RESERVOIRS AND WATERWAYS

Identification and Assessment of Environmental Quality Problems and Research Program Development

TECHNICAL REPORT E-78-1

by

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The Civil Works program of the Corps of Engineers (CE) involves the entire spectrum of water resources development for the Nation and, as such, is unique among Federal agencies. Current concern for energy demands and water supply have emphasized the need for comprehensive water resources development including hydropower, water supply, and navigation as project purposes. Recreational demands are at a record high for most CE facilities and recreation is generally included as a purpose for new projects. Fish and wildlife enhancement plus

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water quality management are project purposes that have a direct relationship to the improvement of the Nation's environmental quality, and flood control remains as a traditional project purpose.

Consistent with all of these project purposes, the CE is required to address or meet local, regional, and national environmental quality objectives. This requirement has resulted in numerous problems for CE projects in the planning, design, and operational stages. This report contains the results of an effort to identify and assess environmental quality problems associated with Civil Works activities of the CE, and a recommended research program to address these problems.

Information was gathered by visits to all CE Division offices and subsequent submission of written information from field offices. As a result of this effort, six key areas of problems related to current practices and priority research needs were identified. The ability to predict the environmental impact of operational alternatives or proposed projects is needed including hydrodynamic, chemical, and biological aspects. There are many CE projects with water quality problems involving dissolved oxygen, nutrients (and resultant eutrophication), and contaminants. Engineering and operational guidance are required to solve these problems. Operational problems relative to fluctuating water levels, minimum releases, and filling alternatives for reservoirs have been documented, and research is required to address these problems. Inadequate or unsystematic environmental assessment procedures have resulted in the delay of many projects and related Civil Works activities. Improved procedures should be developed and tested for application by field offices. Flood control and navigation projects within waterways have environmental impacts that, for the most part, have not been documented or specifically related to CE activities in waterways. Research is required to document those impacts and to provide technology for alleviating adverse impacts or to provide enhancement in conjunction with a specific project. Comprehensive techniques for water resources management harmonious with environmental quality objectives on a regional basis are inadequate or require verification.

A research program to address the stated problems should involve applied research in conjunction with extensive field studies to verify and evaluate program results. A $30 million, six-year research program has been proposed to address the high priority problems documented within this report.

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PREFACE

The study reported herein was conducted during the period February 1976 through October 1976 by an interdisciplinary project team from the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), and the Office, Chief of Engineers (OCE). The WES project team was composed of Dr. John W. Keeley, Project Manager; Dr. Jerome L. Mahloch, Assistant Project Manager; Dr. John Barko; Dr. Douglas Gunnison; and Mr. James D. Westhoff. The OCE team members were Messrs. John Bushman, Earl Eiker, and Milt Millard.

Workshops were conducted at Corps Division offices to obtain information on the nature and significance of environmental quality problems associated with reservoir and waterway activities. Representatives of the Planning, Engineering, and Operations elements of Corps District offices participated in these workshops to ensure a diversity of viewpoints in the case of common problems and identification of problems unique to any of these elements. Participation in various of these workshops also included: Mr. D. L. Robey, Dr. Rex L. Eley, Dr. C. J. Kirby, and Mr. A. J. Green of EL; Messrs. Darrell G. Fontane and Bruce Loftis of the WES Hydraulics Laboratory (HL); and representatives of the Corps Hydrologic Engineering Center, Cold Regions Research and Engineering Laboratory, and Coastal Engineering Research Center.

This report was prepared by members of the WES project team. Information contributed by Corps District and Division offices was the basis of the report and all sections were prepared following WES evaluation of all information received from the Division workshops. Due to the scope of activities and topics included, numerous WES personnel were consulted in the preparation of or made contributions to various aspects of Section B, Part III: Problem Investigation, and Part V: Research Requirements. Principal among these were Dr. Eley, Mr. Robey, Mr. Raymond C. Solomon, Dr. Walter B. Gallaher, and Dr. Paul Becker (all from EL) and Mr. Fontane (HL).

Ms. Dorothy P. Booth (EL) managed formatting and preparation of the report. Ms. Ruth W. Patterson (EL) was the Project Secretary during the study period. The study was performed under the general direction of Dr. John Harrison, Chief of the EL, and Mr. H. B. Simmons, Chief of the HL.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, served as Directors of the WES during the study. Technical Director was Mr. F. R. Brown.

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Section A

INTRODUCTION, ASSESSMENT SUMMARY, AND RECOMMENDED RESEARCH PROGRAM

PART I: INTRODUCTION

Background

The Civil Works program of the Corps of Engineers (CE) involves the entire spectrum of water resources development for the Nation and, as such, is unique among all Federal Agencies. The Corps' role in water resources development traditionally involves the planning, design, construction, operation, and maintenance of projects to meet a variety of purposes. These purposes include flood protection, navigation, water supply, fish and wildlife enhancement, hydropower, water quality management, and recreation. The distribution of these purposes for CE Divisions is shown in Figure 1. Also included in the CE mission is general water and related land resources management through planning studies and regulatory functions. An overview of the Civil Works activities of the Corps is displayed in Figure 2.

The responsibility for water resources development lies generally with the Federal Government, and project activities to accomplish this goal require a detailed economic analysis before investment of tax monies. This economic analysis requires that benefits from the project should be maximized while meeting planned objectives and that the annual benefits derived from a project should exceed the annual costs of the project except for other overriding requirements (national defense or regional development). During the initial stages of water resources development in the United States, projects generally had only one of two purposes (i.e., flood control or navigation); thus, economic analysis and project optimization was not difficult. Currently, most projects in planning have multiple purposes and economic analysis is both complex and difficult. The number of Civil Works projects and their status and number of purposes are shown in Figure 3.

The national concern for the preservation and protection of the environment has resulted in legislation that makes environmental quality an additional consideration in water resources development. For projects in the planning phase, this means that environmental quality objectives

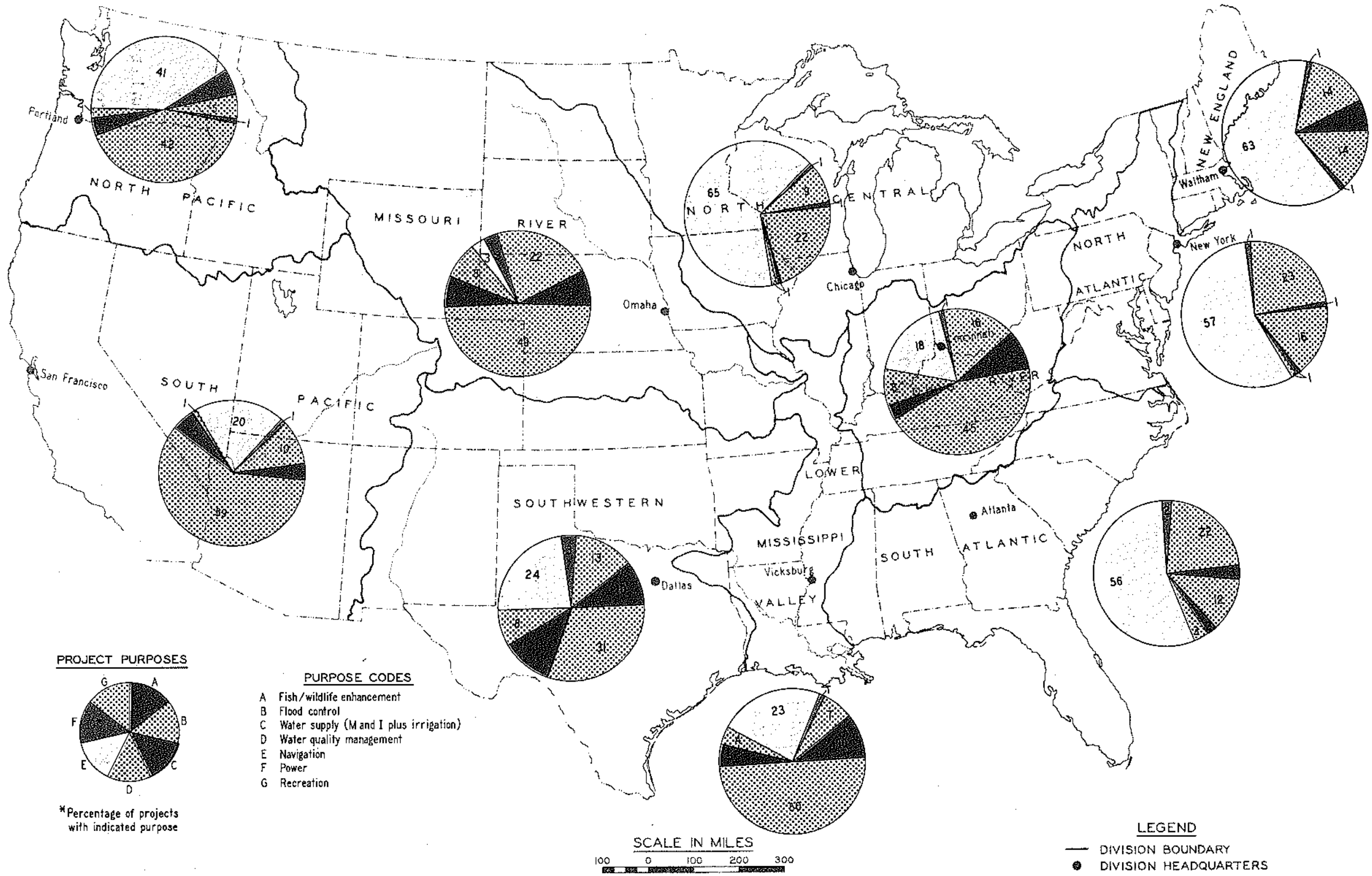


Figure 1. Distribution of Civil Works project purposes

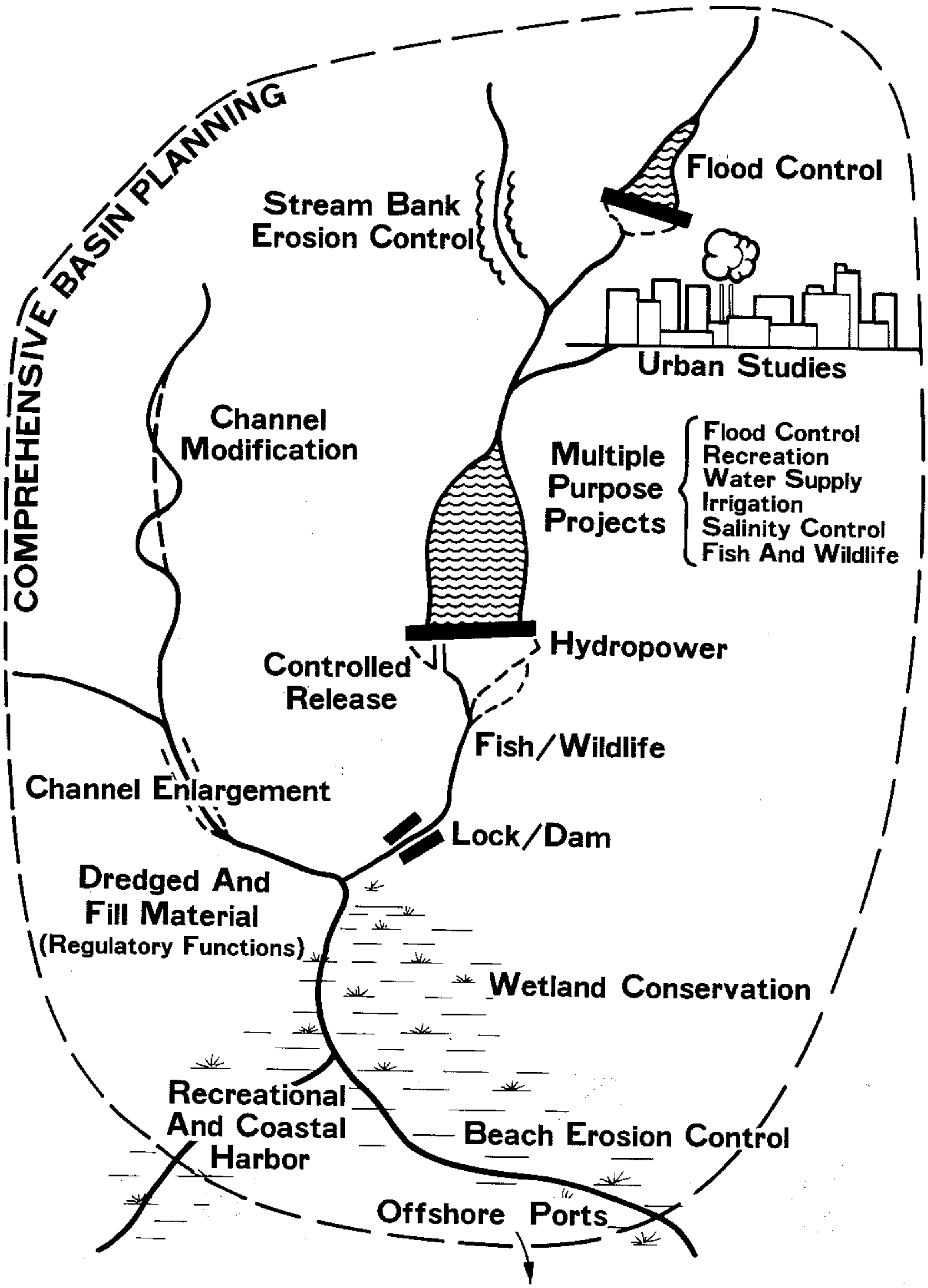


Figure 2. Scope of Civil Works activities of the Corps

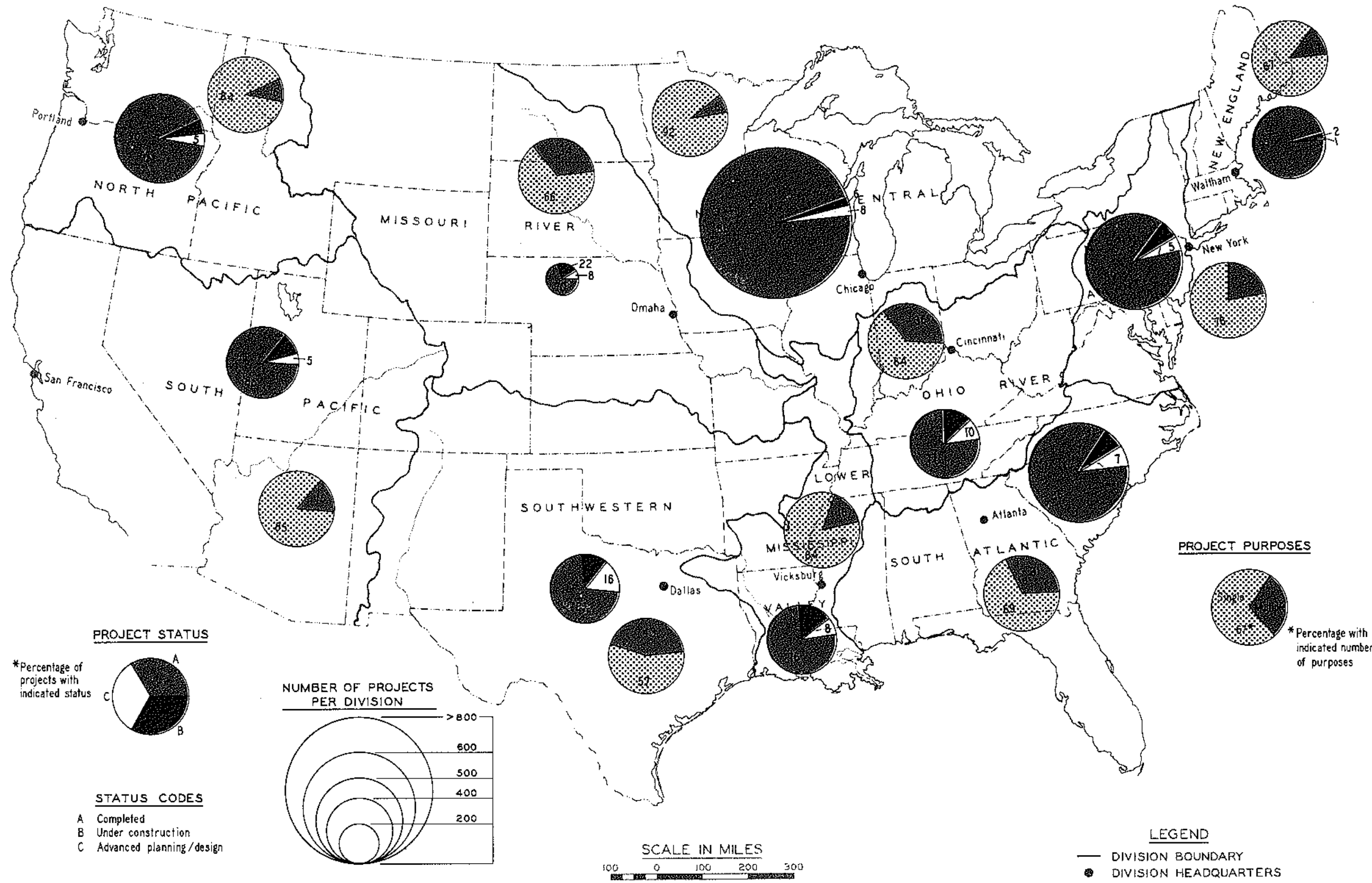


Figure 3. Status and number of purposes of Civil Works projects

and national economic development must be addressed along with and in conjunction to project purposes. For projects that are operational, environmental quality objectives mean additional pressure to meet water quality objectives or to reduce adverse environmental impacts.

Authority

The Waterways Experiment Station (WES) was authorized to perform this study through a Civil Works Research Work Unit entitled Environmental Problem Assessment and Identification of Research Needs (CWIS No. 31257). This research work unit was within the Environmental Impact Program. Work was initiated on 4 February 1976.

