backfill and riprap.

f. Relocation of excess material.

g. Excavation of silt.

h. Cleaning and repairing H-piles.

i. Driving and encasing new H-piles.

Construction of guide walls involves constructing the new cast-in-place guide wall. The new guide wall will be constructed to the same elevation as that of the lock walls, and to the same length as the existing floating guide wall that will measure 685 ft (209 m) long and 60 ft (18 m) high.

Construction of concrete panels is required for all of the three alternatives. For Alternatives A and B, the new concrete panels will be placed in front of the sheet-pile cells to provide a rubbing surface for barges and towboats at low river stages. For Alternative C, the new concrete panels will be built to the same elevation as the existing timber walls to the end of the existing I-wall, and will measure 900 ft (274 m) long and 17 ft (5 m) high.

Removal of earth dike occurs downstream from the new guide wall. Probabilities and consequences are elicited for the entire task, including all related quantities.

Backfill and riprap occurs behind the guide wall. The backfill on the pier side of the guide wall will match the slope of the lock wall backfill and will taper to no backfill at the downstream end of the guide wall. Probabilities and consequences are elicited for the entire task, including all related quantities.

Relocation of excess materials is from the dike to the landside bank of the downstream lock approach channel. All excess material from the dike will be relocated to the left descending bank of the downstream lock approach channel. Probabilities and consequences are elicited for the entire task, including all related quantities.

Excavation of silt is described in Chapter 2. Probabilities and consequences are elicited for the entire task, including all related quantities.

Cleaning and repairing H-piles is necessary for one of the alternatives (Alternative C). Each of the timber wall panels is supported by steel H-pile A-frames. The existing steel H-piles will be cleaned of any foreign materials and repaired as necessary. The new and existing steel H-piles will then be concrete encased.

Issue statements and a questionnaire for the conventional construction issues are provided in Appendix B.2.

4.2.3 Dredging Issues

The alternatives considered have proven to be effective in reducing the accumulation of sediment, although sedimentation will continue to be a problem. Dredging has been required on an annual or sometimes on a semi-annual basis. Based upon dredging results at other installations that employ a guide wall system similar to the proposed system, annual dredging requirements would be approximately 50,000 cu yd (38,000 cu m). This accumulation of sediment could be maintained by maintenance dredging and would not impede barge traffic.

Issue statements and a questionnaire for the dredging issues are provided in Appendix B.3.

4.2.4 Traffic Maintenance Issues

The traffic maintenance issues involve maintaining a navigation channel of varying width through the downstream lock approach. This includes maintaining barge traffic during construction and maintaining traffic during dredging. Depending on the alternative and whether the traffic maintenance is for construction or during dredging, the require navigation channel width may be 42, 84, 115, or 240 ft (13, 26, 35, or 73 m).

Issue statements and a questionnaire for the dredging issues are provided in Appendix B.4.

4.2.5 Inspection, Maintenance, and Repair Issues

Inspection, maintenance, and repair issues relate to any needed inspection, maintenance, and repair. For Alternatives A and B, inspections will be held every year for the first 5 years, then once every 5 years thereafter.

For Alternative C, inspections will be held every year for the first 5 years, then once every 5 years thereafter. In this alternative, inspection, maintenance, and repair include the replacement of the timber fenders of the floating guide wall every 5 years and repainting all metal structures every 17 years.

Replacement of the timber fenders of the floating guide wall every 10 to 12 years has been done on the upstream guide wall and required a crew of approximately 4 to 6 men with a towboat and work barge. This operation took approximately 60 to 90 days to complete. Traffic was not delayed, and the lock was never shut down. The work barge was moved on and off location when needed.

The disposal of old timbers is included in this task. All of the existing timbers are creosoted pine. These old timbers have to be placed on the bank and trucked to a certified state landfill for disposal. This requires numerous truckloads to accomplish.

Probabilities and consequences are elicited for the entire task, including all related quantities. Issue statements and a questionnaire for the inspection, maintenance, and repair issues are provided in Appendix B.5.

4.3 Elicitation and Aggregation of Expert Opinions

The panel of experts, observers, and the facilitator convened in Vicksburg, MS, for a period of 2 days to discuss the issues in Appendix B. The following protocol was followed in the deliberation of the issues:

a. After presenting an issue without any ambiguity and clear conditions, discussion of the issue was encouraged, and a form with a statement of the issue was given to the experts to record their evaluation or input. The experts' judgment, along with their supportive reasoning, was recorded for the issues.

b. The collected assessments from the experts were analyzed and aggregated to obtain composite judgments about the issues. The medians, percentile values, and standard deviations were computed for the issues. Also, a summary of the reasoning provided during the meeting about the issues was developed. Uncertainty levels in the assessed issues should also be quantified.

c. The aggregated results were presented to the experts for a second round of discussion and revision. The experts were given the opportunity to revise their assessments of the individual issues at the end of discussion. Also, the experts were asked to state the rationale for their statements and revisions. The revised assessments of the experts were collected for aggregation and analysis.

d. A comprehensive documentation of the process is essential to ensure acceptance and credibility of the results. This document includes complete descriptions of the initial and revised results.

The nonaggregated and aggregated results are provided in Appendix B, along with the experts' supportive reasoning for each of the issues.

4.4 General Comments and Process Review by the Experts

The experts were requested to comment on the expert-opinion elicitation process, and they provided the following comments:

a. A participant first thought that he/she would be "in over his head," but after the introductory presentation, he/she was much more comfortable.

b. It would be helpful to have more information relative to the issues prior to the workshop.

References

Ayyub, B. M. (1999). “Guidelines on expert-opinion elicitation of probabilities and consequences for Corps facilities,” U.S. Army Engineer Institute for Water Resources, Fort Belvoir, VA.

Ayyub, B. M., Blair, A. N., and Patev, R. C. (2002). “Risk analysis of design-improvement alternatives to the Lindy Claiborne Boggs Lock and Dam,” ERDC/ITL TR-02-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Appendix A Expert-Opinion Elicitation Process

A.1 Process Definition

Expert-opinion elicitation was defined as a formal, heuristic process of obtaining information or answers to specific questions about certain quantities, called issues, such as failure rates, failure consequences, and expected service lives. The suggested steps for an expert-opinion elicitation process depend on the use of a technical integrator (TI) or a technical integrator and facilitator (TIF), as shown in Figure A1 (Ayyub 1999). The details of the steps involved in these two processes are defined in subsequent subsections.

A.2 Need Identification

The primary reason for using expert-opinion elicitation is to deal with uncertainty in selected technical issues related to a system of interest. Issues with significant uncertainty, issues that are controversial or contentious, issues that are complex, and issues that can have a significant effect on risk are most suited for expert-opinion elicitation. The value of the expert-opinion elicitation comes from its initial intended uses as a heuristic tool, not a scientific tool, for exploring vague and unknown issues that are otherwise inaccessible. It is not a substitute to scientific, rigorous research.

The identification of need and its communication to experts are essential for the success of the expert-opinion elicitation process. Need identification and communication should include defining the goal of the study and the relevance of issues to this goal. Establishing this relevance would make the experts stakeholders and thereby increase their attention and sincerity levels. Relevance of each issue or question to the study needs to be established, and is essential to enhancing the reliability of collected data from the experts. Each question or issue needs to be relevant to each expert, especially when dealing with subjects with diverse views and backgrounds.

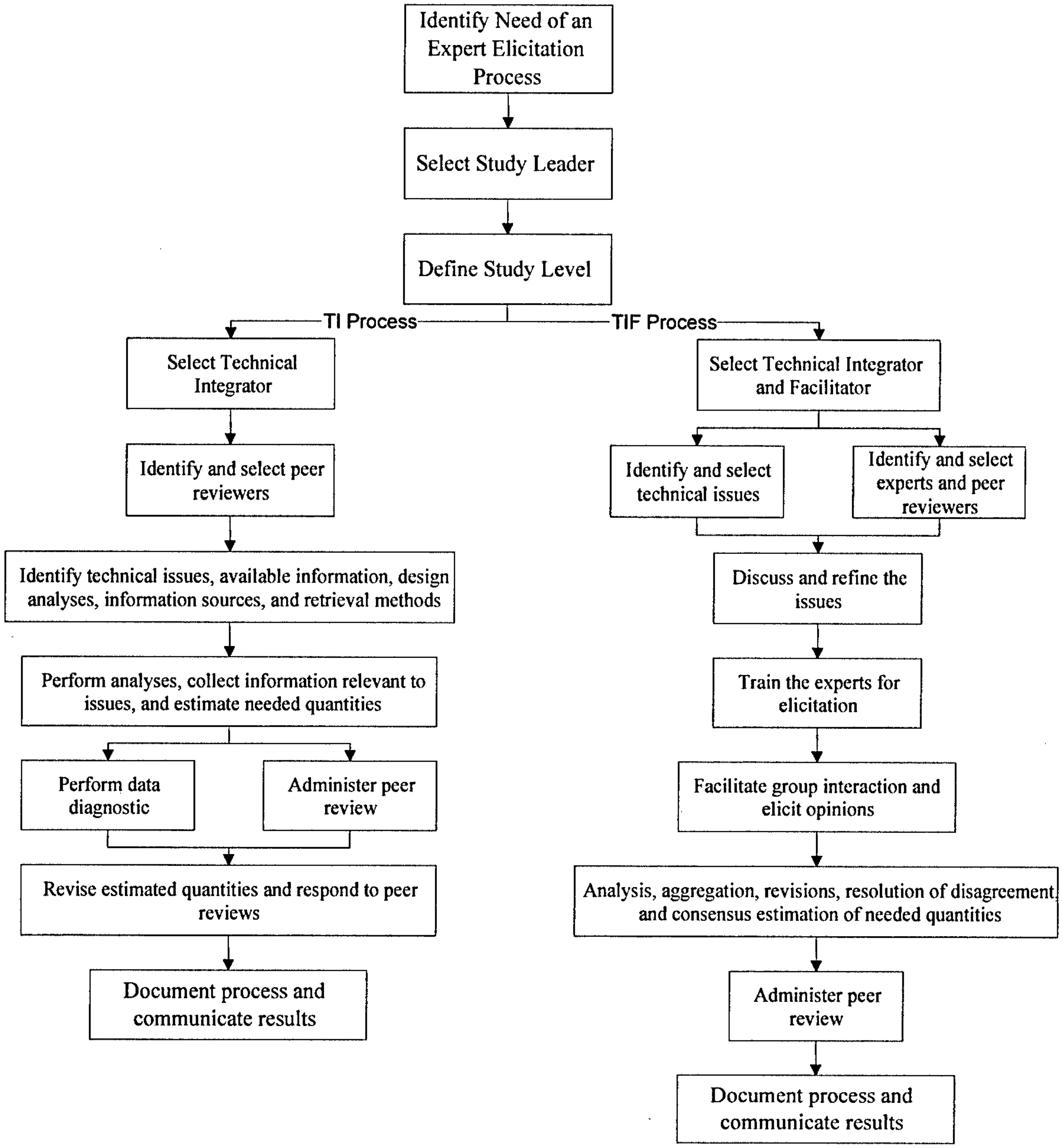

Figure A1. Expert-opinion elicitation process

A.3 Selection of Study Level and Study Leader

The goal of a study and the nature of issues determine the study level (Ayyub 1999). The study leader can be a technical integrator (TI), technical facilitator (TF), or a combined technical integrator and facilitator (TIF). The leader of the study is an entity having managerial and technical responsibility for organizing and executing the project, overseeing all participants, and intellectually owning the results. Expert-opinion elicitation commonly utilizes a TI or TIF leader. The primary difference between the TI and the TIF is in the intellectual responsibility for the study, where it lies with only the TI, compared with the TIF and the experts, respectively. The TIF has also the added responsibility of maintaining the professional integrity of the process and its implementation. The TI is required to use peer reviewers for quality assurance purposes. A study leader should be selected based on the following attributes:

a. An outstanding professional reputation, and wide recognition and competence based on academic training and relevant experience

b. Strong communication skills, interpersonal skills, flexibility, impartiality, and ability to generalize and simplify.

c. A large contact base of industry leaders, researcher, engineers, scientists, and decision-makers.

d. An ability to build consensus, and leadership qualities.

The study leader does not need to be a subject expert, but should be knowledgeable of the subject matter.

A.4 Selection of Peer Reviewers and Experts

A.4.1 Selection of Peer Reviewers

Peer review can be classified according to either peer-review method or subject. Two methods of peer review can be employed: (1) participatory peer review, which would be conducted as an ongoing review throughout all study stages and (2) late-stage peer review, which would be performed as the final stage of the study. The second classification of peer review, based on subject, has two types: (1) technical peer review, which focuses on the technical scope, coverage, contents, and results and (2) process peer review, which focuses on the structure, format, and execution of the expert-opinion elicitation process.

Peer reviewers are needed for both the TI and TIF processes. The peer reviewers should be selected by the study leader in close consultation with perhaps the study sponsor. The following individuals should be sought after to serve as peer reviewers:

a. Researchers, scientists, and engineers who have outstanding professional reputation and widely recognized competence based on academic training and relevant experience.

b. Researchers, scientists, and engineers with general understanding of the issues in other related areas, or with relevant expertise and experiences from other areas.

c. Researchers, scientists, or engineers who are available and willing to devote the needed time and effort.

d. Researchers, scientists, or engineers with strong communication skills, interpersonal skills, flexibility, impartiality, and ability to generalize and simplify.

A.4.2 Identification and Selection of Experts

The size of an expert panel should be determined on a case-by-case basis. The size should be large enough to achieve a needed diversity of opinion, credibility, and result reliability. In recent expert-opinion elicitation studies, a nomination process was used to establish a list of candidate experts by consulting archival literature, technical societies, governmental organizations, and other knowledgeable experts. Formal nomination and selection processes should establish appropriate criteria for nomination, selection, and removal of experts. For example, the following criteria were used to select experts for the Yucca Mountain seismic hazard analysis:

a. Strong relevant expertise through academic training, professional accomplishment and experiences, and peer-reviewed publications.

b. Familiarity and knowledge of various aspects related to the issues of interest.

c. Willingness to act as proponents or impartial evaluators.

d. Availability and willingness to commit needed time and effort.

e. Specific related knowledge and expertise of the issues of interest.

f. Willingness to effectively participate in needed debates, prepare for discussions, and provide needed evaluations and interpretations.

g. Strong communication skills, interpersonal skills, flexibility, impartiality, and ability to generalize and simplify.

In some studies, criteria were set for expert removal that include failure to perform according to commitments and demands, as set in the selection criteria, and unwillingness to interact with members of the study.

The panel of experts for an expert-opinion elicitation process should have a balance and broad spectrum of viewpoints, expertise, technical points of view, and organizational representation. The diversity and completeness of the panel of experts is essential for the success of the elicitation process. For example, it should include the following groups:

a. Proponents who advocate a particular hypothesis or technical position.

b. Evaluators who consider available data, become familiar with the views of proponents and other evaluators, question the technical bases of data, and challenge the views of proponents.

c. Resource experts who are technical experts with detailed and deep knowledge of particular data, issue aspects, particular methodologies, or use of evaluators.

The experts should be familiar with the design, construction, operational, inspection, maintenance, reliability, and engineering aspects of the equipment and components of a facility of interest. It is essential to select people with basic engineering or technological knowledge; however, they do not necessarily need to be all engineers or economists. It might be necessary to include one or two experts from management with engineering knowledge of the equipment and components, consequences, safety aspects, administrative and logistic aspects of operation, expert-opinion elicitation process, and objectives of this study. One or two experts with a broader knowledge of the equipment and components might be needed. Also, one or two experts with a background in risk analysis and risk-based decision-making and their uses in areas related to the facility of interest might be needed.

Observers can be invited to participate in the elicitation process. Observers can contribute to the discussion, but cannot provide expert opinion that enters in the aggregated opinion of the experts. The observers provide expertise in the elicitation process, probabilistic and statistical analyses, risk analysis, and other support areas. The composition and contribution of the observers are essential for the success of this process. The observers may include the following:

a. Individuals with research or administrative-related background from research laboratories or the U.S. Army Corps of Engineers with engineering knowledge of equipment and components of Corps facilities.

b. Individuals with expertise in probabilistic analysis, probabilistic computations, consequence computations and assessment, and expert-opinion elicitation.