Scope of Study

The requirement to consider environmental quality objectives for projects and activities in the planning, engineering, construction, and operations phases has resulted in numerous technical and institutional problems for the Corps' Civil Works program. The impact of these problems may be quantified in both economic and noneconomic terms. Noneconomic impacts are reflected in social concerns, aesthetics, or legal problems. Economic impacts primarily result in increased project costs and effects on economic objectives of the project. The study described herein was conceived to address these problems, to assess their significance, and to identify Corps District and Division needs associated with these problems.

Coordination with Other Federal Agencies

Coordination with Federal agencies was initiated in early 1976 by letters from the Deputy Director of Civil Works. An interagency briefing was conducted on 15 July 1976. Representatives of the Departments of Commerce, Interior, and Agriculture; U. S. Environmental Protection Agency (EPA); Tennessee Valley Authority (TVA); and the Executive Office of the President were in attendance. Liaison is also being maintained with the Bureau of Reclamation and TVA through a Committee on Water Quality and Ecology.

Since the research program recommended within this report represents a combination of two existing Corps programs (Reservoir Water Quality Research Program and the Environmental Impact Research Program), there has been a continuing coordination effort at the individual work unit level with other Federal agencies.

This report was submitted in working draft form to other Federal agencies for formal review and efforts will continue to ensure liaison, coordination, and, wherever appropriate, participation by these agencies in specific research items in the proposed research program. As detailed planning continues for the research program, contacts with other Federal agencies will be expanded to ensure that proposed research tasks build on the latest technical data and do not duplicate research of other agencies.

PART II: CONCLUSIONS AND RECOMMENDATIONS

General

The importance of Corps reservoir and waterway projects to the Nation's economic growth, transportation, hydropower, water supply, and recreation requirements is increasing each year. National concern for the preservation and protection of the environment has resulted in the consideration of environmental quality objectives while planning, designing, constructing, or operating a project to meet its intended purposes. Environmental quality problems often are inherent with or are a result of environmental legislation and may necessitate changes in current practices. This appears particularly true for those projects constructed before passage of major environmental legislation.

The only environmental quality problems discussed in this report are those associated with meeting the Corps legal and directed responsibilities, are a direct result of authorized Corps missions in water resource development or management, or impede the meeting of authorized project purposes. From Corps District and Division input, 420 environmental quality problems were identified in connection with Civil Works activities. Generally these problems result from lack of environmental assessment methods for diagnosis of potential adverse conditions or procedures for dealing with determined environmental quality problems. Environmental assessment problems are generally associated with planning activities and environmental quality problems with operations activities.

Environmental quality problems have resulted in direct economic impacts on Corps projects. Economic impacts may be expressed on either an annual basis (i.e., increased operational cost, loss of benefits) or on a project-specific basis (i.e., increased environmental assessment and design or construction costs for corrective action).

Documented costs of environmental quality problems were $10,000,000 in annual costs and $40,000,000 for project-specific costs. The potential economic impacts are $137,000,000 in annual costs and $164,000,000 for project-specific costs. Annual costs may be expected to increase significantly in the future as more projects with environmental quality problems become operational.

In addition to direct economic impacts to Corps projects, environmental quality problems have caused adverse public reaction, unfavorable aesthetics, and litigations that impact on project acceptability and operation.

Environmental quality problems were documented at 152 Civil Works projects throughout the United States. These projects account for 2000 megawatts of power-generating capacity, 300 billion gallons of water supply, and 125,000,000 recreation days annually.

Water and related land resources planning and development activities must be consistent with national economic and environmental quality objectives. Thirty percent of the 420 environmental quality problems associated with Civil Works activities established the need for improved resource planning and project design procedures.

The majority (70 percent) of all Civil Works environmental quality problems are associated with operation and maintenance of existing projects. Guidance is needed for operation of the individual project, as well as for compatible operation of many projects located within a river basin, to meet environmental quality objectives while efficiently achieving project purposes.

Specific

Impounded waters often have low concentrations of dissolved oxygen, resulting in poor quality water and declining fishery resources. Design methods for minimizing conditions of low dissolved oxygen such as reaeration or destratification require improvement and appropriate operational guidance must be developed to minimize problems within reservoirs and their release waters.

Algal blooms and the excessive growth of other aquatic plants at Corps projects often cause unfavorable aesthetics, taste and odor problems, undesirable effects on fishery resources, and oxygen depletion.

Present technology does not allow adequate evaluation of the Corps activities that may cause accelerated eutrophication or provide suitable techniques for corrective action.

The presence of contaminants such as heavy metals and pesticides often result in conservative and overly costly corrective actions and losses of project benefits. Better environmental assessment procedures are needed for diagnosis of the nature and significance of potential contaminant problems, and improved coordination is needed with Federal, State, and local regulatory agencies to obtain enforcement of legislation and policies governing point and nonpoint contaminant loadings in the upstream watershed.

Environmental simulation techniques show promise of providing the Corps with methods to evaluate project planning, design, and operational alternatives to meet environmental quality objectives. Environmental simulation capability is currently limited by a lack of specific information on important biogeochemical parameters and interactions among them relative to environmental quality objectives.

Corps sample-collection practices and field and laboratory analyses require both technical and administrative input to ensure necessary efficiency, quality control, and standardization. Guidelines are needed for the acquisition of adequate and reliable data for environmental impact assessments, project planning and design, and postconstruction monitoring. A majority of the needed guidance, subject to minor modification, is available through EPA and the Interior Department and therefore does not require a major research effort.

A standardized procedure for conducting environmental assessments on proposed Corps activities is required. Currently, no standardized environmental assessment procedure has been found to be generally applicable to proposed projects or useful in evaluating the effect of various project alternatives on environmental quality objectives.

Methods for managing water resource projects on a regional basis while achieving project purposes and environmental quality objectives are currently inadequate. Techniques are needed for planning and operations that allow the evaluation of conflicting water resource demands and that ensure environmental quality objectives are attained on a regional basis.

The environmental impacts of waterway flood control and navigation activities are poorly defined and quantified. To ensure that waterways activities are compatible with desired environmental quality objectives, the impacts of current practices must be determined in order to develop corrective actions or improved operational techniques.

Both the nature and the commonality of the problems and associated research requirements identified in this report indicate that a centralized program of research would be of benefit. Inherent in this conclusion is the recommendation that the Corps' ongoing Reservoir Water Quality (RWQ) and Environmental Impact (EI) Research Programs be combined to allow pursuance of any particular problem to its logical conclusion. The recommended increase in annual funding over that for the two ongoing research programs should satisfy some critical needs within two years and also support long-term field application, verification, and demonstration studies. Direct benefits of the proposed research program will be a reduction (30 to 50 percent) of noneconomic and economic impacts of environmental quality problems.

PART III: RESEARCH PROGRAM

Research Requirements

Many environmental quality problems were identified during the assessment phase of this study as being amenable to research. Both the nature and the commonality of the research requirements associated with these Civil Works problems indicate that a centralized program of research would be of benefit. Although the nature of Civil Works activities and associated environmental quality problems is extremely diverse, the results necessary from research all fall into one of two categories: either new or improved environmental assessment (diagnostic) procedures or new or improved design, management, or correction guidelines.

Environmental assessment procedures include any interpretive techniques for examination of the symptoms of an environmental quality problem and for predicting the consequences of future actions or conditions. As such, environmental assessment techniques are necessary not only to provide a wide selection of tools that aid in the wise use of the Nation's resources, but to do so in an efficient and economic manner through minimizing costly trial-and-error solutions and conservative decisionmaking. Such procedures include the full range of laboratory bioevaluation techniques, systematic environmental impact methodologies, and sophisticated numerical and physical models.

Environmental quality problems are no different than other types of problems in that diagnostic procedures are a necessary first step that should be taken to determine the nature and significance of a problem and whether or not corrective measures are needed. Once such a decision is made, planning, engineering, design, and operational guidelines suitable for use on a case-by-case basis are necessary. Guidelines for corrective measures include structural design techniques (e.g., selective withdrawal structures for meeting appropriate downstream water quality objectives), and planning guidance (nonstructural flood control), and operational strategies (meet project purposes while maintaining environmental quality). While solutions per se to many environmental quality problems cannot be foreseen within the near future, guidelines, design techniques, and operational procedures for recognizing and minimizing or avoiding such problems are within reach.

The recommended Reservoir/Waterways Environmental Research Program has been designed and structured to satisfy Corps District and Division R&D needs for methods to solve or reduce high-priority environmental quality problems resulting from or associated with reservoir and waterways activities and administrative functions. This research program will incorporate the results of research conducted by other Federal agencies such as EPA, TVA, and the Departments of the Interior and Agriculture and will use, to the maximum extent possible, research conducted through 1977 under the Corps' RWQ and EI Research Programs.

Analysis of the ongoing RWQ and EI Research Programs indicates that the recommended Reservoir/Waterways Environmental Research Program will not differ substantially in scope. Instead, the difference will be one of intensity -- primarily in the area of field application, evaluation, and demonstration of present and future R&D findings. It is emphasized that field trials are required in order to validate and improve R&D results and realize maximum monetary return on the research investment.

The recommended Research Program (Table 1) is divided into two research areas: reservoir environmental research and waterways environmental research. Each area is further subdivided into research tasks. Each of the recommended research task areas is directed toward satisfying a major Corps R&D need. Each task is highly dependent on the others, and the results of each will be applied, evaluated, improved, and demonstrated at Corps project sites chosen for long-term field studies.

Detailed planning for Tasks Id and IId (Reservoir/Waterways Field Studies) will be conducted during 1977 and will consist of site selection and preparation of comprehensive plans of study. Site selection will depend to a large measure on the nature and representativeness of the field situation and Corps activities as well as on the existence of baseline data. Each plan of study will define objectives and methods of approach; will establish channels of Federal, State, and local

Table 1

Recommended Research Program

Research Area	Objective	Recommended Funding - Millions of Dollars						
		FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	Total
I. Reservoir Environmental Research		2.70	3.30	3.70	3.70	3.00	1.00	17.40
a. Predictive Techniques for Determining Environmental Effects	Provide reliable methods for evaluating environmental effects and water quality objectives of planning, design, construction, and operational alternatives in order to anticipate and minimize environmental quality problems and to ensure the realization of reservoir project purposes	0.90	0.90	0.80	0.70	0.70	0.50	4.50
b. Engineering Techniques for Water Quality Objectives	Provide new or improved design criteria for project outlet works, stilling basins, and reaeration and destratification techniques to meet project water quality objectives	0.40	0.40	0.60	0.60	0.40	0.20	2.60
c. Operational and Management Techniques to meet Environmental Quality Objectives	Provide new or improved project operation and management procedures to ensure realization of environmental and water quality objectives in a cost-effective manner	0.40	0.40	0.60	0.70	0.50	0.20	2.80
d. Field Evaluation, Application, and Demonstration of New or Improved Techniques for Environmental Quality Management	Evaluate, demonstrate, and verify at selected field sites predictive techniques and design, operational, and management alternatives developed to minimize environmental quality problems associated with minimum reservoir releases, fluctuating water levels, nuisance algal blooms, major contaminants, non-point source watershed loadings, low dissolved oxygen, and other high priority reservoir problems	1.00	1.60	1.70	1.70	1.40	0.10	7.50
II. Waterways Environmental Research		1.30	1.70	2.30	3.30	3.00	1.00	12.60
a. Environmental Assessment/Impact Techniques for Civil Works Activities	Provide procedures, methods, and guidelines to predict and assess the impact of Civil Works activities on the environment and to recommend project alternatives designed to protect or enhance the Nation's aquatic resources	0.50	0.50	0.40	0.40	0.40	0.40	2.60
b. Environmental Impacts of Design and Structural Alternatives for Waterways	Define and quantify the environmental impacts resulting from waterways engineering activities and to evaluate cost-effective, environmentally compatible design and structural alternatives	0.20	0.30	0.40	0.50	0.40	0.20	2.00
c. Waterway and Multi-Project Operations for Environmental Objectives	Provide information and tools for comprehensive water resource management and guidance for multi-project operations to achieve environmental quality objectives	0.20	0.30	0.40	0.60	0.40	0.20	2.10
d. Field Evaluation, Application, and Demonstration of New or Improved Techniques for Environmental Quality Management	Evaluate and demonstrate at selected field sites the reliability of investigative and predictive techniques for determining the environmental impacts associated with navigation and flood-control practices, modifications to backwater areas, changes in river basin management, and the feasibility and cost-effectiveness of procedures developed to reduce adverse impacts or enhance environmental quality	0.40	0.60	1.10	1.80	1.80	0.20	5.90
							TOTAL	30.00

coordination and cooperation; and will identify the research talent necessary for conduct of the study.

Research Benefits

Research directed at environmental quality problems of the Civil Works program should result in a tangible return. This return would be a reduction in current economic and noneconomic impacts of problems on the Civil Works program. Additionally, this research program will facilitate balancing of environmental quality objectives with economic objectives of water resource projects by (1) providing better techniques for assessment of potential environmental quality problems and their relationship to project purposes, (2) identifying costs and benefits associated with meeting environmental quality objectives, and (3) providing guidelines for balancing these objectives if they cannot be quantified in economic units. Furthermore, the problem identification and resultant research program were structured in such a manner as to facilitate inclusion of potential or future problems that may arise or may become more critical during the execution of the proposed research program.

Direct reduction of presently documented and potential environmental impacts and the associated costs incurred by the Civil Works program are the major benefits expected from this research program. The research program should also reduce those impacts that are noneconomic and generally reflect social concerns over problems by providing corrective actions that will alleviate the problems (i.e., aesthetics, adverse public relations) or will improve assessment techniques to prevent adverse social reaction (i.e., public acceptability of a project, litigations related to the National Environmental Policy Act (NEPA), Public Law (PL) 91-190).

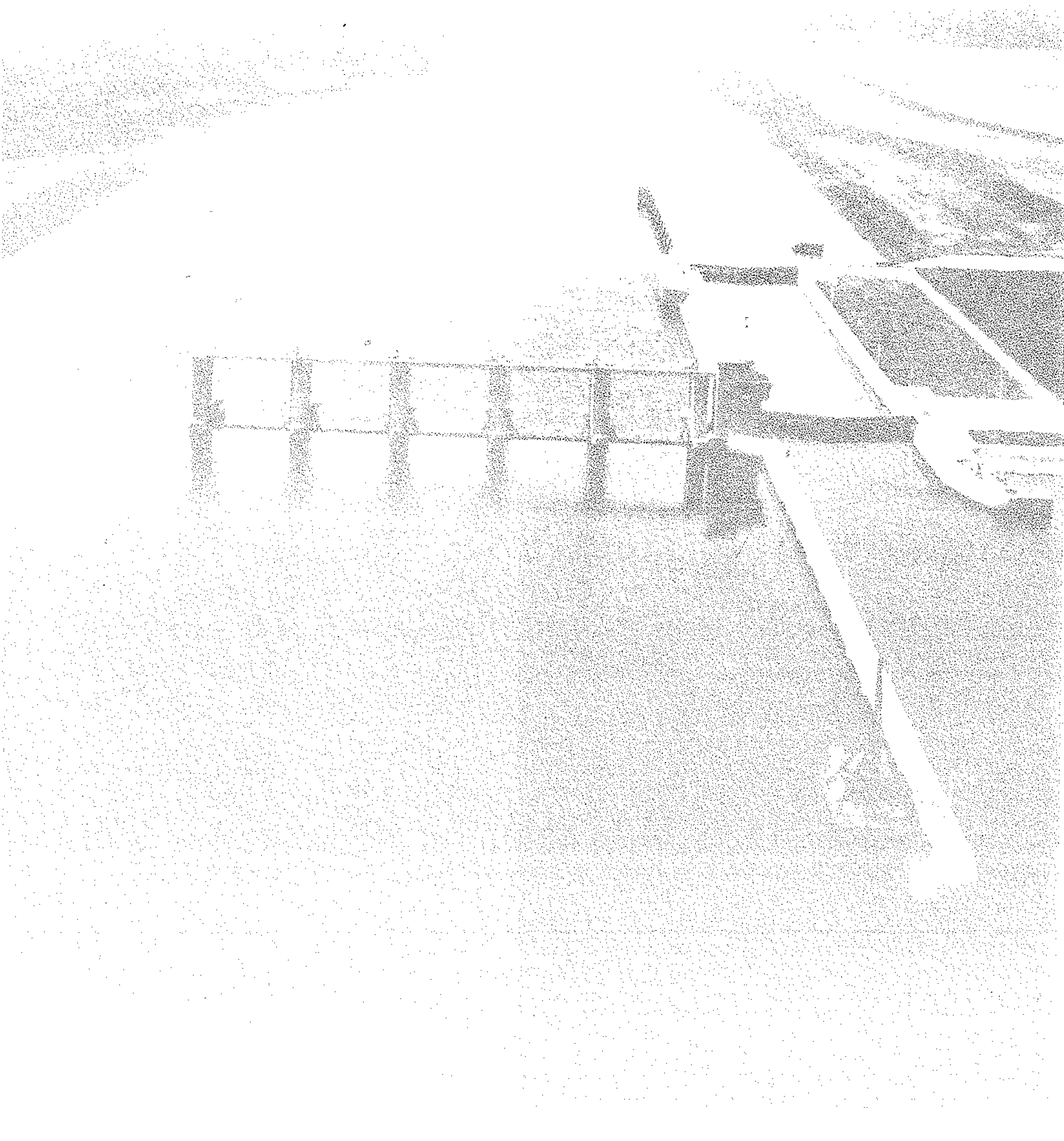
Reductions by the research program in economic impacts due to environmental quality problems may be expected in the following areas:

- Improvement in project-specific studies and research by providing generalized techniques to address problems in the planning and design phases.
- Reduction in costs associated with required functions (preparation of Environmental Impact Statements (EIS's) or issuing permits) by providing guidelines and procedures to perform these functions in a more efficient manner.
- Reduction in costs for corrective actions in construction and operation phases by addressing problems in the planning and design of a project or by providing techniques for efficient operation of a project, thus minimizing net economic impact.
- Elimination of a portion of benefit losses attributable to environmental quality problems by providing techniques to assess their potential (thus addressing the problem early in project life) or by providing corrective actions that would allow realization of a net benefit for the purpose affected.
- Reduction in costs associated with project delays through improved assessment procedures.