A list of names with biographical statements of the study leader, technical integrator, technical facilitator, experts, observers, and peer reviewers should be developed and documented. All attendees can participate in the discussions during the meeting. However, only the experts can provide the needed answers to questions on the selected issues. The integrators and facilitators are responsible for conducting the expert-opinion elicitation process. They can be considered to be a part of the observers or experts, depending on the circumstances and the needs of the process.

A.4.3 Items Sent to Experts and Reviewers Prior to Meeting

The experts and observers need to receive the following items before the expert-opinion elicitation meeting:

a. An objective statement of the study.

b. A list of experts, observers, integrators, facilitators, study leader, sponsors, and their biographical statements.

c. A description of the facility, systems, equipment, and components.

d. Basic terminology and definitions, including probability, failure rate, average time between failures, mean (or average) value, median value, and uncertainty.

e. Failure consequence types.

f. A description of the expert-opinion elicitation process.

g. A related example on the expert-opinion elicitation process and its results, if available.

h. Aggregation methods of expert opinions such as computation of percentiles.

i. A description of the issues in the form of a list of questions with background descriptions. Each issue should be presented on a separate page with spaces for recording an expert's judgment, any revisions, and comments. Clear statements of expectations from the experts in terms of time, effort, responses, communication, and discussion style and format.

It might be necessary to personally contact individual experts for the purpose of establishing a clear understanding of expectations.

A.5 Identification, Selection, and Development of Technical Issues

The technical issues of interest should be carefully selected to achieve certain objectives. In these guidelines, the technical issues can be related to the quantitative assessment of failure probabilities and consequences for selected components, subsystems, and systems within a facility. The issues should be selected such that they would have a significant impact on the study results. These issues should be structured in a logical sequence starting with background statement, followed by questions, and then answer selections or answer format and scales. Personnel with risk-analysis background, who are familiar with the construction, design, operation, and maintenance of the facility, need to define these issues in the form of specific questions. Also, background materials about these issues need to be assembled. The materials will be used to familiarize and train the experts about the issues of interest, as described in subsequent steps.

An introductory statement for the expert-opinion elicitation process should be developed that includes the goal of the study and establishes relevance. Instructions should be provided with guidance on expectations, answering the questions, and reporting. The following are guidelines for constructing questions-and-issues based social research practices:

a. Each issue can include several questions; however, each question should consist of only one sought-after answer. It is a poor practice to include two questions in one.

b. Question-and-issue statements should not be ambiguous. Also, the use of ambiguous words should be avoided. In expert-opinion elicitation of failure probabilities, the word "failure" might be vague or ambiguous to some subjects. Special attention should be given to its definition within the context of each issue or question. The level of wording should be kept to a minimum. Also, the choice of words might affect the connotation of an issue, especially by different subjects.

c. The use of factual questions is preferred over abstract questions. Questions that refer to concrete and specific matters result in desirable concrete and specific answers.

d. Questions should be carefully structured to reduce biases of subjects. Questions should be asked in a neutral format, sometimes more appropriately without lead statements.

e. Sensitive topics might require stating questions with lead statements that would establish supposedly accepted social norms in order to encourage subjects to answer the questions truthfully.

Questions can be classified as open-ended or closed-ended. The format of the question should be selected carefully. The format, scale, and units for the response categories should be selected to best achieve the goal of the study. The minimum number of questions and the question order should be selected using practices and methods of educational and psychological testing and social research, as provided by Ayyub (1999).

Once the issues are developed, they should be pretested by administering them to a few subjects for the purpose of identifying and correcting flaws. The results of this pretesting should be used to revise the issues.

A.6 Elicitation of Opinions

The elicitation process of opinions should be systematic for all the issues according to the steps presented in this section.

A.6.1 Issue Familiarization of Experts

The background materials that were assembled in the previous step should be sent to the experts about 1 to 2 weeks in advance of the meeting, with the objective of providing sufficient time for them to become familiar with the issues. The objective of this step is, also, to ensure that there is a common understanding among the experts of the issues. The background material should include the objectives of the study; description of the issues and lists of questions for the issues; description of systems and processes, their equipment. and components; description of the elicitation process and selection methods of experts; and biographical information for the selected experts. Also, example results and their meaning, methods of analysis of the results, and lessons learned from previous elicitation processes should be made available to the experts.

It is important to break down the questions or issues in components that can be easily addressed. Preliminary discussion meetings or telephone conversations between the facilitator and experts might be necessary in some cases to prepare for the elicitation process.

A.6.2 Training of Experts

This step is performed during the meeting of the experts, observers, and facilitators. During the training, the facilitator needs to maintain flexibility to refine wording or even to change the approach based on feedback from experts. For instance, experts may not be comfortable with "probability" but they may answer on "events per year" or "recurrence interval." Additional information on the indirect elicitation is provided by Ayyub (1999). The meeting should begin with presentations of background materials to establish relevance of the study and study goals to the experts, in order to establish rapport with the experts. Then, information on uncertainty sources and types, occurrence probabilities and consequences, expert-opinion elicitation process, technical issues and questions, and aggregation of expert opinions should be presented. Also, experts need to be trained on providing answers in an acceptable format that can be used in the analytical evaluation of the failure probabilities or consequences. The experts need to be trained in certain areas, such as the meaning of probability, central tendency, and dispersion measures, especially for those experts who are not familiar with the language of probability. Additional training might be needed on consequences, subjective assessment, logic trees, problem structuring tools such as influence diagrams, and methods of combining expert evaluations. Sources of bias, including overconfidence and base-rate fallacy, and their contribution to bias and error should be discussed.

This step should include a search for any motivational bias of experts due to, for example, previous positions experts have taken in public, wanting to influence decisions and funding allocations, preconceived notions that they will be evaluated by their superiors as a result of their answers, or need to be perceived as an authoritative expert. These motivational biases, once identified, can sometimes be overcome by redefining the incentive structure for the experts.

A.6.3 Elicitation and Collection of Opinions

The opinion elicitation step starts with a technical presentation of an issue and, by decomposing the issue to its components, discussing potential influences, and describing event sequences that might lead to top events of interest. These top events are the basis for questions related to the issue in the next stage of the opinion elicitation step. Factors, limitations, test results, analytical models, and uncertainty types and sources need to be presented. The presentation should allow for questions to eliminate any ambiguity and to clarify scope and conditions for the issue. The discussion of the issue should be encouraged. The discussion and questions might result in refining the definition of the issue. Then, a form with a statement of the issue should be given to the experts to record their evaluation or input. The experts' judgment along with their supportive reasoning should be documented about the issue. It is common that experts would be asked to provide several conditional probabilities in order to reduce the complexity of the questions and thereby obtain reliable answers. These conditional probabilities can be based on fault tree and event tree diagrams. Conditioning has the benefit of simplifying the questions by decomposing the problems. Also, it results in a conditional event that has a larger occurrence probability than its underlying events; therefore making the elicitation less prone to biases since experts tend to have a better grasp of larger probabilities in comparison to very small ones. It is desirable to have the elicited probabilities in the range of 0.1 to 0.9 if possible. Sometimes it might be desirable to elicit conditional probabilities using linguistic terms as described by Ayyub (1999). If correlation among variables exits, it should be presented to the experts in great detail, and conditional probabilities need to be elicited.

Issues should be dealt with one issue at a time although, sometimes, similar or related issues might be considered simultaneously.

A.6.4 Aggregation and Presentation of Results

The collected assessments from the experts for an issue should be assessed for internal consistency, analyzed, and aggregated to obtain composite judgments for the issue. The means, medians, percentile values, and standard deviations need to be computed for the issues. Also, a summary of the reasoning provided during the meeting about the issues needs to be developed. Uncertainty levels in the assessments should also be quantified. A summary of methods for combining expert opinions was provided by Ayyub (1999). The methods can be classified into consensus methods and mathematical methods. The mathematical methods can be based on assigning equal weights to the experts or different weights. Appendix C provides percentile mathematical methods for combining opinions of experts.