The results of the proposed research program may involve costs for corrective actions, but these corrective actions will be applied to maximize net project benefits while minimizing adverse environmental impacts. Thus, environmental quality objectives may be achieved with a net benefit as opposed to the present situation where benefits are lost and corrective actions do not adequately address the problems but do result in additional costs. Improved assessment techniques should substantially reduce economic impacts in the planning and engineering stages of projects.

Section B

PROBLEM DEFINITION AND ASSESSMENT



PART I: SCOPE OF THE CIVIL WORKS PROGRAM

To establish a perspective on water resources development by the Civil Works program, a discussion of the scope of the program is in order. This discussion will aid in establishing the potential magnitude of problems associated with meeting current and projected environmental quality objectives. Table 2 is a summary of Civil Works activities by project purpose and associated water and related land resource management and/or development functions.[1*]

Navigation

Navigation is the oldest mission of the Corps of Engineers. The number and class distribution of Civil Works projects possessing a navigation purpose are shown in Figure 4. Major objectives of Corps navigation activities include participation in initiation, improvement, safety, operation, and efficiency of interstate and foreign waterborne commerce; provision for recreational boating needs; enhancement of seafood production; improvement of environmental quality; promotion of the development of present and potential agricultural and industrial capacities; elimination of transportation handicaps existing in various areas of the country as a result of their remote locations; development of fish and wildlife resources; and the improvement and protection of the general welfare of the public.

Flood Control

Flood control is the second of the Corps' traditional missions. Federal involvement in flood control has been authorized through a series of legislative acts establishing flood-control practices on navigable waters and their tributaries in the interest of general welfare. Figure 5 shows the number and class distribution of Civil Works flood-control projects.

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* Superscript numbers refer to similarly numbered items in the References.

Table 2

Summary of the Corps' Civil Works Program[1]

Project Purpose or Function	Activities Performed Under Project Purpose
Navigation	Inland Waterways Improve natural rivers for open-channel navigation Construct locks and dams Construct canals Deep-Draft Harbors and Channels* Improve natural harbors and channels Construct new harbors and channels Small-Boat Harbors and Channels Improve natural small-boat harbors and channels Construct new small-boat harbors and channels Activities oriented to development of commercial and sport fishing, general recreational boating, and harbors of refuge
Flood Control	Structural Planning, design, construction, and operation of physical structures to contain or otherwise modify the flow of flood waters Measures used to reduce the frequency of damaging overflows including dams and reservoirs, levees, dikes, floodwalls, diversion channels and tunnels, channel alterations, pumping, and land treatment Nonstructural Regulatory and other land use adjustment measures that serve to modify flood damage susceptibility. These measures exclude physical control of floodwaters Activities included in these measures are flood forecasting and warning systems; temporary or permanent evacuation and relocation; emergency flood fighting and financial relief; land use regulations including floodway delineation, floodplain zoning, subdivision regulations and building codes; flood-proofing with or without land-use restrictions; area renewal and conversion to open space; and flood insurance
Beach Erosion and Hurricane Protection	Restoration Activities directed to restoration of historic shorelines to prevent or control erosion caused by wind and tide-generated waves breaking along shorelines Participation made toward periodic beach nourishment (sand replacement) Hurricane, Tidal, and Lake Flood Protection Authorization for and specific activities conducted to protect against hurricane, abnormal tidal, and Great Lakes flood damage is not defined by legislation
Streambank Erosion Control	Restrictions Except in serious cases affecting general public welfare, interest limited to bank-stabilization measures required as components of flood control, navigation, and water resources development projects Measures undertaken for purposes of flood-damage prevention which involve construction, repair, restoration, and modification of emergency streambank and shoreline protection works to prevent damage to:
	(Continued) (Sheet 1 of 4)

* Activities can occur on Atlantic, Pacific, or Gulf coasts and on the Great Lakes.

Table 2 (Continued)

Project Purpose or Function	Activities Performed Under Project Purpose
Streambank Erosion Control (Continued)	<u>Restrictions</u> (Continued) Highways Bridge approaches Public works Churches Hospitals Schools Nonprofit public services
Hydroelectric Power	<u>Incorporation of Hydroelectric Power</u> Add power as integral parts of comprehensive plans for regulation, control, conservation, and utilization of water resources Install penstocks and other facilities adapted to possible future use in the development of power in any dam when recommendation to do so has been made <u>Pumped Storage Power</u> Investigate possibilities for pumped storage developments in preauthorization and postauthorization studies for optimal development of water resources Consider engineering and economic aspects of project for pumped storage power Consider integral facilities versus adjoining plant design <u>Release Control from Power Plants</u> Consider flow rates compatible with stream regimen and to avoid reduction of other project benefits, including recreation, pollution abatement, and water supply Consider positive measures to prevent or reduce adverse effects of power projects during planning and project operation phases (mitigation) Determine minimum flow rates and volume of power project in accordance with downstream effects and examine possibilities for benefits obtainable with modification of project operations
Recreation	<u>Planning, Design, Construction, Operations and Maintenance</u> Benefits for recreation included in economics of contemplated water resources project Activities include purchase of needed lands and construction of facilities needed for public health and safety (minimum includes turnaround, guardrails, barriers, and sanitary facilities at reservoir projects) at reservoirs. More fully developed projects require incorporation of trails, commercial concessions, and downstream use areas
Water Supply	<u>Storage</u> Storage capacity for municipal and industrial uses is added to project purposes based on demand, cost of addition, and relationship of storage to other project purposes Supply water impounded in flood control used to recharge ground water supplies
Water Quality Control	<u>Stream Flow Regulation</u> Stream flow regulation capacity of reservoir used to improve water quality (Sheet 2 of 4) (Continued)

Table 2 (Continued)

Project Purpose or Function	Activities Performed Under Project Purpose
Water Quality Control (Continued)	Stream Flow Regulation (Continued) CE requests EPA to assess water quality relative to water-quality control storage in projects Salinity Control Includes some activity in relieving salinity in return flow from irrigation and natural salts in waters Control of salt water wedges intruding in estuaries by: Upstream freshwater releases Instream estuary structures Mine Drainage Abatement - present work confined to studies of physical measures of acid or sediment-load reduction to reflect area needs and associate improvement in stream use
Wastewater Management	Conduct pilot studies giving consideration to plans for construction, operation, and maintenance of facilities in selected regions including wastewater conveyance systems, regional water and wastewater treatment, interception and holding facilities, land treatment of wastewater, recharging of groundwater aquifers, and recycling and reuse of wastewater Consult with and provide technical assistance to State and local interests in developing and operating a continuing areawide waste treatment management planning process
Urban Studies	Assist and aid urban planners by developing a range of alternative water resource plans and programs compatible with and able to be made integral segments of urban master plans. Plans and programs should solve specific urban water problems and help to solve related urban problems
Fish and Wildlife	Mitigation Measures to offset damages to fish and wildlife to be included in projects Fish and wildlife conservation receives equal consideration with other project purposes and is coordinated with other features of water resource programs Area of interest includes impoundments, diversions, channel deepening, or any modification of stream or other body of water Coordinate activities with Fish and Wildlife Service (Dept. of Interior), National Marine Fisheries Service (Dept. of Commerce), and agency administering fish and wildlife resources of state in which construction is proposed Enhancement - include fish and wildlife improvements in projects as appropriate
Wetlands Conservation	Corps ensures that activities conducted on or in wetlands are planned, designed, constructed, operated, and maintained to minimize adverse environmental effects Mitigation measures are performed whenever practical Civil Works activities undertaken subsequent to approval of a State's Coastal Zone Management (CZM) plan are determined to be consistent with that plan Corps ensures that permit applications for CE-regulated activities are certified to be in accordance with approved State CZM plan CE provides technical assistance requested by States to assist implementation of national policy for CZM

(Continued)

(Sheet 3 of 4)

Table 2 (Concluded)

Project Purpose or Function	Activities Performed Under Project Purpose
Aquatic Plant Control	Planning Studies - survey reports
Regulatory Functions	Permitting Regulation of dredging and other construction work in U. S. navigable waters Prevent obstructions to navigation Dredge and fill material Work in navigable waters shoreward of harbor lines Determine public interest as required by law: Require five-point EIS for actions that may have significant impact on human environment Require proposed activities that may modify a body of water to be reviewed by Federal and State Fish and Wildlife departments Require applicant for permit for any activity that may result in any discharge to furnish water-quality certificate from appropriate State/interstate agency Requires all Federal agencies with activities directly affecting CZ or with development projects in CZ be consistent with State CZM program Regulations for use, administration, and navigation of U. S. navigable waters Danger zones Restricted areas Speed limits Depths of cable and pipelines

(Sheet 4 of 4)

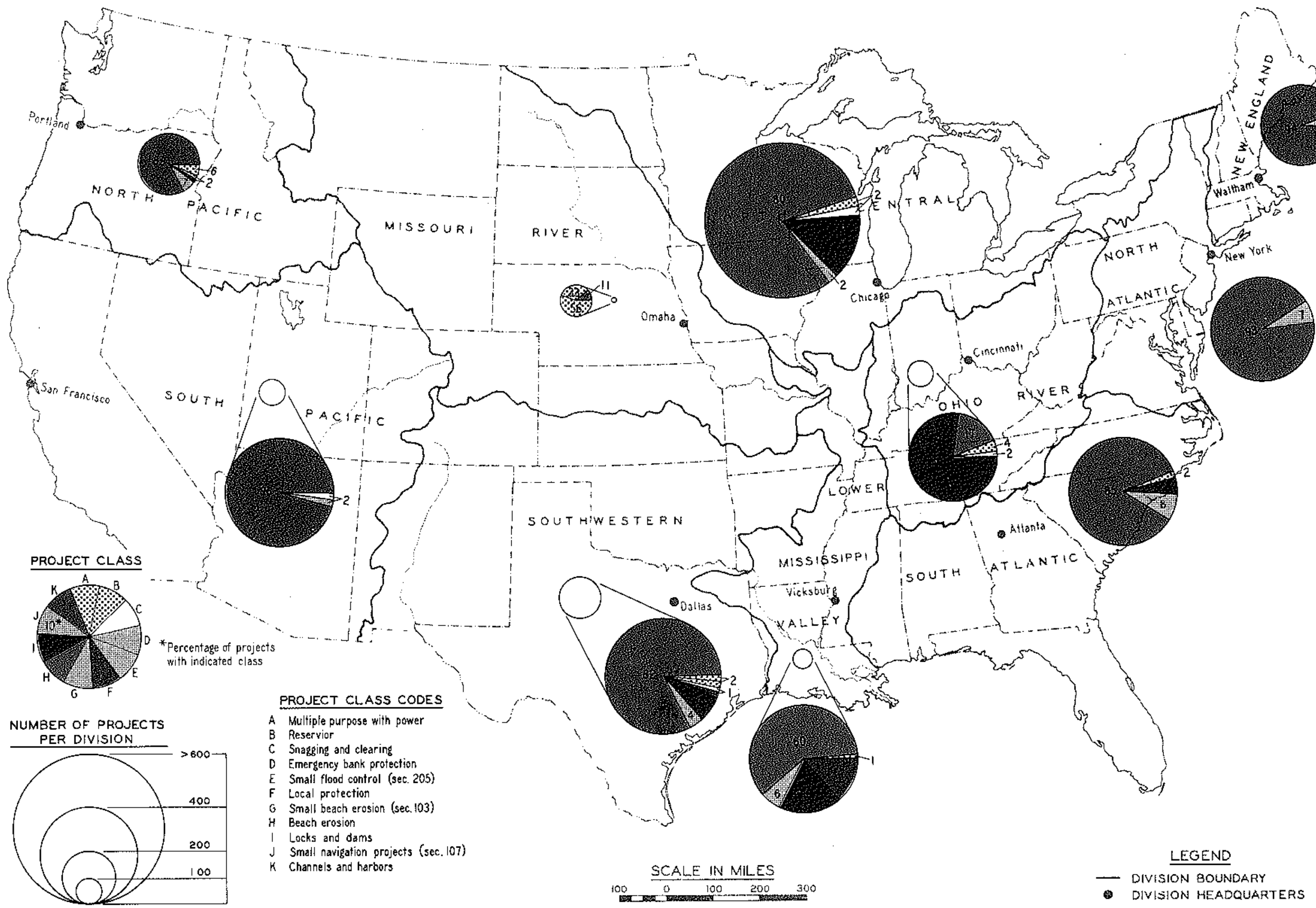

Figure 4. Number and class distribution of Civil Works projects with a navigation purpose

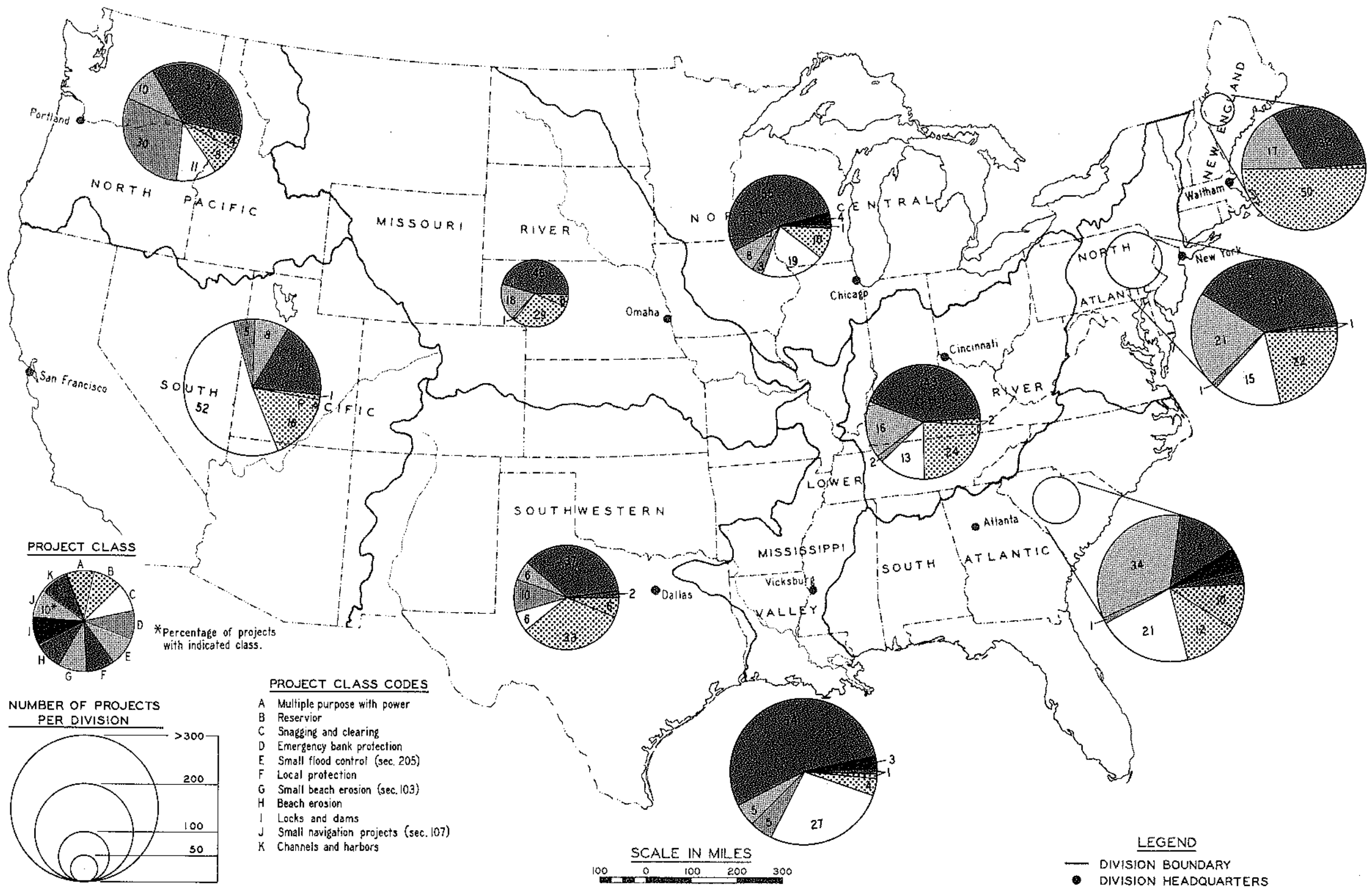

Figure 5. Number and class distribution of Civil Works projects with a flood-control purpose

The following are objectives of the Corps flood-control mission:

1. Provide an effective and continuous floodplain management program that functions at Federal and non-Federal levels and is directed toward optimum economic use and maintaining or improving environmental quality of inland and coastal floodplains.
2. Reduce the frequencies of damaging floods and the susceptibility of property to flood damage and provide information to regulate floodplain use and development.
3. Include all relevant alternatives necessary for intelligent floodplain management in the planning phase of each flood-control project.
4. Design flood-control projects that provide the maximum amount of protection for life and property within a framework of acceptable costs and minimal hazards.
5. Provide emergency repair and restoration of flood- and storm-control structures while assisting States and localities with needed disaster relief.

Beach Erosion and Hurricane Protection

Beach erosion activities involve the Corps in the restoration and protection of the shore of public and Federal property on the Atlantic and Pacific Oceans, the Gulf of Mexico, and the Great Lakes and on lakes, bays, and estuaries connected to these bodies of water. The objective of beach erosion activities is to prevent or control shore erosion caused by wind and tide-generated waves breaking along shores and coasts. The objectives of hurricane, tidal, and lake flood protection include protection of open coasts against flooding, prevention of land loss and associated physical damages, minimization of business and emergency relief costs, improvement of recreational usage of protected areas, and prevention of the loss of historic or scenic aspects of the environment.

Streambank Erosion Control

With the exception of situations creating hazards to the general public welfare, Corps participation in streambank erosion control is confined to bank stabilization measures associated with other activities. The general objectives of streambank erosion control activities are (1) to prevent streambank erosion and the consequences thereof, including land losses, stream pollution, decreases in reservoir storage capacities, silting of estuaries and wetlands, and disturbance of ecologic processes and economic activities associated with riverine habitats and (2) to protect streambanks and prevent flood damages to streamside highways, highway bridge approaches, public works, and nonprofit public facilities.