A.6.5 Group Interaction, Discussion, and Revision of Results

The aggregated results need to be presented to the experts for a second round of discussion and revision. The experts should be given the opportunity to revise their assessments of the individual issues at the end of discussion. Also, the experts should be asked to state the rationale for their statements and revisions. The revised assessments of the experts need to be collected for aggregation and analysis. This step can produce either consensus or no consensus. The selected aggregation procedure might require eliciting weight factors from the experts. In this step the technical facilitator plays a major role in developing a consensus and in maintaining the integrity and credibility of the elicitation process. Also, the technical integrator is needed to aggregate the results without biases with reliability measures. The integrator might need to deal with varying expertise levels for the experts, outliers (i.e., extreme views), nonindependent experts, and expert biases.

A.7 Documentation and Communication

A comprehensive documentation of the process is essential to ensure acceptance and credibility of the results. The document should include complete descriptions of the steps, the initial results, revised results, consensus results, and aggregated results spreads and reliability measures.

Appendix B
Definition of Issues

The three alternatives involve sets of similar tasks and issues. They also involve tasks and issues that are of specific nature to each alternative. Five sets of issues are identified (as described in Chapter 4 of the main text):

a. Specialty construction issues.

b. Conventional construction issues.

c. Dredging issues.

d. Traffic maintenance issues.

e. Inspection, maintenance, and repair issues.

This appendix specifies the issue statements for the five issue sets.

For each issue, various initiating events are identified, and each initiating event has a number of scenarios. Likelihoods and consequences for each scenario are elicited from experts, and the cost of risk for each initiating event is obtained by calculating the expected value of the probabilities and consequences of its scenario. Expert opinions from the various experts are aggregated by calculation of percentiles using the formulas given in Appendix C. The expected value for any initiating event is the sum of the product of the median (50th percentile) probabilities and consequences of all scenarios in that initiating event.

Scenarios in a given initiating event may not be independent, and they might not be mutually exclusive. For example, the probability of operations hampered by weather and the probability of damage to pontoons in the pontoon removal initiating event are not mutually exclusive. A probability exists that both the operations are hampered by weather and damage to pontoons occurs. This situation is depicted in the Venn diagram (Figure B1), where

W = scenario in which operations are hampered by weather

P = scenario in which pontoons are damaged

a, b, and c = probabilities of portions of the events W and P (as shown in Figure B1)

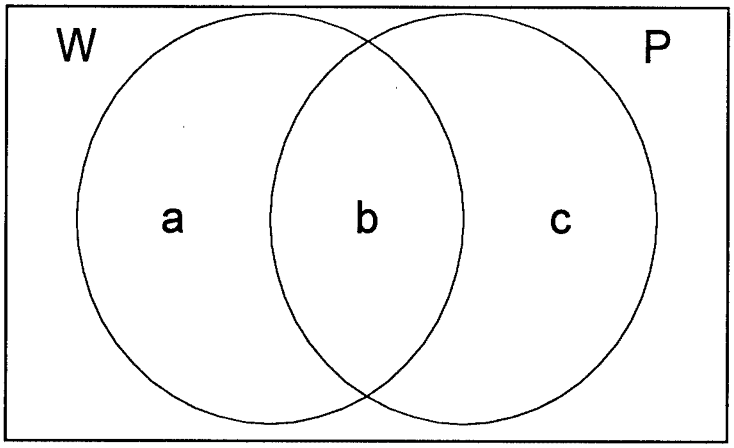

Figure B1. Venn diagram of dependent scenarios

The probability that operations are hampered by weather is given by

$$P(W) = a + b \tag{B1}$$

The probability that pontoons are damaged is given by

$$P(P) = b + c \tag{B2}$$

Conditional probabilities are

$$P(W/P) = P(P/W) = b \tag{B3}$$

$$P(W/not\ P) = a \tag{B4}$$

$$P(P/not\ W) = c \tag{B5}$$

Assuming the consequences of W are x and those of P are y, the expected value of the cost of risk for both scenarios without consideration of conditional probabilities is given by

$$xP(W) + yP(P) = x(a+b) + y(b+c) = ax + bx + by + cy \tag{B6}$$

The expected value of the cost of risk for both scenarios considering conditional probabilities is given by

$$\begin{aligned} xP(W/not\ P) + xP(W\ and\ P) + yP(P\ and\ W) + yP(P/not\ W) \\ = ax + bx + by + cy \end{aligned} \tag{B7}$$

The results of Equations B6 and B7 are the same and, thus, expected values of risk are calculated from probabilities of given scenarios without consideration of conditional probabilities and correlation. It is therefore necessary that the sum of probabilities of all scenarios for a given initiating meet the following conditions:

a. If the events are mutually exclusive, the sum of probabilities of P and W must be 1.

b. If the events are not mutually exclusive, the sum of probabilities of *P* and W can be larger than 1.

B.1 Specialty Construction Issues

Specialty construction issues are specific to lock and dam construction. Tasks in this group include

a. Removal of pontoons.

b. Reinstallation of pontoons.

c. Removal of I-wall and sheet pile.

d. Removal of T-wall.

e. Removal of timber curtain wall.

f. Attachment of precast concrete panels.

The experts discussed the issues that produced the assumptions of Table B1. The results of the expert-opinion elicitation are provided in Tables B2 and B3. Each expert is asked to provide his/her best estimate of the median value, and the respondents' level of confidence in their estimates is recorded as low, medium, or high.

Table B1
Summary of Supportive Reasoning and Assumptions by Experts on Specialty Construction Issues

Category	Assumptions
Removal of pontoons	Water level below 20-ft elevation Low-water conditions Pontoons moved by government not contractor Wind is the primary aspect of weather Operations as planned, 10 hr Correlation between weather and damage to lock
Reinstallation of pontoons	Same as removal of pontoons More difficult process than removal of pontoons
Removal of I-wall and sheet pile	River conditions are the primary factor River conditions–consists of elevation and velocity The events can be independent or fully dependent Loss of navigation to the industry costs about $65,000 per day Contractor does work
Removal of T-wall	Same as I-wall
Removal of timber curtain wall	Same as I-wall
Attachment of precast concrete panels	Same as timber curtain Alternative C – attach certain length Alternatives A and B – set at low water: contractor move out of way to let traffic through delays may be 2+ hr start downstream to upstream (no exposed corners) in putting in panels

Table B2
Expert-Opinion Elicitation and Results Matrix for Specialty Construction Issue

Initiating Event	Scenario		Expert Opinion Collection							Expert Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Remove pontoons: This applies to the construction phase of Alternatives A and B and the utilization phase of Alternative C.	Operations as planned	Probability	0.95	0.9	0.895	0.7	0.9	0.9	0.95	0.7	0.8975	0.9	0.925	0.95	103.95
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Operations hampered by weather	Probability	0.1	0.1	0.03	0.5	0.1	0.1	0.1	0.03	0.1	0.1	0.1	0.5	
		Consequences (K$)	2	8	3	10	4	5		2	3	4.5	8	10	
	Damage to lock structure	Probability	0.1	0.1	0.03	0.1	0.02	0.1	0.01	0.01	0.025	0.1	0.1	0.1	
		Consequences (K$)	500	1000	2000	500	500	1000		500	500	750	1000	2000	
	Pontoon lightly damaged	Probability	0.15	0.15	0.025	0.1	0.2	0.45	0.05	0.025	0.075	0.15	0.175	0.45	
		Consequences (K$)	50	20	8	50	2	10		2	8	15	50	50	
	Pontoon severely damaged	Probability	0.05	0.05	0.015	0.01	0.01	0.3	0.05	0.01	0.0125	0.05	0.05	0.3	
		Consequences (K$)	150	100	50	500	100	500		50	100	125	500	500	
	Pontoon sinks	Probability	0.02	0.01	0.005	0.002	0.002	0.05	0.001	0.001	0.002	0.005	0.015	0.05	
		Consequences (K$)	2000	3500	1000	5100	5000	4500		1000	2000	4000	5000	5100	
Reinstallation of pontoons: This applies to the utilization phase of Alternative C.	Reinstallation as planned	Probability	0.85	0.9	0.88	0.5	0.85	0.85		0.5	0.85	0.85	0.88	0.9	123.363
		Consequences (K$)	0	0	0	0	0	0		0	0	0	0	0	
	Operations hampered by weather	Probability	0.2	0.1	0.04	0.5	0.1	0.2		0.04	0.1	0.15	0.2	0.5	
		Consequences (K$)	2	8	3	20	4	5		2	3	4.5	8	20	
	Damage to lock structure	Probability	0.1	0.1	0.04	0.15	0.02	0.2		0.02	0.04	0.1	0.15	0.2	
		Consequences (K$)	500	1000	2000	500	500	1000		500	500	750	1000	2000	
	Pontoon lightly damaged	Probability	0.2	0.2	0.035	0.2	0.2	0.2		0.035	0.2	0.2	0.2	0.2	
		Consequences (K$)	50	20	8	50	2	10		2	8	15	50	50	
	Pontoon severely damaged	Probability	0.1	0.05	0.025	0.015	0.01	0.1		0.01	0.015	0.0375	0.1	0.1	
		Consequences (K$)	150	100	50	500	100	500		50	100	125	500	500	
	Pontoon sinks	Probability	0.02	0.01	0.01	0.004	0.002	0.05		0.002	0.004	0.01	0.02	0.05	
		Consequences (K$)	2000	3500	1000	5100	5000	4500		1000	2000	4000	5000	5100	
Remove I-wall and sheet pile: This applies to the construction phase of Alternatives A and B.	Operations as planned	Probability	0.5	0.85	0.95	0.8	0.85	0.8		0.5	0.8	0.825	0.85	0.95	86.5625
		Consequences (K$)	0	0	0	0	0	0		0	0	0	0	0	
	Operations hampered by river conditions	Probability	0.5	0.15	0.04	0.2	0.1	0.1		0.04	0.1	0.125	0.2	0.5	
		Consequences (K$)	100	100	100	100	100	100		100	100	100	100	100	
	Loss of navigation	Probability	0.1	0.05	0.01	0.1	0.05	0.1		0.01	0.05	0.075	0.1	0.1	
		Consequences (K$)	650	650	975	1300	1000	1000		650	650	987.5	1000	1300	

(Continued)

Table B2 (Concluded)

Initiating Event	Scenario		Expert-Opinion Collection							Expert-Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Remove T-wall: This applies to the construction phase of Alternatives A and B.	Operations as planned	Probability	0.5	0.85	0.95	0.7	0.85	0.8	0.9	0.5	0.75	0.85	0.875	0.95	60
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Operations hampered by river conditions	Probability	0.5	0.15	0.04	0.3	0.1	0.1	0.1	0.04	0.1	0.1	0.225	0.5	
		Consequences (K$)	100	100	100	100	100	100	100	100	100	100	100	100	
	Loss of navigation	Probability	0.1	0.05	0.01	0.1	0.05	0.1	0.01	0.01	0.03	0.05	0.1	0.1	
		Consequences (K$)	650	650	975	1300	1000	1000	1000	650	812.5	1000	1000	1300	
Remove timber curtain wall: This applies to the construction phase of Alternatives A, B, and C and removing A-frames from Alternatives A and B.	Operations as planned	Probability	0.5	0.85	0.95	0.9	0.85	0.85	0.9	0.5	0.85	0.85	0.9	0.95	65
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Operations hampered by river conditions	Probability	0.5	0.15	0.04	0.1	0.15	0.15	0.1	0.04	0.1	0.15	0.15	0.5	
		Consequences (K$)	100	100	100	100	100	100	100	100	100	100	100	100	
	Loss of navigation	Probability	0.1	0.1	0.01	0.01	0.05	0.05	0.01	0.01	0.01	0.05	0.075	0.1	
		Consequences (K$)	650	650	975	1300	1000	1000	1000	650	812.5	1000	1000	1300	
Attach precast concrete panels: This applies to the construction phase of Alternative C.	Operations as planned	Probability	0.5	0.98	0.75	0.95	0.85	0.85	0.85	0.5	0.8	0.85	0.9	0.98	25
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Operations hampered by river conditions	Probability	0.5	0.02	0.2	0.05	0.15	0.15	0.15	0.02	0.1	0.15	0.175	0.5	
		Consequences (K$)	100	100	100	150	100	100	100	100	100	100	100	150	
	Loss of navigation	Probability	0.01	0.001	0.05	0.001	0.05	0.01	0.01	0.001	0.0055	0.01	0.03	0.05	
		Consequences (K$)	650	650	975	1300	1000	1000	1000	650	812.5	1000	1000	1300	
Attach precast concrete panels: This applies to the construction phase of Alternatives A and B.	Operations as planned	Probability	0.5	0.8	0.75	0.5	0.7	0.85		0.5	0.5	0.725	0.8	0.85	54.625
		Consequences (K$)	0	0	0	0	0	0		0	0	0	0	0	
	Operations hampered by river conditions & navigation	Probability	0.5	0.2	0.2	0.5	0.3	0.15		0.15	0.2	0.25	0.5	0.5	
		Consequences (K$)	200	100	100	150	100	100		100	100	100	150	200	
	Loss of navigation	Probability	0.05	0.001	0.05	0.01	0.05	0.01		0.001	0.01	0.03	0.05	0.05	
		Consequences (K$)	650	650	975	1300	1000	1000		650	650	987.5	1000	1300	

Table B3
Level of Confidence of Experts in Opinion Elicited for Specialty Construction Issue

Initiating Event	Confidence in:	Confidence Level						
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Remove Pontoons	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	
Reinstallation of pontoons	probability	high	high	high	high	high	high	
	cost	low	medium	medium	medium	medium	medium	
Remove I-wall and sheet pile	probability	medium	medium	high	high	medium	medium	
	cost	low	medium	medium	medium	medium	medium	
Remove T-wall	probability	medium	medium	high	high	medium	medium	high
	cost	low	medium	medium	medium	medium	medium	medium
Remove timber curtain wall	probability	medium	medium	high	high	medium	medium	high
	cost	low	medium	medium	medium	medium	medium	medium
Attach precast concrete panels: Alternative C	probability	medium	medium	high	high	medium	medium	high
	cost	low	medium	medium	medium	medium	medium	medium
Attach precast concrete panels: Alternatives A & B	probability	medium	medium	medium	medium	medium	medium	
	cost	low	medium	medium	medium	low	medium	

B.2 Conventional Construction Issues

A number of tasks and initiating events for each alternative and phase can be treated as conventional construction activities with related risks similar to conventional construction risks. In assessing risks for each alternative and phase, these activities are considered initiating events and the failure scenarios. Consequences and occurrence probability are assessed for the category as a whole.

The tasks involved in conventional construction are

a. Construction of guide walls.

b. Construction of footings.

c. Construction of concrete panels.

d. Removal of earth dike.

e. Backfill and riprap.

f. Relocation of excess material.

g. Excavation of silt.

h. Cleaning and repairing H-piles.

i. Driving and encasing new H-piles.

The experts discussed the issues that produced the assumptions of Table B4. The results of the expert-opinion elicitation are provided in Tables B5 and B6.

Table B4 Summary of Supportive Reasoning and Assumptions by Experts on Conventional Construction Issues	
Category	**Assumptions**
Construction of guide walls	Construction can occur as long as water below concrete pours. Construct only when at low water condition. 3-year construction duration for the entire project. Pontoons are used to fill gaps between guide wall segments. Build each guide wall section at a time and use pontoons in other sections.
Construction of concrete panels	Contractor assumes liability and risk.
Removal of earth dike	Same as removal of T-walls.
Backfill and riprap	Same as rock earth dike.
Relocation of excess material	Same as removal of earth dike.
Excavation of silt	Guide walls not present. Sink barge in channel.
Cleaning and painting	Schedule delays only.
Driving and encasing new H-piles	To be performed by contractor under contract that transfers risk to the contractor. No risk cost is included in this analysis since this cost would be part of contract sum.
Traffic issues	Contractor's boat leaves as soon as possible. Traffic is delayed until construction boat is able to stabilize and move.

Each expert is asked to provide his/her best estimate of the median value, and the respondents' level of confidence in their estimates is recorded as low, medium, or high.

B.3 Dredging Issues

The alternatives considered have proven to be effective in reducing the accumulation of sediment although sedimentation will continue to be a problem. Dredging has been required on an annual or sometimes on a semi-annual basis. Based upon dredging results at other installations that employ a guide wall system similar to the proposed system, annual dredging requirements would be approximately fifty thousand cubic yards. This accumulation of sediment could be maintained by maintenance dredging and would not impede barge traffic. The experts discussed the issues that produced the assumptions of Table B7. The results of the expert-opinion elicitation are provided in Tables B8 and B9. Each expert is asked to provide his/her best estimate of the median value, and the respondents' level of confidence in their estimates is recorded as low, medium, or high.