Hydroelectric Power

The Corps role in hydroelectric power has been developed through legislative acts in which Congress has authorized hydroelectric power on a case-by-case basis. Provisions are made not only for power generation, but also for determining environmental effects of operation. The number and class distribution of Civil Works projects with a hydroelectric power purpose are shown in Figure 6. The principal objective of the hydroelectric projects is to provide power with cost savings compared to other power production alternatives.

Recreation

The purpose of recreation is directed toward maximizing the advantages obtained from Corps water resource projects by the public. Figure 7 shows the number and class distribution of Civil Works projects with a recreation purpose. The primary objective of the recreation activities is to ensure continued public enjoyment and continuous use of lands, waters, forests, and other recreational resources associated with Corps projects.

Water Supply and Water Quality Control

Participation in water supply and water quality management establishes an important Corps role in long-term management of water supplies.

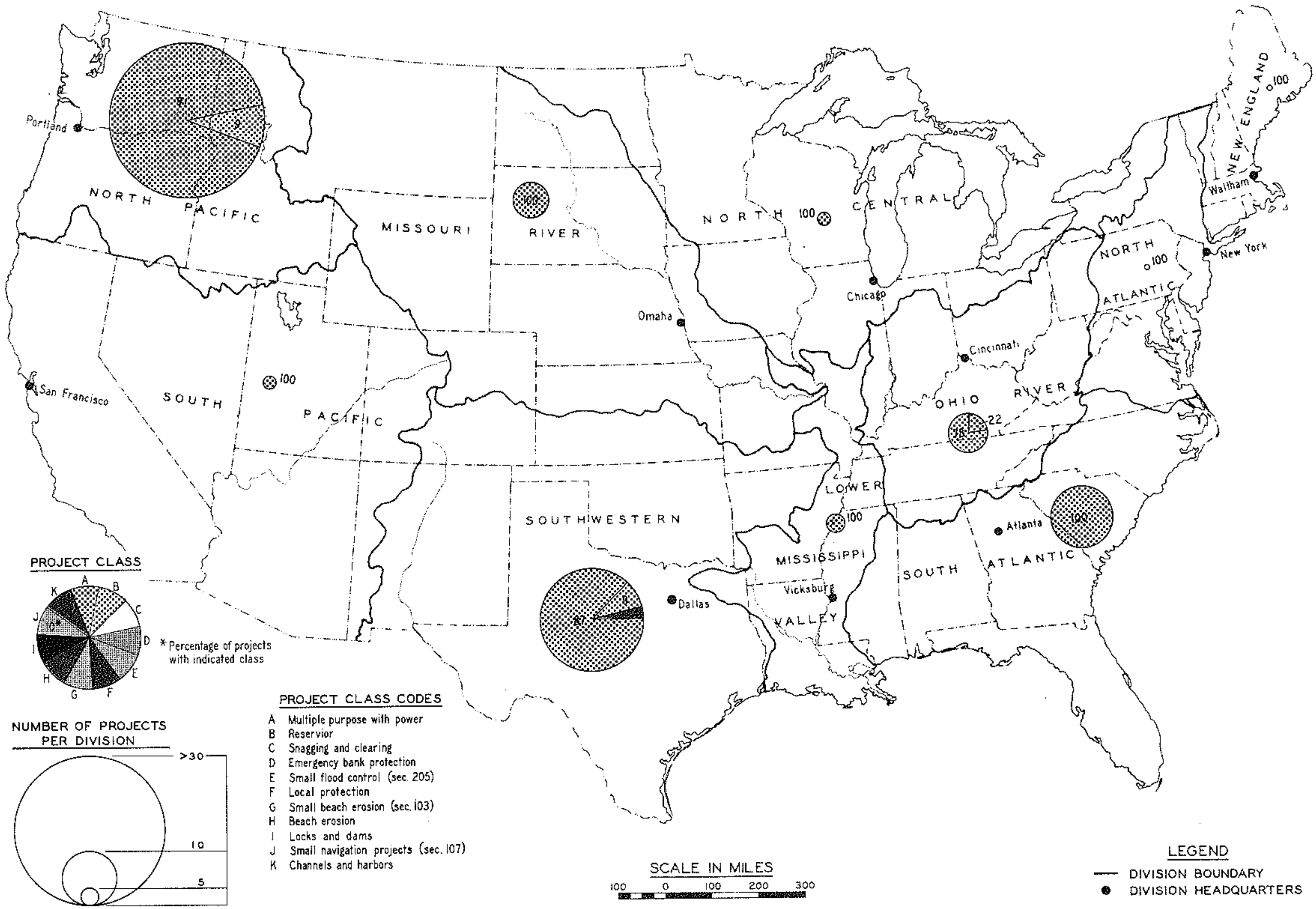

Figure 6. Number and class distribution of Civil Works projects with a hydroelectric power purpose

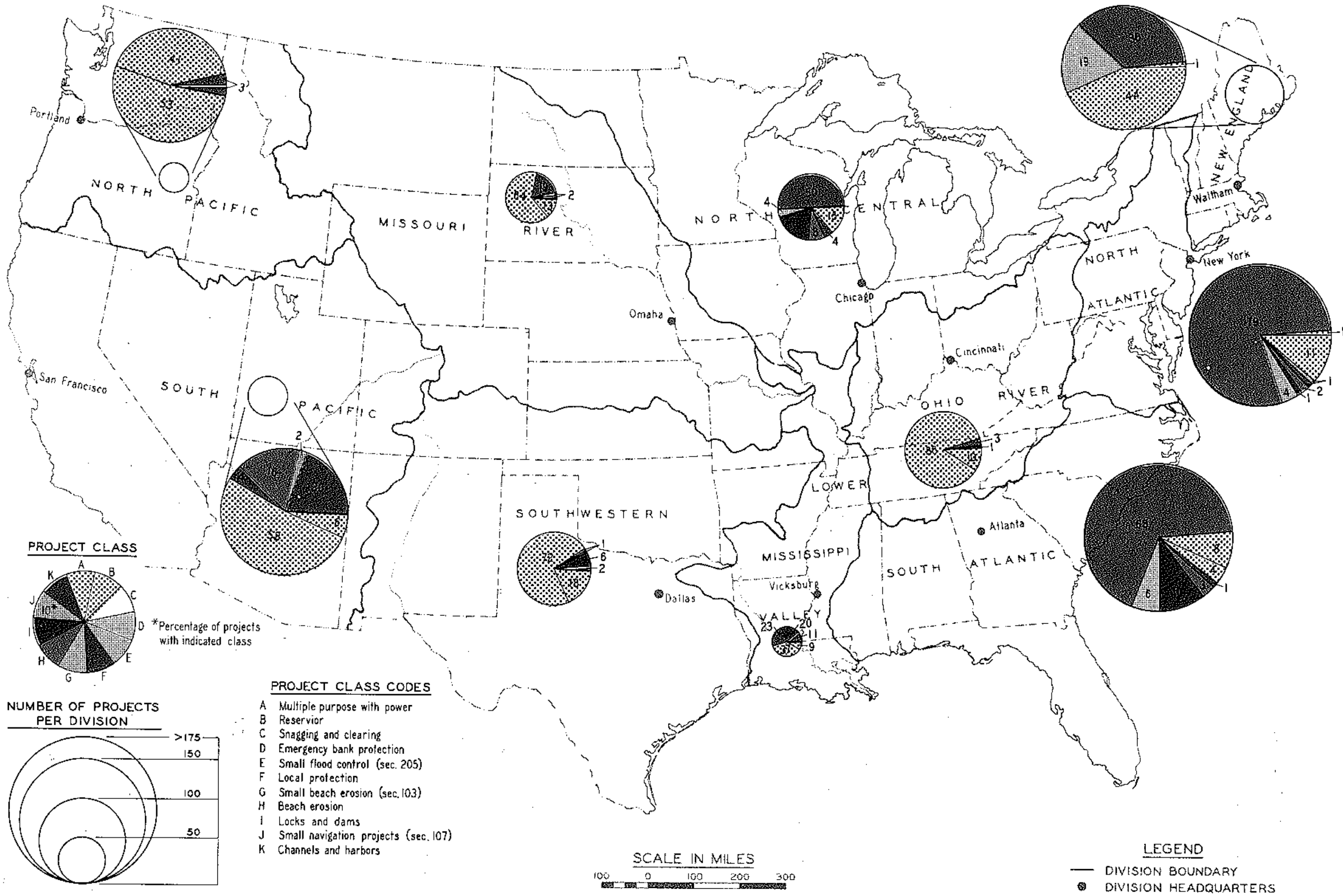

Figure 7. Number and class distribution of Civil Works projects with a recreation purpose

The objective of water supply and water quality management project purposes is to ensure a continuous supply of water that is adequate in quantity and quality for urban and rural needs and for downstream water resource requirements. Figures 8 and 9 show the number and class distribution of Civil Works projects with water supply and water quality management purposes, respectively.

Wastewater Management

The Corps participation in wastewater management is authorized by Section 208(h) of PL 92-500. This legislation directs the Corps to provide State and local governments with assistance in planning, developing, and operating areawide wastewater treatment systems. Specifically, the objective of the Corps wastewater activity is to assist in the development of approved and continuous regional wastewater management plans. Such plans include a complete study and coordination of all possible management alternatives for wastewater.

Urban Studies

Urban area planning provides water resource programs that are consistent with and complementary to urban master plans. The object is to develop solutions to water resource problems and to provide integrated urban water resource plans that supplement local plans.

Fish and Wildlife

The fish and wildlife project purpose provides fish and wildlife conservation equal consideration with other project purposes. The number and class distribution of Civil Works projects with a fish and wildlife enhancement purpose are shown in Figure 10. The goal of the Corps fish and wildlife activities is to enhance fish and wildlife in project areas and to mitigate damages to fish and wildlife resulting from projects.

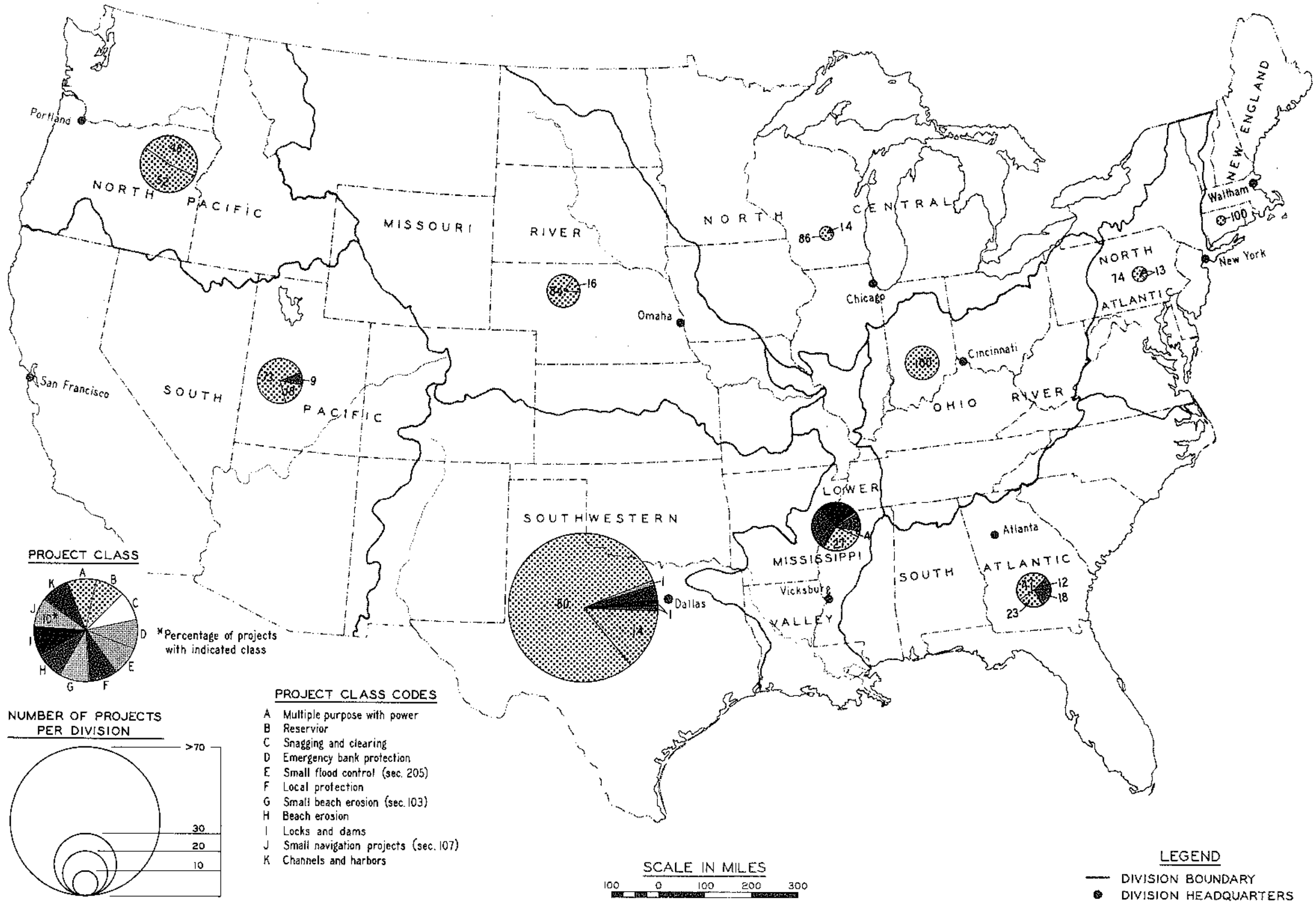

Figure 8. Number and class distribution of Civil Works projects with a water supply purpose

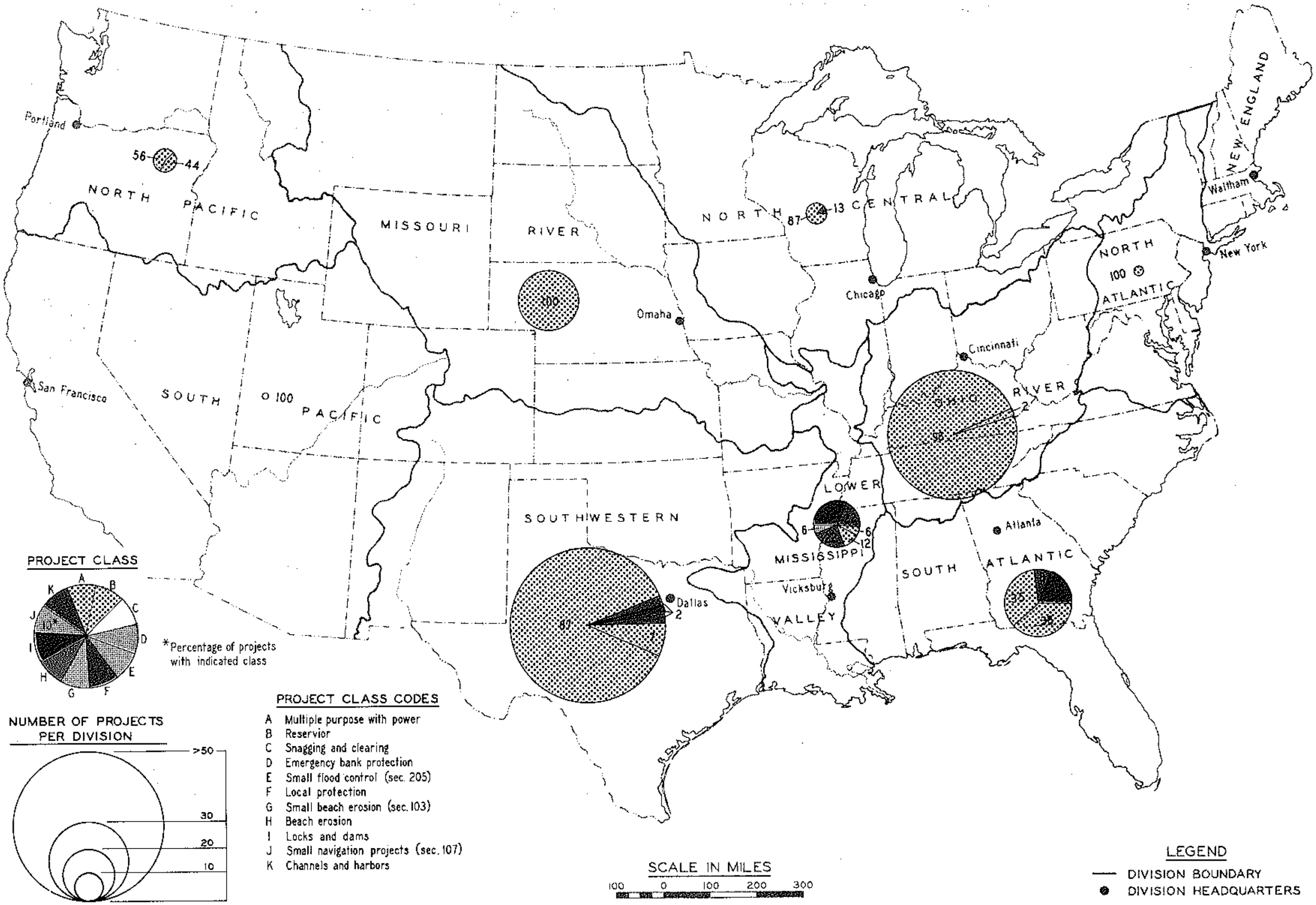

Figure 9. Number and class distribution of Civil Works projects with a water quality management purpose