Table B5
Expert-Opinion Elicitation Matrix for Conventional Construction Issues

Initiating Event	Scenario		Expert-Opinion Collection							Expert-Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Construction of guide walls (above 16.5 ft): This applies to the construction phase of Alternatives A and B.	Construction as planned	Probability	0.6	0.95	0.9	0.8	0.9	0.8	0.9	0.6	0.8	0.9	0.9	0.95	20
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Construction hampered by river conditions	Probability	0.2	0.05	0.08	0.2	0.1	0.1	0.1	0.05	0.09	0.1	0.15	0.2	
		Consequences (K$)	100	100	100	500	100	100	100	100	100	100	100	500	
	Barge impact	Probability	0.2	0.01	0.02	0.05	0.1	0.1	0.1	0.01	0.035	0.1	0.1	0.2	
		Consequences (K$)	200	100	200	100	100	100	200	100	100	100	200	200	
Construction of guide wall base (lower than el 16.5): This applies to the construction phase of Alternatives A and B.	Construction as planned	Probability	0.5	0.85	0.85	0.8	0.9	0.6	0.9	0.5	0.7	0.85	0.875	0.9	33
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Construction hampered by river conditions	Probability	0.25	0.1	0.13	0.2	0.1	0.2	0.1	0.1	0.1	0.13	0.2	0.25	
		Consequences (K$)	100	100	100	500	100	100	100	100	100	100	100	500	
	Barge impact	Probability	0.25	0.05	0.02	0.1	0.1	0.2	0.1	0.02	0.075	0.1	0.15	0.25	
		Consequences (K$)	200	250	200	500	200	250	200	200	200	200	250	500	
Construction of concrete panels: This applies to the construction phase of Alternatives A, B, and C. Contractor's risk.	Construction as planned	Probability	1	1	1	1	1	1	1	1	1	1	1	1	0
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Moderate cost and schedule delays	Probability	0	0	0	0	0	0	0	0	0	0	0	0	
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	High cost and schedule delays	Probability	0	0	0	0	0	0	0	0	0	0	0	0	
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
Removal of earth dike: This applies to the construction phase of Alternative A.	Construction as planned	Probability	0.9	0.98	0.9	0.98	0.98	0.98	0.95	0.9	0.925	0.98	0.98	0.98	7.5
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to lock structure	Probability	0.05	0.01	0.05	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.045	0.05	
		Consequences (K$)	100	50	150	100	50	100	100	50	75	100	100	150	
	Loss of navigation	Probability	0.05	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.05	
		Consequences (K$)	650	650	150	1300	500	650	500	150	500	650	650	1300	
Construct new T-wall: This applies to the construction phase of Alternative C.	Construction as planned	Probability	0.5	0.85	0.95	0.7	0.85	0.8	0.9	0.5	0.75	0.85	0.875	0.95	60
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Operations hampered by river conditions	Probability	0.5	0.15	0.04	0.3	0.1	0.1	0.1	0.04	0.1	0.1	0.225	0.5	
		Consequences (K$)	100	100	100	100	100	100	100	100	100	100	100	100	
	Loss of navigation	Probability	0.1	0.05	0.01	0.1	0.05	0.1	0.01	0.01	0.03	0.05	0.1	0.1	
		Consequences (K$)	650	650	975	1300	1000	1000	1000	650	812.5	1000	1000	1300	

(Continued)

Table B5 (Concluded)

Initiating Event	Scenario		Expert-Opinion Collection							Expert-Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Backfill and riprap: This applies to the construction phase of Alternatives A, B, and C.	Construction as planned	Probability	0.9	0.98	0.9	0.98	0.98	0.98	0.95	0.9	0.925	0.98	0.98	0.98	7.5
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to lock structure	Probability	0.05	0.01	0.05	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.045	0.05	
		Consequences (K$)	100	50	150	100	50	100	100	50	75	100	100	150	
	Loss of navigation	Probability	0.05	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.05	
		Consequences (K$)	650	650	150	1300	500	650	500	150	500	650	650	1300	
Relocation of excess material: This applies to the construction phase of Alternative A.	Construction as planned	Probability	0.9	0.98	0.9	0.98	0.98	0.98	0.95	0.9	0.925	0.98	0.98	0.98	7.5
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to lock structure	Probability	0.05	0.01	0.05	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.045	0.05	
		Consequences (K$)	100	50	150	100	50	100	100	50	75	100	100	150	
	Loss of navigation	Probability	0.05	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.05	
		Consequences (K$)	650	650	150	1300	500	650	500	150	500	650	650	1300	
Excavation of silt: This applies to the construction phase of Alternatives A, B, and C.	Construction as planned	Probability	0.9	0.98	0.99	0.9	0.98	0.98	0.95	0.9	0.925	0.98	0.98	0.99	7.5
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to lock structure	Probability	0.05	0.01	0.005	0.05	0.01	0.01	0.04	0.005	0.01	0.01	0.045	0.05	
		Consequences (K$)	100	50	150	250	50	100	100	50	75	100	125	250	
	Loss of navigation	Probability	0.05	0.01	0.005	0.05	0.01	0.01	0.01	0.005	0.01	0.01	0.03	0.05	
		Consequences (K$)	650	650	150	1300	500	650	500	150	500	650	650	1300	
Cleaning, repairing, and encasing existing H-piles: This applies to the construction phase of Alternative C.	Construction as planned	Probability	0.75	0.75	0.75	0.75	0.5	0.6	0.8	0.5	0.675	0.75	0.75	0.8	112.5
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Schedule delays	Probability	0.25	0.25	0.25	0.25	0.5	0.4	0.2	0.2	0.25	0.25	0.325	0.5	
		Consequences (K$)	250	360	250	250	250	250	250	250	250	250	250	360	
		Probability	0	0.5	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	
		Consequences (K$)	0	100	100	100	100	100	100	0	100	100	100	100	
Driving and encasing new H-piles: This applies to the construction phase of Alternative C. Contractor's risk	Construction as planned	Probability	1	1	1	1	1	1	1	1	1	1	1	1	0
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Moderate cost and schedule delays	Probability	0	0	0	0	0	0	0	0	0	0	0	0	
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	High cost and schedule delays	Probability	0	0	0	0	0	0	0	0	0	0	0	0	
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	

Table B6
Level of Confidence of Experts in Opinion Elicited for Conventional Construction Issues

Initiating Event	Confidence in:	Confidence Level						
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Construction of guide walls (above 16.5')	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	low	medium	medium	medium
Construction of guide wall base (lower than elevation 16.5')	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	low	medium	medium	medium
Construction of concrete panels	probability							
	cost							
Removal of earth dike	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium
Construct new T-wall	probability	medium	medium	high	high	medium	medium	high
	cost	low	medium	medium	medium	medium	medium	medium
Backfill and riprap	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium
Relocation of excess material	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium
Excavation of silt	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium
Cleaning, repairing & encasing existing H-piles	probability	high	high	high	medium	high	high	high
	cost	low	low	low	low	low	low	low
Driving & encasing new H-piles	probability							
	cost							

Table B7
Summary of Supportive Reasoning and Assumptions by Experts on Dredging Issues

Category	Assumptions
Dredging	Same as removal of earth dike and excavation of silt.
Relocation of excess material	Same as removal of earth dike.
Excavation of silt	Guide walls not present. Sink barge in channel.
Traffic issues	Contractor's boat leaves as soon as possible. Traffic is delayed until construction boat is able to stabilize and move.