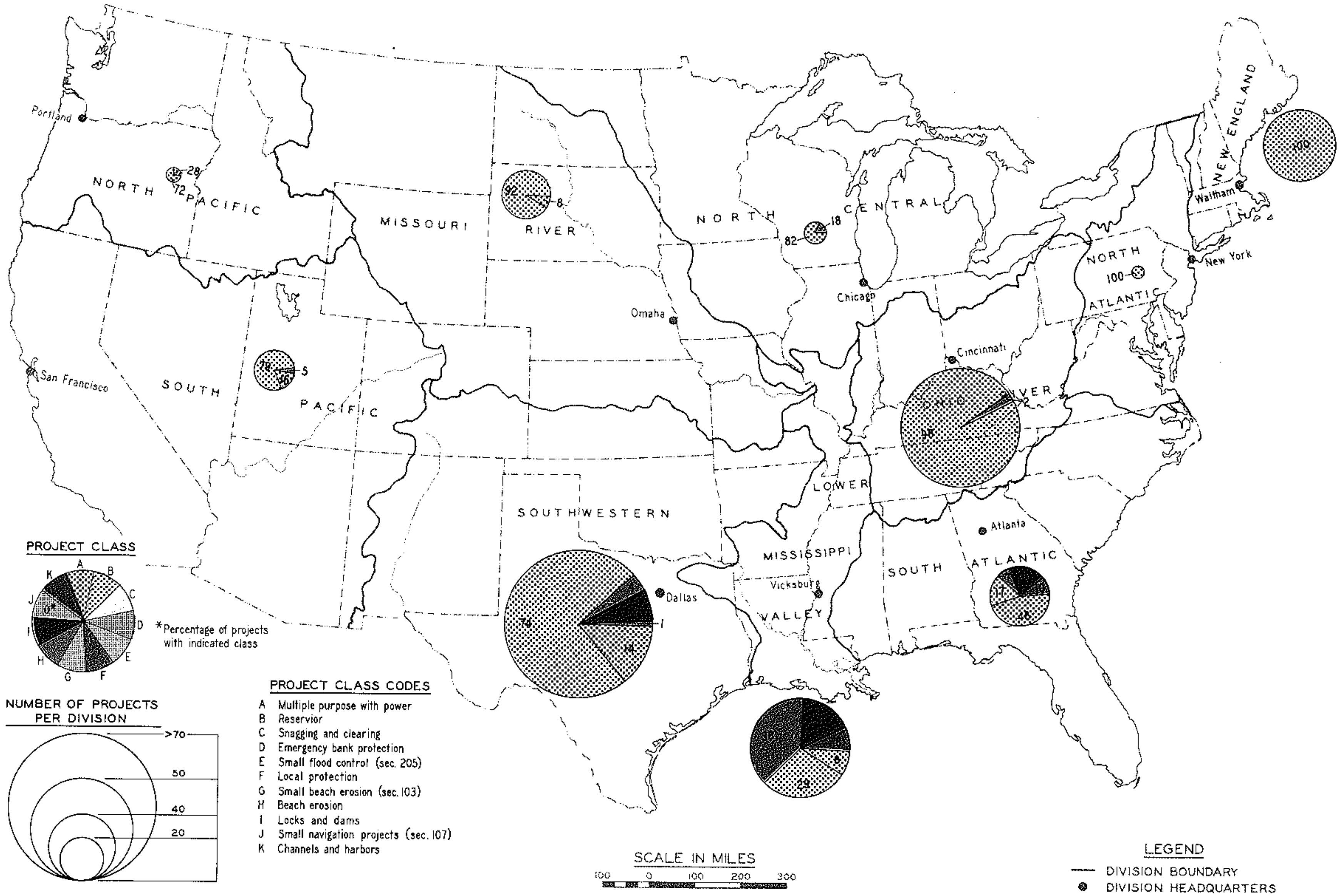

Figure 10. Number and class distribution of Civil Works projects with fish and wildlife enhancement purposes

Wetlands Conservation

The purpose of the Corps participation in wetlands conservation is to ensure the protection of wetlands by regulating planning, designing, construction, operations, and maintenance activities to minimize or eliminate adverse impacts in wetland areas.

Aquatic Plant Control

The objective of the Corps' Aquatic Plant Control Program is to provide the necessary technology to ensure the freedom of navigational waterways from obstruction by vegetation.

Regulatory Functions

The purpose of the regulatory program is to protect the quality of the aquatic resource by regulating the discharge of dredged and fill material and to ensure navigation through regulation of structures intended for placement in navigable waters of the United States.

PART II: FRAMEWORK FOR PROBLEM IDENTIFICATION

Mission Objectives

Concurrently with fulfilling its mission, the Corps must also meet national economic and environmental quality objectives. The interrelationships between missions, economic objectives, and environmental quality objectives form the framework for problem identification. A schematic of these interrelationships is shown in Figure 11.

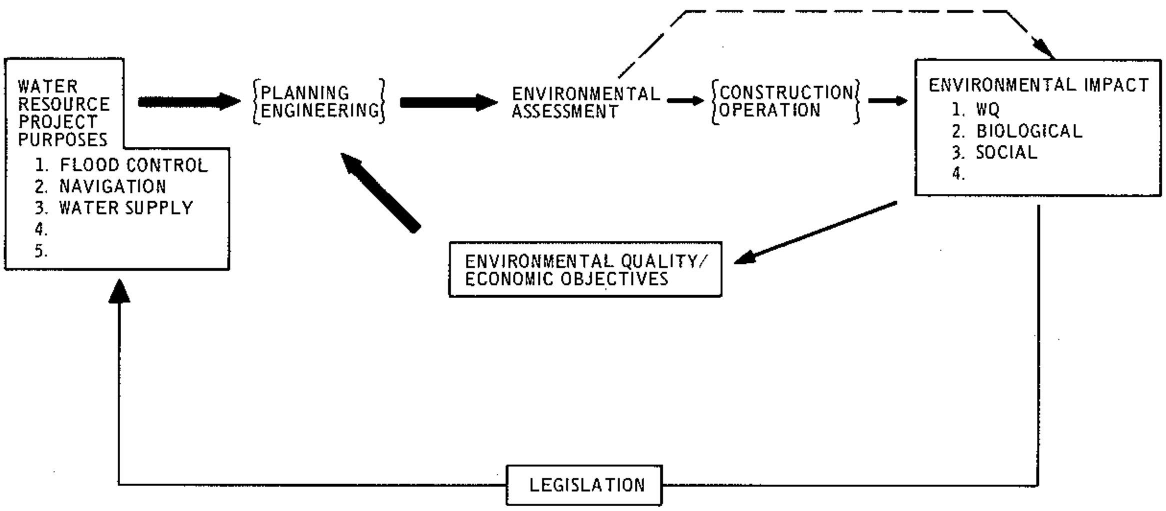

Figure 11. Interrelationship of the mission, economic objectives, and environmental quality objectives of the Civil Works program

Environmental Quality Objectives

Environmental quality objectives are directed at minimizing the adverse environmental impacts of a water resource project. The environmental quality objectives associated with a water resource project normally include water and air quality and biological, social, archeological/historical, aesthetic, land-use, transportation, and recreational aspects. The attainment of these objectives may subsequently affect economic goals if the associated costs of attaining these objectives when added to other project costs are greater than project benefits.

During the planning and design stages of a project, an environmental assessment of the proposed project is conducted. This assessment identifies potential environmental impacts associated with a project and permits alternative designs and operations to be evaluated. The actual magnitude of environmental impact caused by the project can be documented during construction and operation. Problems may be identified with projects in the planning or engineering phases, but these are only potential problems. Because of the need to meet environmental quality objectives, assessment becomes important during the planning and engineering phases, and documentation during construction and operation. All project phases were considered in analyzing the environmental quality problems encountered in this study.

Economic Objectives

The significance of the problems is a direct function of their relationship to economic objectives of the water resource project. Problem impact on economic objectives may be ascertained by considering project-specific costs and annual costs associated with the problem. Project-specific costs refer to those costs that are identifiable with a specific project, such as costs for planning or design studies and costs associated with corrective actions to achieve environmental quality objectives. Annual costs refer to increased operational expenditures and/or loss of project benefits resulting from an existing environmental impact that may be expressed on an annual basis.

The problem effect on economic objectives must be considered in view of existing and future practice with respect to water resource development. If proper techniques for making environmental assessments or correcting environmental impacts can be developed within economic constraints, then environmental quality objectives can be achieved while meeting water resource project purposes.

Legal Considerations

A possible response to environmental problems associated with water resource development is legislation to modify water resource development objectives. Legislation, thus enacted, may modify implementing activities (e.g., planning, engineering, etc.) of water resource projects or may modify environmental quality or economic objectives. These modifications are stated in the form of directives such as Executive Orders and, in many cases, result in additional requirements for water resource development and in expenditure of funds to meet these requirements. Furthermore, where legislative requirements are not precisely detailed, there is confusion in what course of action to follow in meeting requirements. In this instance, efficiency may be sacrificed in meeting requirements not precisely defined with a resultant economic impact on the project. Because the legislative process is dynamic, the implication to operational projects must also be considered, particularly in the case where requirements are retroactive.

Table 3 is a summary of currently applicable legislative acts and Executive Orders that relate to environmental activities of the Civil Works program. The requirements of these legislative mandates and their associated Executive Orders are complex. This complexity results in problems for District and Division offices in executing their assigned missions primarily by requiring environmental assessments and impact evaluation for all proposed activities and by exerting pressure to meet environmental quality objectives for operational projects. Additionally, legislative requirements create specific problems that will be identified and assessed in subsequent sections of this report.

Table 3

Summary of Legislative Acts and Executive Orders that Relate to Environmental Activities of the Civil Works Program

Public Laws		Executive Orders	
River and Harbor Act of 1899		EO- 11514	Protection and Enhancement of Environmental Quality
PL 65-31	Submerged Lands Act	EO- 11574	Administration of Refuse Act Permit Program
PL 85-624	Fish and Wildlife Conservation and Resource Development Coordination Act	EO- 11593	Protection and Enhancement of the Cultural Environment
PL 87-874	River and Harbor and Flood Control Acts of 1962	EO- 11738	Administration of Clean Air and Water Pollution Control Acts for Federal Contracts Grants and Loans
PL 88-578	Land and Water Conservation Fund Act	EO- 11752	Prevention, Control and Abatement of Environmental Pollution at Federal Agencies
PL 89-72	Federal Water Project Recreation Act		
PL 89-80	Water Resources Planning Act		
PL 89-298	River and Harbor and Flood Control Act Administrative Authority		
PL 89-551	Oil Pollution Act		
PL 89-665	National Historic Preservations Act of 1966		
PL 89-669	Rare and Endangered Species Act		
PL 90-454	Estuarine Study Act--Inventory of Estuaries		
PL 90-542	Wild and Scenic River Act--Selection of Wild Rivers		
PL 91-190	National Environmental Policy Act		
PL 91-224	Water Quality Improvement Act of 1970 and Environmental Quality Improvement Act of 1970		
PL 91-512	Solid Waste Disposal Act		
PL 91-604	Clean Air Act		
PL 91-611	River and Harbor and Flood Control Act of 1970		
PL 92-340	Ports and Waterways Safety Act of 1972		
PL 92-362	Historic Monuments Preservation Act		
PL 92-500	Federal Water Pollution Control Act Amendments of 1972		
PL 92-516	Federal Environmental Pesticide Control Act		
PL 92-532	Marine Protection, Research, and Sanctuaries Act of 1972		
PL 92-574	Noise Control Act of 1972		
PL 92-583	Coastal Zone Management Act of 1972		
PL 93-205	Conservation, Protection and Propagation of Endangered Species		
PL 93-251	Water Resources Development Act		
PL 93-523	Safe Drinking Water Act		
PL 93-627	Deep Water Port Act of 1974		
PL 93-359	Game Fish Research Act		

PART III: PROBLEM INVESTIGATION

Background

Investigation into environmental quality problems associated with the Civil Works program was initiated on 4 February 1976 at the Waterways Experiment Station (WES). The primary purposes of this investigative phase were to identify and assess environmental quality problems associated with the Civil Works activities of the Corps and to recommend research to address identified problems of major significance.

Visits were made to all Corps Division offices in the continental United States to explain the nature of the program and to solicit input regarding environmental quality problems. Problem input solicited was restricted to those environmental problems that are associated with meeting legal and directed responsibilities of the Civil Works program, are a direct result of authorized missions in water resource development or management, or interfere with meeting authorized project purposes. These restrictions were imposed to obtain input that reflected problems that are unique to or are within the authority of the Civil Works program. Secondly, these restrictions allowed subsequent identification of problems that the Corps can effectively address in a research program (i.e., solutions are implementable by the Corps) wherein the research is a primary responsibility of the Corps due to assigned missions and activities in water resource development.

Problem Statement Input

After the initial Division meetings were held and problem input was received, the Divisions were requested to formalize their problem statement input. The principal components of the requested input were (1) a narrative description of the problem and its frequency and importance, (2) a description of projects that are directly affected by the problem, in what manner, and to what degree, (3) the direct costs associated with the problem, (4) a summary of prior research and development work done, if any, to attempt to solve the problem, (5) any indirect or secondary effects of the problem (i.e., public relations, legal, aesthetic), and (6) any litigation resulting from the problem.

The requested information was checked for completeness and in some cases followup contact was made to obtain missing data or to obtain clarification of items. All information was sorted into key areas that reflected major components of the problem statement input and was classified as shown in Figure 12. The objective was to classify problems into functional categories that would serve in assessment and development of research needs and not to catalogue problems on a unique or separate basis.

Problem Areas Related to Current Practices

Information compiled from Corps Division visits and supplemental data received from District and Division offices were used to determine the nature of environmental quality problems associated with Civil Works activities. The information varied widely in its content and in its relationship to specific environmental quality objectives and project purposes. However, the problems being experienced by Corps offices fell within one of eight major categories. Close consideration was given to the underlying causes of each problem -- or to the real situation of which the observed problem represented only a symptom. A commonality was often found that then enabled the problem described to be placed into one of the major categories, which are discussed in the following paragraphs.

Dissolved oxygen

The impoundment of waters has oftentimes resulted in low concentrations of dissolved oxygen both within the impoundment and in the release waters. In some instances, this condition results in accompanying undesirable products of anaerobic processes such as hydrogen sulfide. The problem merits special consideration because of the adverse consequences of such conditions on recreational aesthetics in general and the fisheries resource in particular and because of the increased costs to downstream users.

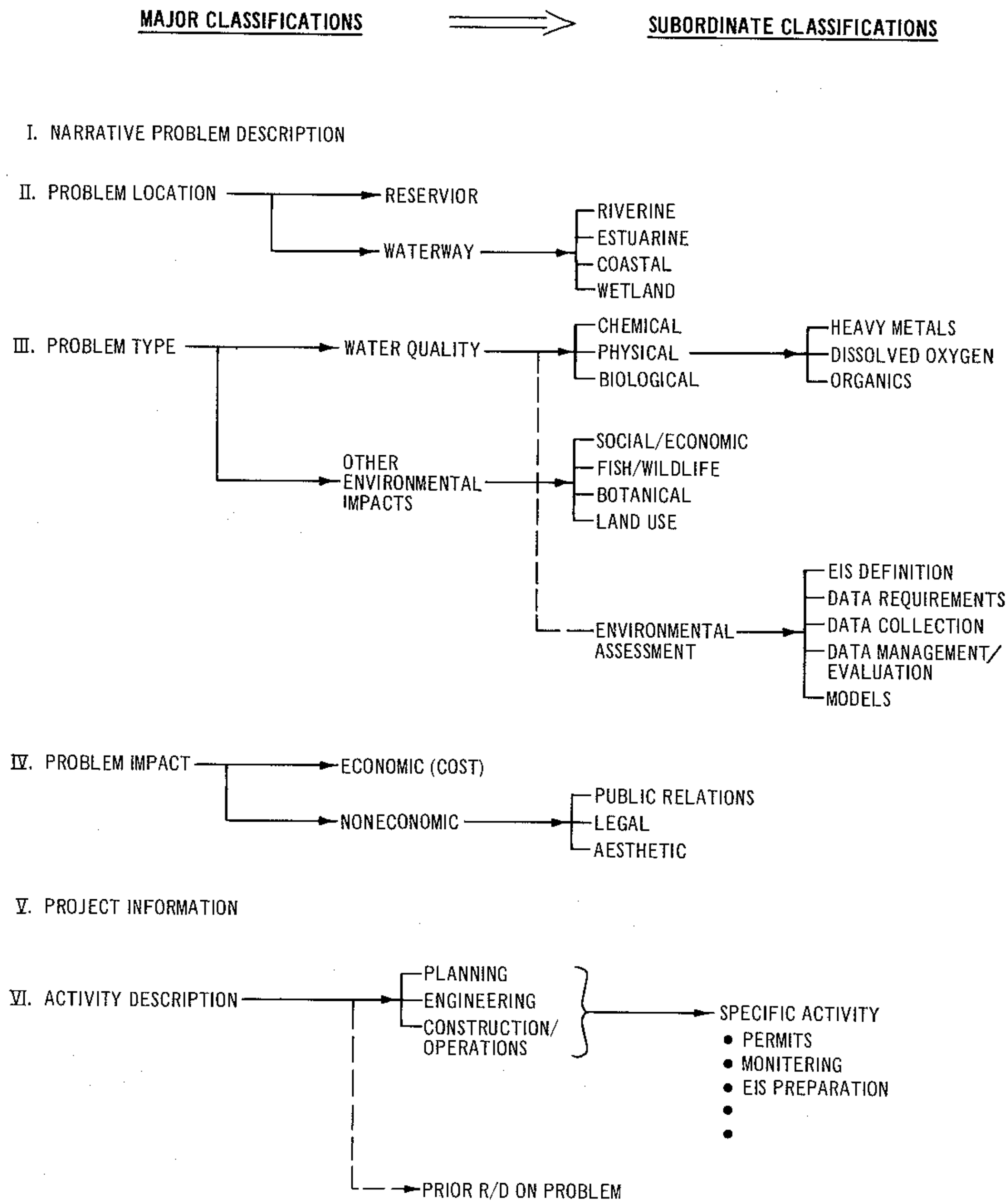

Figure 12. Classification format used for problem statements

Many reservoirs become thermally stratified during the summer months and to a lesser extent during the winter. Thermal and/or chemical stratification act as barriers to vertical mixing and prevent hypolimnetic waters from circulating and mixing with surface waters that undergo atmospheric reaeration. Atmospheric reaeration of hypolimnetic waters is prevented until destratification occurs. Figure 13 is a highly

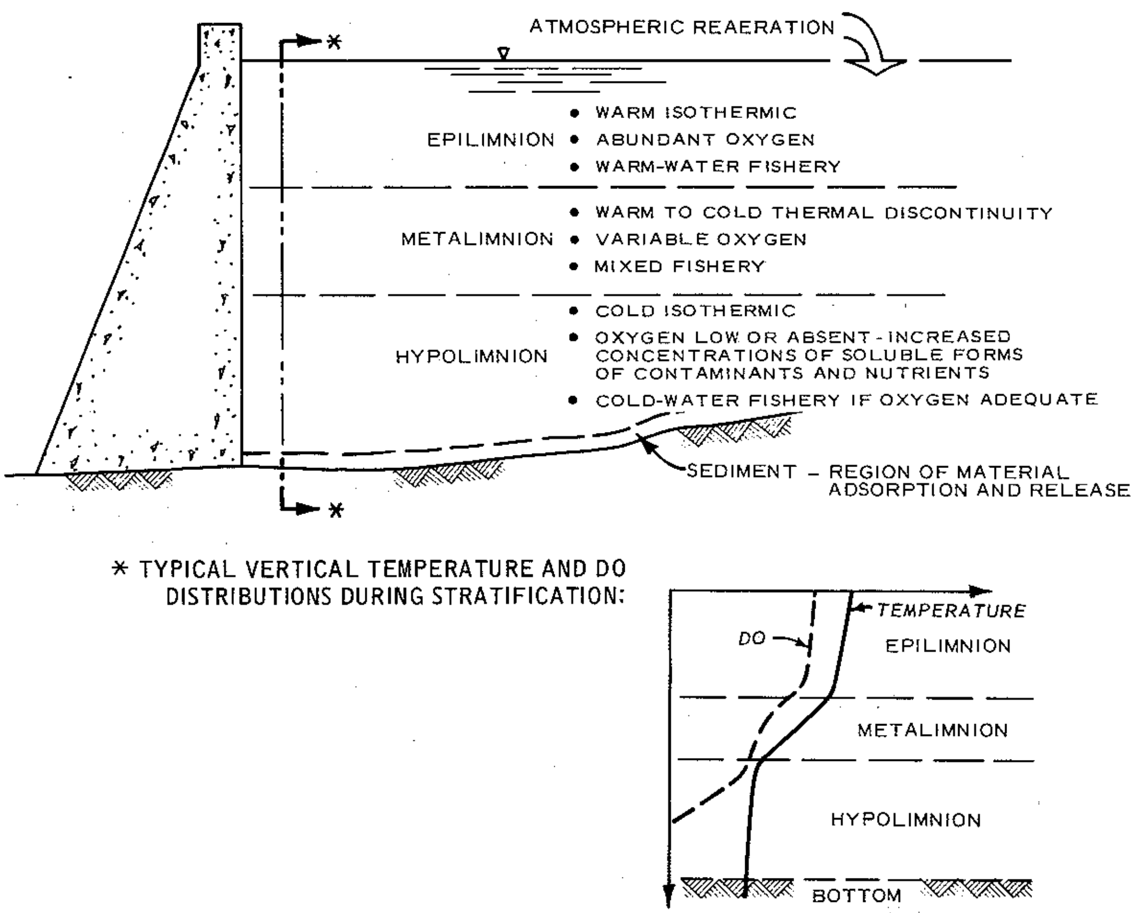

Figure 13. Thermally stratified reservoir and associated conditions of low dissolved oxygen

idealized illustration of a thermally stratified reservoir and associated conditions of low dissolved oxygen. This severely limits the habitat suitable for fisheries management; in reservoirs subject to severe oxygen depletion, often only the surface waters contain adequate oxygen to support fish during late summer months. During times of ice cover, oxygen concentrations may become so uniformly low that severe fish mortalities result.

In general, the extent of oxygen depletion in reservoirs is directly proportional to the residence time of impounded waters. Therefore, most problems associated with low dissolved oxygen become paramount during periods of low flow. Oxygen depletion is the result of complex integrated physical, chemical, and biological processes. In virtually all reservoirs, processes of oxygen utilization exceed processes of oxygen production. This is a consequence of reservoirs acting as processors of oxygen-demanding organic matter and chemically reduced materials.

The biological and chemical processes that occur in the absence of oxygen are much different from those occurring in an aerobic environment. Relatively high concentrations of soluble iron, manganese, and sulfides that build up under anoxic conditions may cause associated taste, odor, and staining problems, thereby increasing treatment costs borne by water users for removal of these substances. In addition, the accompanying release of nutrients may stimulate unwanted algal blooms.

The formation of hydrogen sulfide and other noxious gaseous or dissolved products of partial decomposition often occurs in anaerobic waters and sediments. Several major problems associated with reservoirs are a direct result of hydrogen sulfide production. As a consequence of its malodor, there is an obvious aesthetic displeasure associated with its release from reservoir waters. Project operators have experienced severe headaches and nausea while performing the duties involved in the operation of structures associated with waters that contain high levels of gaseous hydrogen sulfide. Hydrogen sulfide is very corrosive and causes accelerated deterioration of outlet works with attendant high maintenance and eventual replacement costs.

The existence of low levels of dissolved oxygen within reservoirs can adversely affect the downstream aquatic environment when these waters are released. The consequences may be a loss of downstream benefits such as fisheries resources.

Numerous corrective measures have been attempted at various reservoir projects to increase dissolved oxygen to acceptable levels. Generalized guidelines do not exist for the selection of the most appropriate reaeration methodologies to permit operation of the project with simultaneous achievement of specific project purposes. Consequently, reaeration efforts have largely been approached on a trial-and-error basis and have been too costly for the most part because of the tendency in such situations to err on the safe side. In addition, present operational release techniques for reaeration are few and are not capable of satisfying a high oxygen demand. High oxygen demand contributes substantially to the expense and unsuitability of many currently available reaeration procedures. Although structures that have selective withdrawal capabilities can be operated to minimize conditions of low downstream oxygen concentrations, guidance is lacking on procedures to avoid conflicts between multiple project purposes.

Reaeration within release structures has included the use of different types of gates or valves in conjunction with various operating procedures, increased turbulence within the exit channel, and, in the case of hydropower projects, the use of turbine venting or penstock injection of molecular oxygen. Such procedures often accomplish the intended purpose of bringing dissolved oxygen levels in tailwaters up to desired objectives. However, continued presence of oxygen-demanding biological and chemical materials in the tailwaters can cause dissolved oxygen levels to again fall below necessary levels. In addition, aeration procedures, especially oxygen injection, are extremely costly. Lack of guidance on when to initiate and when to terminate these procedures and their relative effectiveness can result in both under- and over-aeration. Thus, installation and use of reaeration devices may not be cost effective.

Some methods have centered on in-pool aeration and have included approaches to destratify the impoundment or portions of the impoundment to permit mixing of the oxygen-depleted hypolimnion and the oxygen-bearing surface waters. Other strategies have involved the injection of air or molecular oxygen to restore dissolved oxygen in the hypolimnion, thus avoiding high energy-consuming thermal destratification procedures. These processes all suffer from the same difficulty experienced with structural reaeration -- lack of guidance on the necessary intensity and duration.

Any project that temporarily causes a slowing or cessation of water flow may create problems related to low dissolved oxygen. For example, in many dead-end ship channels and in navigation structures, water circulation and turbulence are minimal during periods of inactivity. The resulting lack of atmospheric reaeration acting in concert with microbial decomposition processes produces low dissolved oxygen problems similar to those of reservoirs. Flood diversion tunnels constructed for the purposes of conveying excessive floodwaters can have problems associated with stagnation of waters within the tunnel and generation of toxic gases and anaerobic decomposition products that become trapped in the tunnel and its waters. During periods of high flow, receiving waters are then "slug loaded" with poor quality water.

Reaeration of oxygen-deficient waters in dead-end ship channels, mainstem locks and dams, flood diversion tunnels, and other waterways projects such as harbors is extremely difficult. The appropriateness of various reaeration strategies and their effectiveness are not known. In some cases, the simplest solution apparently lies in the expensive process of redesigning or altering the structure or channel to improve flow or, in the case of tunnels, atmospheric ventilation. However, in most cases, guidance is necessary to eliminate unnecessary expenditures. Finally, the inability to deal with low dissolved oxygen creating situations quickly, effectively, and within reasonable costs suggests that such problem situations will continue.

Nutrients and eutrophication

Although the term "eutrophication" connotes many things to different people, it usually refers to macronutrient enrichment by man's activities resulting in undesirable changes in water quality. Nutrient enrichment is not inherently bad, since a continual supply of biologically available nutrients is essential for sustaining high rates of biological productivity. However, excessive nutrient enrichment may promote nuisance algal blooms, the excessive growth of submerged plants, the formation of noxious decomposition products, fishkills, tastes, odors, and undesirable aesthetic conditions.

A major source of nutrient input into many reservoirs is runoff from agricultural lands. This source, along with other nonpoint sources of nutrient input, is much more difficult to control than point sources. Excessive inputs of nutrients can also be attributed, in some areas, to poor management of forested lands and also to mining activities in upstream portions of the watershed. Nitrate- and phosphate-rich runoff from feedlots and cattle grazing near the reservoir are other sources of enrichment. Even if external nutrient loadings are reduced through the enforcement of effluent controls and application of land-use guidelines, reservoir sediments that serve as effective nutrient traps in many cases may continue to serve as significant sources of nutrient regeneration and promote the continuation of undesirable eutrophic conditions.

The excessive growth of algae, particularly blue-greens, promotes a whole host of related problems. The microbially mediated release of toxins from blue-green algae has killed fish or, in some cases, the flesh of game fish has become tainted and inedible due to algal consumption. Where reservoir waters are used as a water supply source, treatment costs escalate. Under bloom conditions, algal respiration at night or during periods of heavy cloud cover may reduce dissolved oxygen concentrations in surface waters below that required to support many species of fish. The accumulation of dense algal scums on the downwind side of reservoirs and their rapid decomposition have forced the closing of recreational areas, are aesthetically intolerable, and may cause water supply problems. Due to the associated depletion of dissolved oxygen and changes in aquatic food chains, eutrophication can promote a dominance of rough fish populations over those of game fish with resultant depreciation of sport fishing benefits.

Concern over the adverse conditions associated with accelerated eutrophication is widespread and involves frustration in dealing with the problem where it exists, as well as the effective prediction of whether or not it will be associated with planned projects and activities.

Contaminants

Contaminants are certain microorganisms or chemical substances that may deleteriously affect the environmental quality of the aquatic resource primarily through their effects on the food chain or on man. Some substances (i.e., the array of chlorinated hydrocarbons) are of entirely man-made origin and are potentially toxic at extremely low concentrations. Heavy metals may become toxic when their biological availability and concentration exceeds that necessary for normal biological activity.

The presence of various contaminants frequently poses a significant problem in the planning, design, and operation of Civil Works projects. In some cases, Corps activities may affect the mobility, availability, or residence time of contaminants, and these effects must be considered in the preparation of EIS's and in project design and operation. In other cases, contaminants may interfere with the ability to meet authorized project purposes and established water quality objectives at existing projects.

Certain chemical contaminants such as heavy metals (mercury, etc.) and pesticides (chlorinated hydrocarbons, etc.) are capable of undergoing bioaccumulation in food chains. This bioaccumulation is an important aspect to consider when assessing the impacts of these types of contaminants on important sport and commercial fish species and subsequently on man. Reservoirs that presently do not have immediate contaminant problems may be subjected to continual low-level contaminant loadings. These loadings have the potential for being accumulated and causing significant problems in later years of project life. In cases where these problems do materialize, extensive restoration efforts may be required.

In the majority of cases where the presence of contaminants is confirmed, the immediate problem usually is the inability to determine the nature and significance of the effect of these contaminants on the ecosystem and project purposes. The inability to understand and predict quantitatively water quality and ecological problems resulting from contaminants has often resulted in the abandonment of badly needed projects or in the adoption of extremely conservative and costly measures. Only with the advent of technically sound diagnostic procedures will it be possible to determine the instances in which such decisions are justifiable.

In addition to facing problems that interfere with project purposes, cause the abandonment of needed projects, or result directly from authorized activities, the Corps also has a major responsibility for evaluating the potential for contaminant problems as part of the regulatory functions authorized by Section 404 of PL 92-500. In terms of required expenditures of time and money, the number of personnel who must become involved, and the complexity of necessary procedures, the effort required to evaluate the potential for contaminant problems associated with a proposed Federal or permitted activity varies widely with the nature and magnitude of the activity. Since each has close relationships with man and the aquatic environment, almost all activities require the prediction and evaluation of the fate and effect of contaminants whose distribution, availability, and mobility may be affected.

Types of contaminants. For most Corps projects, the contaminants of greatest concern fall into one of the five major groups: heavy metals, pesticides and organic substances of anthropogenic origin, acid mine drainage, both pathogenic and nonpathogenic microorganisms that are usually of fecal origin, and turbidity-producing substances.

Heavy metals. Heavy metal contamination of streams and waterways results from natural erosional processes acting on the wastes of metal mining and refining operations, municipal and industrial discharges, and various nonpoint discharges and usually consists of such elements as chromium, lead, mercury, and zinc. Once in the waterways, the metals can undergo a wide variety of interactions and transformations including chelation by organic materials of both natural and man-made origin, concentration in aquatic organisms, and microbial transformations from various inorganic forms to other inorganic and organic forms. The toxicities and solubilities of these metals are also altered with subsequent variations in their effect.

Pesticides and organic substances. Man is responsible for the entry of an increasing array of pesticides and other organic compounds into natural waters. For example, agriculture has come to depend on the use of pesticides and other chemicals to ensure maximum yields, high product quality, and economical production. However, evidence has accumulated that certain of these chemicals, especially the chlorinated hydrocarbon insecticides, are persistent and may accumulate in food chains of various nontarget species. While the use of some insecticides, such as endrin, has been greatly restricted, the potential toxicity problem they represent may continue for some time because of their persistent nature. Commercial pesticides are generally applied during spring planting, which in most areas of the country coincides with the wet season.

Other organic compounds of environmental concern and importance include polychlorinated biphenyls (PCB's), phenols, petroleum and petroleum products, and, to a lesser extent, detergents. In some cases when degradation occurs, the chemical derivative is equally or even more toxic than the parent compound. For example, 2-(2,4-dichlorophenoxy) ethyl sulfate is biologically inactive; however, upon microbial degradation, this substance is converted to 2,4-dichlorophenoxyacetic acid (also known as 2,4-D) and related materials that have herbicidal activities.[2] The problems with these organic materials are often most serious when runoff or spills bring large concentrations into project areas. Construction phases of various Corps projects may cause the entry of long-lived pesticides and other organic materials into waterways by perturbing contaminant-laden soils or sediments.

Acid mine drainage. The U. S. Department of the Interior has estimated that thousands of miles of streams and thousands of surface acres of impoundments and reservoirs are seriously affected by surface mine drainages, with acid mine drainage contributing millions of tons of acidity annually.[3] In abandoned and active coal and metal mines, the decomposition of solid iron pyrites (ferrous sulfide) to release soluble iron is followed by chemical and microbial oxidation of sulfides to form sulfuric acid with resulting pH ranges of 1 to 3. Subsequent combinations of ferric iron with other materials in waters yield iron oxide and hydroxide precipitates known as "yellow boy," a turbid suspension. Attempts to correct mine drainage problems chemically have been ineffective and extremely costly. Such methods also suffer because of periodic shutdowns during which slugs of acid mine drainage go untreated with subsequent serious environmental impacts.

Fecal bacteria. The wastes of man and animals are a major source of waterborne pathogens that enter water resources projects from both point and nonpoint sources. Sources include municipal sewage effluents, stormwater runoff from urban and agricultural areas, subsurface drainage from septic tanks, and wastes from recreational boating and swimming. Because of their use as indicator organisms for human pathogens, the presence of fecal coliforms may cause significant losses of fishing activity, body-contact recreation, and potable water supplies.

Although there has recently been a large increase in research dealing with the survival of pathogenic microorganisms in natural waters, guidelines must be developed for the operation and management of Corps projects having microbial water quality problems. Moreover, techniques for assessing and predicting the movement, survival, and potential reproduction of waterborne pathogens are required to permit development of guidelines for the location, operation, and management of recreational areas and water supply intakes in existing and proposed projects.

Turbidity. Turbidity within the reservoir and in release waters is often caused by activities in the upstream watershed. A variety of materials, such as clay, silt, suspended solids associated with domestic and industrial wastes, mining activities, and glacial flour, contribute to turbidity.

A large amount of suspended material settles out in lakes and reservoirs and, in this manner, the lakes and reservoirs function as clarifiers of the water. Turbidity entering the reservoir from upstream may move straight through the system, being delayed in its appearance in release waters in direct proportion to the retention time of the transporting stream water within the reservoir. The net effect is to decrease the intensity of the turbidity while prolonging the period during which the turbidity is released downstream. If the turbid inflow is of a colloidal nature, it may remain in the impoundment for long periods of time.

Reservoir activities such as rapid drawdown may increase levels of turbidity by resuspending bottom materials. Turbid releases may cause loss of downstream recreation benefits such as fishing and canoeing. Moreover, continued release of turbid waters after the apparent cessation of storm-induced turbid inflows gives the erroneous appearance that the reservoir is serving as a source of turbidity. The mode of project operation therefore becomes very important following storm events. Little can be done to alter the losses of benefits presently being suffered because of the nature and many causes of turbidity and the lack of predictive and corrective procedures for dealing with it.

A wide variety of meteorological and physiographic characteristics, construction and agricultural activities, structural features, and project operations contribute to the turbidity and sedimentation in reservoirs and waterways. These loadings may impair water supply purposes and require extensive filtration for removal, hinder recreational purposes because of aesthetic appearance, reduce the project life of reservoirs by siltation, and often increase the need for maintenance dredging of downstream waterways to maintain navigation channels. Reduced transparency resulting from high turbidity is the most common factor limiting biological productivity and controlling excessive algal blooms. Turbid runoff from construction activities frequently does not meet water quality objectives; therefore, more efficient control measures are needed. Sediment that continually accumulates in the bottom of reservoirs acts as a sink for a variety of contaminants, many of which may migrate back into the water during anoxic conditions. The requirements of existing legislation establish the need to predict the movement and evaluate the environmental significance of turbidity in association with project activities; however, present knowledge restricts the development of guidance.