Table B8
Expert-Opinion Elicitation Matrix for Dredging Issues

Initiating Event	Scenario		Expert-Opinion Collection							Expert-Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Annual dredging: This applies to the utilization phase of Alternatives A, B, and C.	Dredging as planned	Probability	0.93	0.88	0.9	0.89	0.97	0.97	0.97	0.88	0.895	0.93	0.97	0.97	8.5
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to lock structure	Probability	0.01	0.01	0.04	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.025	0.05	
		Consequences (K$)	100	30	50	100	50	50	50	30	50	50	75	100	
	Loss of navigation	Probability	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
		Consequences (K$)	650	650	600	1300	650	650	1000	600	650	650	825	1300	
	Delay of navigation	Probability	0.05	0.1	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.1	
		Consequences (K$)	50	25	30	50	20	50	30	20	27.5	30	50	50	
Dredging every 3 years: This applies to the utilization phase of Alternative C.	Dredging as planned	Probability	0.93	0.88	0.9	0.88	0.97	0.97	0.93	0.88	0.89	0.93	0.95	0.97	8.2
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to lock structure	Probability	0.01	0.01	0.04	0.04	0.01	0.01	0.05	0.01	0.01	0.01	0.04	0.05	
		Consequences (K$)	100	100	50	50	50	50	50	50	50	50	75	100	
	Loss of navigation	Probability	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	
		Consequences (K$)	650	650	600	1300	650	650	1000	600	650	650	825	1300	
	Delay of navigation	Probability	0.05	0.1	0.05	0.04	0.01	0.01	0.01	0.01	0.01	0.04	0.05	0.1	
		Consequences (K$)	50	25	30	50	20	50	30	20	27.5	30	50	50	

Table B9
Level of Confidence of Experts in Opinion Elicited for Dredging Issues

Initiating Event	Confidence in:	Confidence Level						
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Annual dredging	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium
Dredging every three years	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium

B.4 Traffic Maintenance Issues

The traffic maintenance issue involves maintaining a navigation channel of varying width through the downstream lock approach. This includes maintaining barge traffic during both construction and dredging. Depending on the alternative and whether the traffic maintenance is for construction or dredging, the required navigation channel width may be 42, 84, 115, or 240 ft (13, 26, 35, or 73 m).

The experts discussed the issues that produced the assumptions of Table B10. The results of the expert-opinion elicitation are provided in Tables B11 and B12. Each expert is asked to provide his/her best estimate of the median value, and the respondents' level of confidence in their estimates is recorded as low, medium, or high.

B.5 Inspection, Maintenance, and Repair Issues

This set of issues refers to any needed inspection, maintenance, and repair. For Alternatives A and B, inspections will be held every year for the first 5 years, then once every 5 years thereafter.

For Alternative C, inspections will be held every year for the first 5 years, then once every 5 years thereafter. In this alternative, inspection, maintenance, and repair include the replacement of the timber fenders of the floating guide wall every 5 years and repainting all metal structures every 17 years.

The experts discussed the issues that produced the assumptions of Table B13. The results of the expert-opinion elicitation are provided in Tables B14 and B15. Each expert is asked to provide his/her best estimate of the median value, and the respondents' level of confidence in their estimates is recorded as low, medium, or high.

Table B10
Summary of Supportive Reasoning and Assumptions by Experts
Traffic Maintenance Issues

Category	Assumptions
Traffic maintenance	The risk of unforeseen costs being incurred during traffic maintenance affects only Alternatives A and B. Alternative C is not affected because operations during construction and utilization are such that the navigation channel remains clear.

Table B11
Expert-Opinion Elicitation Matrix for Traffic Maintenance Issues

Initiating Event	Scenario		Expert-Opinion Collection							Expert-Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Maintain traffic: This applies to the construction phase of Alternatives A and B.	Smooth traffic flow	Probability	0.25	0.25	0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.25	0.5	950
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Delay of navigation	Probability	0.75	0.75	0.5	0.95	0.95	0.95	0.95	0.5	0.75	0.95	0.95	0.95	
		Consequences (K$)	1000	650	400	1500	1000	1000	1000	400	825	1000	1000	1500	

Table B12
Level of Confidence of Experts in Opinion Elicited for Traffic Maintenance Issues

Initiating Event	Confidence in	Confidence Level						
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Maintain traffic	probability	high	high	high	high	high	high	high
	cost	low	medium	low	low	moderate	moderate	moderate

Table B13
Summary of Supportive Reasoning and Assumptions by on Experts Inspection, Maintenance, and Repair Issues

Category	Assumptions
Cleaning and painting	Schedule delays only.
Traffic issues	Contractor's boat leaves as soon as possible. Traffic is delayed until construction boat is able to stabilize and move.

Table B14
Expert-Opinion Elicitation Matrix for Inspection, Maintenance, and Repair Issues

Initiating Event	Scenario		Expert-Opinion Collection							Expert-Opinion Aggregation					Expected Value
			Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Minimum	25th	50th	75th	Maximum	
Inspection maintenance and repair: This applies to the utilization phase of Alternatives A, B, and C (every 5 years).	Inspection as planned	Probability	0.999	0.999	0.999	0.95	0.999	0.999	0.999	0.95	0.999	0.999	0.999	0.999	0.001
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Injury	Probability	0.001	0.001	0.001	0.05	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	
		Consequences (K$)	1	1	1	1	1	1	1	1	1	1	1	1	
Replace timber fenders: This applies to the utilization phase of Alternative C.	Replacement as planned	Probability	0.95	0.8	0.8	0.8	0.88	0.85	0.89	0.8	0.8	0.85	0.885	0.95	10
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Damage to Pontoons	Probability	0.02	0.02	0.05	0.05	0.01	0.05	0.05	0.01	0.02	0.05	0.05	0.05	
		Consequences (K$)	100	150	75	150	100	100	100	75	100	100	125	150	
	Delayed navigation	Probability	0.02	0.08	0.05	0.05	0.1	0.05	0.05	0.02	0.05	0.05	0.065	0.1	
		Consequences (K$)	30	30	30	50	20	50	25	20	27.5	30	40	50	
	Injury	Probability	0.01	0.1	0.1	0.1	0.01	0.05	0.01	0.01	0.01	0.05	0.1	0.1	
		Consequences (K$)	50	100	100	50	100	100	75	50	62.5	100	100	100	
Repainting all metal structures every 17 years: This applies to the utilization phase of Alternative C.	Painting as planned	Probability	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.01
		Consequences (K$)	0	0	0	0	0	0	0	0	0	0	0	0	
	Injury	Probability	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
		Consequences (K$)	1	1	1	2	1	1	1	1	1	1	1	2	

Table B15
Level of Confidence of Experts in Opinion Elicited for Inspection

Initiating Event	Confidence in:	Confidence Level						
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
Inspection maintenance and repair	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	low	medium	medium	medium
Replace timber fenders	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium
Repainting all metal structures every 17 years	probability	high	high	high	high	high	high	high
	cost	low	medium	medium	medium	medium	medium	medium

Appendix C
Computation of Percentiles

A p-percentile value (x_p) for a random variable based on a sample is the value of the parameter such that p percent of the data is less or equal to x_p. On the basis of this definition, the median value is considered to be the 50-percentile value.

Aggregating the opinions of experts requires the computation of the 25-, 50-, and 75-percentile values. The computation of these values depends on the number of experts providing opinions. Table C1 provides a summary of the needed equations for 4, 5, 6…20 experts. In the table, X_i means the opinion of an expert with the i^{th} smallest value; i.e., $X_1 \geq X_2 \geq X_3 \geq ... \geq X_n$, where n = number of experts. In the table, the arithmetic average was used to compute the percentiles. In some cases, where the values of X_i differ by power order of magnitude, the geometric average can be used. This appendix was taken from Ayyub (1999).

Table C1
Computations of Percentiles

Number of Experts (n)	25 Percentile		50 Percentile		75 Percentile	
	Arithmetic Average	Geometric Average	Arithmetic Average	Geometric Average	Arithmetic Average	Geometric Average
4	$(X_1 + X_2)/2$	$\sqrt{X_1X_2}$	$(X_2 + X_3)/2$	$\sqrt{X_2X_3}$	$(X_3 + X_4)/2$	$\sqrt{X_3X_4}$
5	X_2	X_2	X_3	X_3	X_4	X_4
6	X_2	X_2	$(X_3 + X_4)/2$	$\sqrt{X_3X_4}$	X_5	X_5
7	$(X_2 + X_3)/2$	$\sqrt{X_2X_3}$	X_4	X_4	$(X_5 + X_6)/2$	$\sqrt{X_5X_6}$
8	$(X_2 + X_3)/2$	$\sqrt{X_2X_3}$	$(X_4 + X_5)/2$	$\sqrt{X_4X_5}$	$(X_6 + X_7)/2$	$\sqrt{X_6X_7}$
9	$(X_2 + X_3)/2$	$\sqrt{X_2X_3}$	X_5	X_5	$(X_7 + X_8)/2$	$\sqrt{X_7X_8}$
10	$(X_2 + X_3)/2$	$\sqrt{X_2X_3}$	$(X_5 + X_6)/2$	$\sqrt{X_4X_5}$	$(X_8 + X_9)/2$	$\sqrt{X_8X_9}$
11	X_3	X_3	X_6	X_6	X_9	X_9
12	X_3	X_3	$(X_6 + X_7)/2$	$\sqrt{X_6X_7}$	X_{10}	X_{10}
13	$(X_3 + X_4)/2$	$\sqrt{X_3X_4}$	X_7	X_7	$(X_{10} + X_{11})/2$	$\sqrt{X_{10}X_{11}}$
14	$(X_3 + X_4)/2$	$\sqrt{X_3X_4}$	$(X_7 + X_8)/2$	$\sqrt{X_7X_8}$	$(X_{11} + X_{12})/2$	$\sqrt{X_{11}X_{12}}$
15	X_4	X_4	X_8	X_8	X_{12}	X_{12}
16	X_4	X_4	$(X_8 + X_9)/2$	$\sqrt{X_8X_9}$	X_{13}	X_{13}
17	$(X_4 + X_5)/2$	$\sqrt{X_4X_5}$	X_9	X_9	$(X_{13} + X_{14})/2$	$\sqrt{X_{13}X_{14}}$
18	$(X_4 + X_5)/2$	$\sqrt{X_4X_5}$	$(X_9 + X_{10})/2$	$\sqrt{X_9X_{10}}$	$(X_{14} + X_{15})/2$	$\sqrt{X_{14}X_{15}}$
19	X_5	X_5	X_{10}	X_{10}	X_{15}	X_{15}
20	X_5	X_5	$(X_{10} + X_{11})/2$	$\sqrt{X_{10}X_{11}}$	X_{15}	X_{15}

Appendix D
Definitions and Terminology

Term	Definition
Average	A central tendency measure that is computed as the sum of values divided by their count.
Cause-consequence diagrams (CS)	These diagrams can be developed for the purpose of assessing and propagating the conditional effects of failure using a tree representation. The analysis according to CS starts with selecting a critical event. Critical events are commonly selected as convenient starting points for the purpose of developing the CS diagrams. For a given critical event, the consequences are traced using logic trees with event chains and branches. The logic works both backward (similar to fault trees) and forward (similar to event trees). The procedure for developing a CS diagram can be based on answering a set of questions at any stage of the analysis.
Coefficient of variation	Standard deviation divided by mean.
Dispersion	Measure of variability or scatter in data.
Evaluators	Evaluators consider available data, become familiar with the views of proponents and other evaluators, question the technical bases of data, and challenge the views of proponents.
Event-tree analysis	This analysis results in failure sequences (scenarios) with associated probabilities. The analysis is based on an inductive logic that moves forward in failing a system of interest. For example, starting with an initiating event, questions such as What might happen next? and What are the associated probabilities? are asked. Therefore, the tree results by branching forward toward the failure of the system.
Expert	A person with related or unique experience to an issue or question of interest for the process.
Expert elicitation	A formal process of obtaining information or answers to specific questions about certain issues.
Expert-opinion elicitation (EE) process	A formal, heuristic process of gathering informing and data or answering questions on issues or problems of concern.
Failure event	Any event that will have an adverse impact on lock performance is defined a failure event.
Failure rate	The probability of failure per unit time or a unit of operation, such as cycle, revolution, rotation, startup, etc.

Term	Definition
Leader of EE process	An entity having managerial and technical responsibility for organizing and executing the project, overseeing all participants, and intellectually owning the results.
Mean	Refer to "Average."
Median value	The point that divides the data into two equal parts, i.e., 50% of the data are above it and 50% are below it.
Observers	Observers can contribute to the discussion, but cannot provide expert opinion that enters in the aggregated opinion of the experts.
Peer reviewers	Experts that can provide an unbiased assessment and critical review of an expert-opinion elicitation process, its technical issues, and results.
p-percentile value	The value of the parameter such that p% of the data are less or equal to this value.
Probability	Measured by dividing the number of occurrences by the total number of repetitions.
Proponents	Proponents are experts who advocate a particular hypothesis or technical position. In science, a proponent evaluates experimental data and professionally offers a hypothesis that would be challenged by the proponent's peers until proven correct or wrong.
Resource experts	Resource experts are technical experts with detailed and deep knowledge of particular data, issue aspects, particular methodologies, or use of evaluators.
Sponsor of EE process	An entity that provides financial support and owns the rights to the results of the EE process. Ownership is in the sense of property ownership.
Standard deviation	Square root of variance.
Subject	A person who might be affected or might affect an issue or question of interest for the process.
Technical facilitator (TF)	An entity responsible for structuring and facilitating the discussions and interactions of experts in the EE process; staging effective interactions among experts; ensuring equity in presented views; eliciting formal evaluations from each expert; and creating conditions for direct, noncontroversial integration of expert opinions.
Technical integrator (TI)	An entity responsible for developing the composite representation of issues based on informed members and/or sources of related technical communities and experts; explaining and defending composite results to experts and outside experts, peer reviewers, regulators, and policy makers; and obtaining feedback and revising composite results.
Technical integrator and facilitator (TIF)	An entity responsible for both functions of TI and TF.
Uncertainty	The doubt (or the lack of sureness) about the outcomes (in number or magnitude) of a system.
Variance	Measure of dispersion.

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14. ABSTRACT

This report documents the expert-opinion elicitation performed to meet risk analysis needs of the lower lock approach sediment management improvement alternatives to the Lindy Claiborne Boggs Lock and Dam. A companion report (ERDC/ITL TR-02-1) describes the review and assessment of the Preliminary Hazard Analysis conducted for the alternatives.

The Lindy C. Boggs Lock and Dam experiences large water-level fluctuations. To accommodate the large fluctuation of water levels, floating guide walls upstream and downstream of the lock were incorporated into the plans. To retain the riverside lock wall backfill, a concrete "T-wall" was constructed for a distance of 130 ft (approximately 40 m) perpendicular from the lock on the downstream end. Anticipating that sediment would deposit in the navigation channel underneath the downstream floating guide wall, provisions were included in the original plans in the form of an earthen dike and a composite "I-wall" (steel sheetpiling and concrete wall) on top of the dike. The I-wall was connected to the T-wall and continued 130 ft offset from and parallel to the floating guide wall for 1,100 ft (335 m). The purpose of the dike and I-wall was to divert the flow and sediment from the floating guide wall and the navigation channel, thus providing a slack-water lock approach channel. Nonetheless, an average of approximately 310,000 cu yd of silt has been removed annually from the lower lock approach channel at Lindy C. Boggs Lock and Dam. Three alternative improvements are proposed to control this sedimentation: a new fixed guide wall with dike removal, a new fixed guide wall with retention of the dike, and barrier extension and use of concrete panels.

(Continued)

15. SUBJECT TERMS

Design alternatives	Expert opinion	Locks	Probabilistic risk assessment	Risk assessment
Dams	Elicitation	Navigation project	Reliability	Uncertainties
Delphi process	Innovative construction	Preliminary hazard analysis	Risk analysis	

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The U.S. Army Engineer District, Vicksburg, has the requirement to determine the probability of catastrophic failure during the construction and utilization phases of the lock-improvement alternatives, including potential catastrophic damage occurring to the floating guide wall pontoons while they are being removed, transported to and from their temporary storage area, and reinstalled. The tasks in every phase of each alternative are assessed for risk, examining associated initiating events, failure scenarios, occurrence probabilities, and associated consequences. Initiating events and failure scenarios are identified and enumerated. Consequences and occurrence probability are determined by expert-opinion elicitation, as documented in this report.

Information related to failure probability and consequences is not available from historical records, prediction methods, or literature review. Expert-opinion elicitation provides a means of gaining information on these essential risk-related quantities. The expert-opinion elicitation process is a formal, heuristic process of obtaining information or answers to specific questions about certain quantities, called issues, such as failure rates (probability) and failure consequences. In this report, the different components of the expert-opinion elicitation process are described, the process itself is outlined, and the results are documented.