Sources of contaminants. A wide variety of sources of contaminants may pose problems for Civil Works activities. While some of these problems are caused by contaminants from point sources that can be regulated by the enforcement of established legislation, a large percentage of contaminant sources are more diffuse and less easily controlled. Some of the major sources of contaminants are discussed in the following paragraphs.

Stormwater runoff. Stormwater runoff from urban, agricultural, and managed forestry areas serves as one of the most important nonpoint sources of contaminants to Corps projects. Typical urban and agronomic contaminants include oxygen-demanding organic materials, turbidity-causing substances, nutrients, heavy metals, and pesticides. Some of the more significant forest management activities include clear-cutting, road building, and the use of fire retardants, herbicides, and insecticides. Major contaminants in runoff from agricultural activities include suspended solids from clearing and cultivation and a variety of herbicides and insecticides. The frequency, duration, and magnitude of storm-event loadings are almost impossible to anticipate and even more difficult to quantify. Relationships between flow and contaminant flux under elevated flow conditions are not adequately understood to permit the design of cost-effective data-collection programs or to develop reliable tools for prediction and evaluation.

Structural and nonstructural alternatives for controlling stormwater runoff must be field tested for practicality and effectiveness. Design and operational strategies for reservoirs and other Corps structures must be developed to minimize adverse effects of contaminant loadings from storm runoff. Contaminants vary significantly in mobility, availability, and thus their overall effect on environmental quality. This must be taken into account in project design and operation to avoid resultant problems.

Natural mineral deposits. In many parts of the country, waterways transect or drain areas containing natural deposits of salts and heavy metals that by leaching may contribute significant contaminant loads. Drainage from several areas within the Great Plains contribute high concentrations of chlorides and sulfates that adversely affect downstream water usage and project operation. As waters high in dissolved solids mix with less saline waters in downstream impoundments, the resulting density differentials inhibit vertical mixing during periods of isothermy, thereby causing associated water quality problems. Naturally occurring high concentrations of iron and manganese are increased under anaerobic conditions in the hypolimnetic waters of some reservoirs, requiring extensive treatment for water supply uses.

Municipal and industrial effluents. Municipal and industrial waste effluents serve as point sources of contaminants that contribute a significant portion of the total contaminant load to reservoirs and waterways. Although existing legislation calls for the control of such loadings by 1983, significant contaminant problems are presently common in heavily populated regions. Importantly, progress toward achieving established control objectives indicates that point-source effluents may continue to affect the operation of Civil Works projects for some time in the future. As water and energy demands increase, it is probable that the use of Corps reservoirs as a major source of cooling water will increase significantly. The associated thermal discharges are likely to create significant water quality and operational problems.

Fisheries considerations

In response to the Fish and Wildlife Coordination Act (PL 85-264), NEPA (PL 91-190), and the increasing Corps involvement in recreational activities, more attention is being given to maintaining productive fish and wildlife habitats in project areas and lessening habitat losses associated with these projects.

One of the major physical problems associated with fisheries management is temperature. Inability to achieve sufficiently low reservoir release temperatures creates difficulties in maintaining downstream cold-water fisheries; alternatively, cold-water releases can destroy warm-water fisheries. Water resource management activities have a profound impact on water temperatures both within impoundments and downstream. Cold-water reserves are often necessary to maintain needed downstream temperatures. The lack of operational guidelines for regulating structures to avoid conflicts between project purposes and fisheries requirements has resulted in problems in many areas of the country. As an example, such guidelines are necessary for operation of hydropower projects to avoid sending pulses of cold water downstream that may adversely affect fisheries.

A knowledge of reservoir temperature regimes is critical to the development of design criteria for the proper release of water from impoundments to meet downstream objectives. In some cases, fishery agencies desire to maintain a two-story fishery in an impoundment with a warm-water fishery in the surface waters and a cold-water fishery in the bottom waters. The problem involves operating a project to maintain the desired temperature stratification while maintaining sufficient dissolved oxygen in the bottom waters for the cold-water fishery. Therefore, an understanding of operational effects on seasonal patterns of thermal stratification is crucial. Moreover, the Corps is responsible for providing fishery management agencies with information regarding anticipated thermal characteristics of proposed impoundments. Such information is also required for the preparation of EIS's.

Fisheries management related problems are quite varied and depend upon geographical location of projects. For example, principal concerns in the southern United States have been the development and maintenance of warm-water sport fishes including black bass and crappie in reservoirs and in some cases cold-water fisheries in tailwaters. In the Pacific Northwest, some principal concerns include the maximization of successful downstream migration of fingerling anadromous fishes, such as salmon, past hydroelectric dams and the management problems associated with short-stopping anadromous fish at Corps reservoirs. Short-stopping migrating anadromous fish can result in the permanent establishment of a resident population of normally migrant fish species within an impoundment. Exactly how to manage these populations and how they will compete with normal resident populations appear to be questions that will have to be answered before routine fish management procedures can be established at these reservoirs. Similar problems exist in the northeastern states and in places where striped bass fisheries have been established in inland water systems.

Other questions concerning fishery management problems include the effects of dikes and revetments on riverine fisheries, the mitigation of loss of anadromous fish habitat, problems of fish passage around hydroelectric dams, the effect of fluctuating water levels produced by hydroelectric power dams on fish spawning, and the effect on resident fish populations of chemical control of insects and plants on project lands.

Fluctuations in flow and water level

Flow variations. Adverse water quality situations associated with flow variations can be grouped into categories based primarily on the following conditions:

- Lack of reliable techniques to predict minimum reservoir releases necessary to maintain the downstream aquatic environment.
- The effects of pulsating releases from hydropower projects and resultant downstream effects.
- Releases necessary to maintain mainstream navigation pools and associated tributary problems.
- On an individual case-by-case basis, the date that drawdown must be initiated to prepare for flood-control storage space while extending the recreation season to the maximum extent possible.

The Corps is responsible for providing minimum releases from projects to ensure that downstream fisheries and the downstream aquatic environment in general are maintained. Present operational guidelines are not adequate to ensure that this can be accomplished while simultaneously achieving various authorized project purposes. In many cases downstream environmental requirements are not fully understood; consequently, necessary evaluation methodologies are not available. The development of such methodologies is further complicated because of the different requirements of various types of downstream habitats and by the objectives and needs of water users, such as municipalities, industries, and waterborne commerce.

During some periods of the year, minimum flows required to maintain downstream aquatic habitat and associated stream-based recreation are greater than those that can be allowed because of the demands of authorized project purposes. It is during these periods that the problem becomes most critical. The fact that project benefits cannot be accrued for maintaining and, in some cases, enhancing the downstream aquatic habitat complicates the planning for and use of reservoir storage allocations. The situation is often further compounded because preservation of downstream fisheries requires minimum releases to provide an adequate food supply and the water velocities and depths necessary for spawning and juvenile survival. Practical criteria for achieving the required releases in conjunction with meeting other project purposes and downstream environmental objectives are needed. Furthermore, procedures for determining the environmental and economic benefits of making such releases must be developed to provide information necessary for management decisions regarding allocation of project storage and minimization of fish and wildlife losses.

Rapid changes in release volumes place the downstream fishery resources under considerable stress. During periods of fish spawning and rearing, such project operations can severely damage or completely destroy a valuable resource, either because of inadequate water volumes and velocities or from large pulses of water sweeping downstream and scouring the habitat. Preventing floodwaters from periodically inundating downstream floodplain habitats can also be detrimental to the downstream and adjacent terrestrial habitat. The load of suspended matter borne by floodwaters is a valuable source of nutrients for streamside vegetation. Reservoirs also affect floodplain vegetation by influencing the natural flooding regime of an area. Whereas the existence of floodplain vegetation is dependent upon seasonal flooding and a high water table, other types of vegetation cannot withstand inundation by floodwaters. At present, the research necessary for the development of more appropriate flood-control operational procedures consistent with environmental, water quality, and recreational requirements has not been accomplished.

The problem of large pulsating releases from hydropower projects is in some aspects similar to that of large flow variations occurring during flood-control operations. Through the development of proper project and operational alternatives based on a thorough understanding of potential downstream effects, it may be possible to alleviate many of the problems associated with hydropower operations. Insufficient information is presently available to quantify resulting effects of such operations and, therefore, to develop means of satisfying environmental requirements.

The environmental impact problems associated with flow variations are a direct result of project operations. The situation is complicated by the conflicting nature of project purposes and the difficulty in satisfactorily minimizing resultant effects. The problem is further complicated because many of the existing reservoir projects were constructed prior to major environmental legislation; thus, operational flexibility may be limited by structural design. In some instances this may require structural modifications. In others it may require a re-evaluation and possible reallocation of impoundment storage. Changes in operational strategies will probably be required in most instances, but these and other measures cannot be accomplished without a thorough understanding and evaluation of resultant effects.

Water-level fluctuations. The problem of water-level fluctuations in reservoirs has several facets. Since one of the major purposes of many existing reservoir structures is flood control, these reservoirs are operated with strict adherence to generalized and conservative flood-control policies. Guidelines for specific case-by-case application are necessary if the maximum benefits of both flood protection and extended-season recreation are to be realized. Furthermore, changing water levels due to power and flood-control withdrawals often result in recreational impairment due to lack of access and exposed mudbanks. Unfortunately, attempts to reconcile recreational needs with other project purposes suffer from a lack of guidelines based on sound research on the subject.

Water-level fluctuations often result in excessive turbidity associated with bank erosion and mudflats that have formed along the shore-water interface. Mudflat formation is associated with vegetative die-back, which reduces the habitat available for fish and other wildlife and also destabilizes fine-textured sediments thereby causing increased turbidity.

Water-level changes associated with reservoir filling also affect local vegetation and animal life. Reservoir projects subject vegetation that is rarely or never influenced by floodwaters to temporary inundation. Subsequent death of this plant material subjects the impoundment waters to biochemical oxygen demand and nutrient loading. Additionally, exposure of emergent and submergent macrophytes and algae by lowered water levels results in the death of these organisms. Malodor caused by the decay of these materials results in additional aesthetic displeasures. In the past, construction and operation practices traditionally have not given adequate attention to these environmental impacts.

Data collection, management, and interpretation

Water quality and other environmental data are needed in conjunction with virtually every resource activity undertaken in the Corps. Consequently, such data form the foundation for and are inherent in the decisionmaking process in all phases of project planning, design, construction, and operation and maintenance.

One of the major problems involved in water resources environmental assessment activities is the general lack of guidance regarding data collection, management, and interpretation. It should be emphasized that the value of data is dependent upon the accuracy, appropriateness, and precision, rather than on the bulk. Data quality is ensured by proper sampling and analytical methodologies, the development and judicious use of experimental (sampling) designs, and a firm understanding of the intended uses of the data to be collected. Efficient use of the data is necessary to obtain the maximum amount of information from each sample collected.

It is essential in a water quality investigation to set up an efficient, economical, and valid sampling program. Quality control of the data begins with proper field sampling techniques. Laboratory analyses of the data are dependent on the collection of samples; consequently, if a sampler does a poor job of sampling or does not collect a representative sample, the data resulting from laboratory analyses will be invalid. Sample collection requires trained and competent personnel and the use of procedures standardized throughout the Corps. Procedures for holding, storing, and transporting of samples must be uniform and must be adhered to closely. When holding times are exceeded or the procedure for sample storage or preservation is incorrect, changes may occur in the samples that make the data invalid.

In addition to problems associated with invalid data, there are many cases wherein the number of samples collected is not adequate to permit statistically valid conclusions in the evaluation of the effects that the proposed activity will have on environmental quality. The net effect is a loss in time and money. If the inadequacy of the sampling program goes unchecked, the costs can become much higher if the project causes a degradation in environmental quality as a result of erroneous decisionmaking. On the other hand, sampling frequency may be unnecessarily high and could be reduced with a resultant savings in costs.

The lack of existing data bases for planning, environmental impact prediction, and environmental statement preparation is another major problem and is related to the recency of the 1969 passage of NEPA. Because the environmental impact of a project became a major planning concern upon passage of NEPA, adequate data bases for predicting the environmental impact of presently proposed projects do not generally exist. Items such as fauna and flora species lists, identification of endangered species, diversity indices, productivity estimates, and other biological and chemical data are collected and assembled at heavy costs of time and expense, both in terms of manpower and in associated project delays. This situation is further complicated by a lack of guidance for the development of adequate data bases for each of the planning, environmental impact prediction, and environmental statement preparation activities.

In addition to the general requirements for environmental inventory and assessment mentioned above, many problem situations require the use of complex ecological and water quality simulation models. These predictive tools require types of input data that have not been routinely collected in the past. Furthermore, the state-of-the-art in this area is rapidly advancing, and data input requirements change to some extent as modeling improvements are made. Guidance is not available for the collection and analysis of appropriate types of water quality and ecological data required as model input, and as a consequence, much of the data that are being collected specifically as model input is not appropriate.

At the present time, adequate guidance cannot be written for sampling during dynamic events such as storms because of a lack of understanding of relationships between flow and contaminant concentration during various portions of the storm hydrograph or for various storm durations, intensities, and frequencies. Without this type of guidance, it is impossible to ascertain nutrient and contaminant loadings to projects during storms, even though such events probably are the major loading mechanism. The same problem exists with respect to sampling in reservoirs under short-term dynamic situations such as during major changes in project operations. This information is required to develop sound field data-collection programs for management of environmental quality.

Regulatory functions

The expansion of Section 404 of PL 92-500 regulatory jurisdiction from navigable waters of the United States to waters of the United States has resulted in an increase in the Corps' jurisdiction pursuant to the regulation of the discharge of dredged and fill material. As a result of broadening the definition of navigable waters of the United States and expanding the jurisdictional coverage to include much of the waters of the United States, a significant increase will occur in the number of permits authorizing structures and work in or affecting navigable waters and for the discharge of dredged or fill material.

Each application for a permit to discharge dredged or fill material must be evaluated in terms of its potential environmental impacts. Many applications are for routine or general types of activities (e.g., boat slips, piers, minor erosion control) that probably result in minimal adverse affects on the immediate area or within the region. However, other construction activities such as major breakwaters, dams, excavation filling, large docks, etc., may often result in significant effects.

The decision whether to issue a permit or to make a determination on a proposed Federal activity is based on an evaluation of the probable impact of the proposed structure or work and its intended use on the public interest. In determining the public interest, factors such as conservation, aesthetics, general environmental concerns, economics, historic values, fish and wildlife values, water supply, and water quality must be considered.

Upon examination of an application for a proposed discharge, if it appears that the permitted activity will have adverse environmental effects, an environmental assessment is usually prepared. In conducting an environmental assessment, pertinent environmental, social, cultural, and economic data related to the proposed activity must be collected and evaluated. If it is determined that the impacts are significant and/or adverse, an EIS is required.

If an EIS is to be prepared, additional data usually must be collected, analyzed, interpreted, and evaluated in a manner consistent with NEPA, guidelines of the Council on Environmental Quality, and Corps Engineering Regulations. In order to prepare a technically adequate report, it is important that guidance be provided concerning the critical environmental variables that should be measured and the current analytical techniques. In addition, predictive techniques must be developed for delineating short- and long-term impacts of the permitted discharge on water quality and aquatic organisms and for measuring and assessing any secondary and cumulative impacts that may result from the permitted activity.

As a result of the expanded jurisdiction of the permit program, an additional 52,235 square miles of wetlands are now regulated by the Corps. Consequently, in preparing and assessing the effects of discharge activities on wetlands, the identification and inventorying of wetlands is immediately necessary to determine value, public interest, and jurisdiction. The value of various types of wetlands must be evaluated. However, adequate guidelines are not available for wetlands assessment -- a situation that brings with it several additional problems.

Regulatory functions contain two categories of problem situations:

difficulties associated with discharge evaluations and undue difficulties encountered with permitting activities that involve wetlands and their assessment. The difficulties experienced by the Corps in such evaluations are centered around two areas of concern. The first situation is focused on review of permit applications under the National Pollutant Discharge Elimination System (NPDES) and the proposed policy, practice, and procedures pertaining thereto.

The second problem in the area of discharge evaluation is based on the review of permits concerned with placement of non-Corps structures in navigable waters of the United States. The structures involved vary from small floating or pile-supported piers and docks to large docking and cargo-handling facilities. Public concern may result in objections based on potential adverse cumulative impacts on water quality and fisheries due to granting of permits for such structures. Usually no substantive data are available to support or refute the objections. Since the Corps regulatory function activities do require evaluation of applications for permits for these structures, data on their cumulative impacts are necessary in order to make the evaluations technically sound. The problem that results from this situation has two aspects. While refusing a permit because of assumed cumulative effects could have adverse social, political, and public relations effects, the issuance of permits for activities that later prove to have adverse impacts may result in serious environmental damage.

A number of different problems have been identified as falling within the realm of wetlands and their assessment. The problem situations are concerned with the identification and inventory of wetlands, the determination of the value of wetlands, the assessment of wetlands primary productivity, and the use of diversity indices and their alternatives, particularly with respect to activities in wetlands.

Environmental assessment

Since the enactment of NEPA in 1969 (PL 91-190); Executive Order 11514, "Protection and Enhancement of Environmental Quality," 5 March 1960 (30 FR 4247); and Section 122 of the River and Harbor Act of 1970 (PL 91-611), all Federal agencies and departments have been required to prepare detailed EIS's on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. Publication of the Water Resources Council's Principles and Standards for planning water and related land resources in 1973[4] provided supplementary guidelines for environmental impact evaluation to Federal agencies with responsibility for water and related land resources management and/or development. As a result of these legislative acts, the Office, Chief of Engineers, has prepared numerous Engineering Regulations (ER's) that provide guidance to the Corps relative to preparation and coordination of environmental assessments and impact statements.

The multi-objective planning framework specified in the Principles and Standards[4] requires data collection, analysis, and evaluation for alternative plans relative to two national objectives, national economic development and environmental quality, and an accounting of relevant beneficial and adverse effects on national economic development, environmental quality, regional development, and social well-being.

Since 1969, the Corps has submitted 119, 316, 211, 243, 303, and 273 draft EIS's to the Council on Environmental Quality in 1970, 1971, 1972, 1973, 1974, and 1975, respectively. Approximately 10 percent of the Corps projects for which draft EIS's have been prepared have been subjected to litigation on NEPA issues; nearly half of the litigation was on the grounds of inadequate EIS's. Once a project is enjoined in litigation, time delays and costs are incurred due to the need for ancillary studies and inflationary costs of construction materials. An example is the $1.5 million increase in cost for Locks and Dam 26, Upper Mississippi and Lower Illinois Rivers. This figure represents only those costs for preparation of special studies, legal fees, etc., and does not include increases due to delayed construction costs.

Water resources programs and projects are very broad and highly complex from the standpoint of the diverse biological, chemical, physical, social, cultural, and economic factors that may be affected. These complications mandate an assessment approach or methodology to assist in the evaluation of the consequences of a proposed action on each variable used in the data base. Numerous attempts have been made to standardize a methodological approach for alternative selection. However, none have been identified as being generally appropriate for water resources programs and projects.

A specific example of an environmental assessment problem is the evaluation of project impact on historical or archaeological resources of a region. The planning phase for a proposed Corps project that will involve an alteration of the site on which the project is to be established must include an investigation of the possible existence of and damage to sites of historical or archaeological significance. These constitute irreplaceable resources to society as a whole as well as to local and regional cultures. It is the responsibility of the Corps to see that such sites are identified and that their value is assessed prior to project commencement. Areas in the historical/archaeological evaluation process that are particularly difficult are the detection and location of historical or archaeological sites, the assessment of the value of such a site, and the management of the area if the site is to be preserved.

Water resources management

To accomplish the objectives inherent in its role of water resources management requires that, at least on a basinwide basis, the Corps have the capability to evaluate the environmental consequences of management of the water resource within the river basin. The lack of such a capability has adversely affected the planning, design, and operations phases of water resources development. Optimal operation of reservoir projects along a waterway for navigation, flood control, hydropower, water supply, recreation, and fish and wildlife purposes as well as for water quality requires an exact knowledge of the water volumes -- both temporally and spatially. This knowledge must be integrated with quality models of sufficient detail to produce a quality-quantity model for water resource management. The lack of such a quality-quantity option prohibits basinwide planning and operational activities that ensure the steady flow of water through the system, maximum possible quality of water, and simultaneous achievement of project purposes. Moreover, without this capability, the Corps is unable to provide the fastest, most complete and effective total system response to both daily and emergency water resource management situations. Currently, it is often not possible to operate or regulate waterways structures and activities in a comprehensive manner to meet changing water resource management objectives, nor to evaluate the effects of expanded or new facilities.

Irrespective of modeling efforts being made to simulate the basin water resources, the operation of multiple projects to meet varied purposes and environmental quality objectives while satisfying external constraints, presents a very challenging problem to the field offices. In many cases, demands for water resources by local, regional, or state governmental agencies are not compatible with or are in addition to project purposes. No framework exists to allow evaluation of these conflicting demands and to allow the best utilization of water resources within a specified region. These problems exist for both reservoir and waterways projects. This problem impacts the planning process in that the addition of a new project to a basin cannot be evaluated in terms of existing projects, their operation, or future demands on water resources.

One of the primary problems related to planning or management of water resources is the identification and determination of the benefits to be derived from meeting environmental quality objectives. If benefits cannot be determined, they cannot be used to offset the project cost associated with meeting environmental quality objectives. This has an impact on the economic feasibility of a project in the planning phase as well as on the operational strategies. An example of this problem is the identification and determination of benefits to be derived from making minimum releases from reservoirs. Controlled release may provide a stream habitat suitable as a fishery in what was once an intermittently flooded and dry stream. The knowledge of necessary minimal flows would allow meaningful comparison of various stream uses and selection of a management strategy for locations where multiple resource demands such as navigation, recreation, and water supply are encountered. At present, guidelines to assess the effects of various reservoir releases on the downstream aquatic environment are essentially qualitative and thus the ability to balance alternative management schemes with environmental objectives is greatly hampered.

Waterways

Principal Corps activities that take place in waterways generally involve navigation or flood control. The relationship between alternative practices to meet these purposes and environmental quality objectives is largely unknown. In those cases where conflicts have arisen, the problem is often severe. Environmental trade-offs between structural and non-structural flood-control alternatives remain to be resolved in a quantitative manner. The environmental consequences of channel modification or construction in waterways for either navigation or flood control are often poorly defined and possible benefits as well as long-term effects must be determined.

Particular environmental impacts associated with channel modification include both short- and long-term situations such as bank denudation, increased scouring, changing channel depths for bottom organisms, bank stabilization, long-term changes in stream productivity, and invasion of the stream by undesirable plant or animal species after channelization. Channel modification projects often produce conflicts between development and conservation interests since modification of free-flowing stream and rivers, adjacent or contiguous wetlands, and riparian areas may be long term or irreversible. Changes in aquatic systems may include shifts in production, diversity, density, and composition of fisheries and benthic communities, as well as increases in sediment and contaminant loadings. Rapid drainage from adjacent or contiguous wetlands may result in consequent loss of valuable habitat for furbearers, waterfowl, and other backwater biota. Many closely related factors operating synergistically or antagonistically are responsible for these impacts. However, the overall mechanisms are either poorly documented or not documented at all. Present techniques are inadequate to make a systematic determination of the effects of loss of habitat associated with waterways activities. Moreover, corrective or remedial procedures need improvement if the total benefits of water resource projects are to be realized.

Dikes, revetments, and other training structures have been constructed and placed in waterways to maintain a channel of suitable depth for navigation while reducing dredging requirements and minimizing streambank erosion. The overall environmental effects of these structures on river systems, particularly side chutes and backwater areas, is not known. An understanding of the value of these areas as grounds for the rearing, spawning, and dwelling of fish, substrate for development of benthos and periphyton, and recreational uses is necessary for the placement and configuration of training structures. In many cases, dikes and revetments provide a substrate for the development of attached organisms, and, for this reason, these structures frequently attract fish. The possible value of such structures as habitats should not be ignored simply because there has been no definitive work to determine species composition and densities at such structures or to compare these areas with the natural habitat.

The stream ecosystem is a continuous and dynamic environment throughout its course, and all downstream resources are strongly dependent on upstream activities. Detailed information on environmental losses of stream habitats resulting from channelization and other construction activities plus exacting followup investigations to determine validity of pre-construction predictions are required to assist in the planning, design, construction, and operation of waterways projects.

Summary of Input

Input from Division offices resulted in 515 problem statements related to environmental problems of the Civil Works program. Of these 515 problem statements, 420 were directly applicable to this study. The remaining problems were viewed as being addressed in other ongoing research programs, primarily the Dredged Material Research Program, and were not considered further. Included in the 420 problem statements were some problems that were institutional in nature or that would not require any substantial research and development for solution.

A summary of the problem statement input is presented in Table 4. This summary represents the components used in the problem statement

Table 4

Summary of Problem Statement Input

Problem Category	Problem Description	Area Distribution Number (%)		Activity Distribution Number (%)		
		Reservoirs	Waterways*	Planning	Engineering	Con/Op
I. Environmental Quality						
A. Water Quality**	Problem adversely affects those characteristics of water that define its quality	82 (31)	6 (5)	7 (8)	3 (14)	78 (29)
1. Chemical†	Problem adversely affects chemical quality of water (dissolved oxygen, toxic contaminants, nutrients	64 (78)	4 (67)	4 (57)	3 (100)	61 (78)
2. Physical	Problem adversely affects physical characteristics of water (temperature, density, opacity)	12 (15)	2 (33)	3 (43)	--	11 (14)
3. Biological	Problem adversely affects biological quality of water (pathogens)	6 (7)	--	--	--	6 (8)
B. Environmental Impact	Problem causes an adverse environmental impact either directly or indirectly through an effect on water quality	54 (21)	20 (19)	13 (14)	4 (19)	53 (20)
1. Social/Economic	Problem causes an adverse impact on the social well-being or economy of the affected region	34 (63)	12 (60)	8 (62)	4 (100)	34 (64)
2. Fish/Wildlife	Problem impacts adversely on fish/wildlife resources of the affected region	5 (9)	3 (15)	2 (15)	--	4 (7)
3. Botanical	Problem results in undesirable growth of aquatic plants or algae or otherwise affects vegetation	11 (20)	3 (15)	1 (8)	--	11 (22)
4. Land Use	Adverse impacts on desirable land-use patterns	4 (8)	2 (10)	2 (15)	--	4 (7)
II. Environmental Assessment	Problem directly affects the ability to assess environmental quality (existing or future) by field elements in carrying out assigned missions	127 (48)	77 (76)	71 (78)	15 (67)	136 (51)
A. EIS Definition	Problem causes improper preparation of an EIS	1 (1)	3 (4)	2 (3)	--	2 (1)
B. Data Requirements	Problem relates to inadequate or nonexistent data required for environmental assessment	44 (35)	23 (30)	29 (41)	5 (33)	34 (25)
C. Data Collection	Problem relates to procedures for collecting data required for environmental assessment and impact statement preparation	36 (28)	23 (30)	19 (27)	2 (13)	54 (40)
D. Data Management/ Evaluation	Problem relates to interpretation, management, and utilization of data for environmental assessment and impact statement preparation	16 (13)	17 (22)	9 (13)	4 (27)	17 (13)
E. Models	Problem relates to lack of or inadequate predictive models for assessment or operational purposes	30 (23)	11 (14)	12 (16)	4 (27)	29 (21)
All Problems		263 (71)	103 (29)	91 (24)	22 (6)	267 (70)

* Includes all areas outside a reservoir project under CE jurisdiction.
** Percentage distribution between major categories.
† Percentage distribution among subordinate categories.

classification (Figure 12). The problems were broken down by area distribution (reservoir or waterways) and by project stage distribution (planning, engineering, construction/operations). The latter distribution reflects primary organizational divisions within the Civil Works program. The total number of problems by area distribution or project stage distribution (Table 4) will not account for all 420 problem statements, primarily because some were reported as general problems.

Water quality problems were generally related to reservoirs, and a majority of these problems were observed in projects that were operational or under construction (Table 4). A similar trend was observed for other environmental impact problems. Environmental assessment problems were more evenly divided between reservoirs and waterways, but there was a greater majority of these problems in planning and engineering as compared to environmental quality problems.

Overall, environmental assessment problems accounted for 48 percent of the reservoir problems, but were 76 percent of the waterways problems. This fact is primarily a result of permitting and related regulatory activities in waterways that require environmental assessments. Problems related to construction/operation activities were almost equally divided between environmental assessment and environmental quality. Considering all problems, 71 and 29 percent were associated with reservoirs and waterways, respectively; a majority of these were within the construction/operations activity (70 percent).

Project association with problems was deemed critical for assessment. In almost all cases, a project was associated with a particular problem, and in many cases a particular project would possess more than one problem. There were 152 projects, distributed among all Divisions, with documented problems. The relationship of the projects to the problems will be explored in the next section. For those cases where there was no project association, the problems were of a general nature within a specific Corps activity (e.g., permits, EIS preparation). In many cases, multiplicity of problems for a project occurred within environmental assessment and generally related to more than one facet of the problem category or, alternatively, occurred as environmental assessment plus water quality or other environmental impact problems.

The resultant problem statement information was used for subsequent problem identification, assessment, and development of research needs. The organization and classification of the input served as a framework from which these activities were conducted. The problem statement summary, Table 4, provided a link between these activities and also allowed for ready identification of major priority research needs.

PART IV: PROBLEM ASSESSMENT

Introduction

The Civil Works missions of the Corps, as assigned by law, fall generally into water resources related activities. These activities take the form of planning, engineering, construction, and operation and maintenance of water resources projects. While these projects may involve both structural or nonstructural alternatives (e.g., flood control), historically, the Corps has relied on structural alternatives.

Classically, in the planning stages, water resources projects are evaluated according to feasibility. Types of feasibilities generally considered include engineering, social, political, financial, and economic. Engineering feasibility refers to the ability to design and construct the project to meet its intended purposes. Social feasibility refers to the public acceptance of the project by its users or by people affected by the project. Political feasibility generally implies the ability to obtain congressional approval (authorization) of the project plus appropriation of funds for its construction. Financial feasibility refers to the willingness to commit financial or other resources to the project. Economic feasibility refers to an evaluation of the benefits to be gained with the project in excess of costs over benefits without the project. Economic feasibility, generally expressed as a benefit:cost ratio, usually rules and defines project scope. Each type of feasibility is interconnected to a significant degree and will affect overall project feasibility.

In the past decade, increased public concern over the environment resulted in enactment of legislation that, in effect, added environmental feasibility of water resources projects to those types of feasibility mentioned above. Environmental feasibility is addressed by an environmental impact assessment or statement. For those water resources projects in operation, concern has been expressed over meeting environmental quality objectives, and a need exists to solve these problems.

The effect of environmental quality problems on water resource project planning can be considered by examining current requirements under the Water Resources Council's Principles and Standards.[4] Formulation of alternative water resource plans to meet project purposes must include a National Economic Development (NED) Plan and an Environmental Quality (EQ) Plan. The NED plan maximizes net project economic benefits while addressing planning objectives; the EQ plan minimizes adverse environmental impacts while addressing planning objectives. The primary factors (accounts) addressed under each plan include national economic development, environmental quality, regional development, and social well-being. Major components of the environmental quality account include water and air quality, biological elements, noise, archaeological and historical elements, land-use plans, transportation, recreation, and aesthetics. Final selection of a project plan usually includes a compromise between the NED and EQ plans with due consideration to all factors. The above demands are reflected in requirements for comprehensive planning and in decision methodologies to implement the Principles and Standards[4] in EIS preparation.

Projects that are operational face pressures to balance project purposes and benefits with environmental quality objectives. Since many of these projects were planned and constructed prior to directives regarding environmental quality, the primary concern is the development of corrective actions (either structural or operational) that are in harmony with project purposes to meet environmental objectives.

To assess the impact of environmental quality problems on the Civil Works program, an approach was employed that reflected impacts on project feasibility as well as balancing economic objectives with environmental quality objectives while meeting project purposes. Problem impact on financial feasibility was beyond the scope of this report. Problem impact on engineering feasibility, design changes, or project modification will be addressed in subsequent research directed at problems identified in this report.

Problem Impact Classification

In general terms, problem impacts may be classified as economic or noneconomic in terms of their effect on the Civil Works program. Noneconomic impacts are those that reflect public relations, aesthetic, and legal problems associated with meeting environmental quality objectives. Legal problems will also have an associated economic impact, but legal problems arise primarily as a result of social concern over environmental quality. Economic impacts are those that can be quantified in a monetary sense.

The basis for developing economic and noneconomic impacts was the input received from District and Division offices during the problem survey. In the case of economic impacts, a projection of the potential magnitude of these impacts will be made. The information developed in this section serves to place in perspective the problems associated with meeting environmental quality objectives by Civil Works projects. The research requirements documented in the next section of this report need to be addressed to alleviate economic and noneconomic impacts on the Civil Works program.

Noneconomic Impacts

Noneconomic impacts of meeting environmental quality objectives of water resource projects may be gauged by examining the number of problems having associated public relations, legal, or aesthetic impacts. This information is summarized in Table 5. To determine the influence of the problems on noneconomic impacts, the problems have been categorized as to their nature (water quality versus other environmental impacts), location, and functional grouping. It should be noted that these impacts may also have associated cost elements that will be discussed in later portions of this section. Additionally, problem input from the Districts and Divisions represents all phases of Civil Works activities from planning through operation.

Unfavorable public relations related to environmental quality problems are primarily associated with other environmental impacts as opposed to water quality (Table 5). Unfavorable public relations stemming from water quality problems are usually connected with existing

Table 5

Noneconomic Problem Effects

Problem Category		Number of Problems	Impact, Number (%) Public Relations	Legal	Aesthetic
Environmental Quality:					
Water quality		172	62 (39)	3 (7)	32 (54)
Other		248	99 (61)	41 (93)	27 (46)
	Total	420	161	44	59
Location:					
Reservoir		281	101 (68)	11 (32)	52 (90)
Waterway		110	47 (32)	23 (68)	6 (10)
	Total	391	148	34	58
Functional Group:					
Environmental assessment		224	83 (52)	34 (77)	18 (31)
Other (environmental quality not related to assessment)		196	78 (48)	10 (23)	41 (69)
	Total	420	161	44	59

or operational projects. Conversely, poor public relations related to other environmental impacts may arise from both proposed and existing projects. A majority of public relations problems are associated with reservoir projects. These projects have high public exposure due to their recreational aspects and the nature of their construction, and it is to be expected that public relations would be a greater problem for those reservoirs possessing environmental quality problems.

Legal problems were related to litigations over proposed Civil Works projects or to damage claims for environmental impacts of operational projects. A majority of the current litigations are NEPA-related.[5] This fact is supported by noting that the distribution of legal problems between functional groups as shown in Table 5 favors environmental assessment. In this case assessments of proposed projects are being challenged. The distribution between reservoirs and waterways tends to favor waterways. Environmental impacts (and environmental assessment methodologies) are more numerous for waterways projects because of the relatively greater number of projects in this area and the permitting activities associated with wetland conservation.

The present status of litigations concerning Civil Works water resource projects (excluding dredging)[5] is as follows:

Projects enjoined wholly or partly by Federal Courts	13
Project litigation pending	22
Project litigation dismissed	3
Litigation not involving specific projects	4

The distribution of aesthetic aspects of the problems favor water quality over other environmental impacts. This type of distribution would be expected since aesthetics normally relate to something that can be perceived as opposed to something that may be expected. This would also influence the distribution of public relations problems by problem location, which was discussed earlier. The distribution of aesthetic problems is almost exclusively to reservoirs as opposed to waterways and appears not to be strongly related to the environmental assessment function. These facts would suggest that aesthetic aspects are chiefly associated with operational projects of high public visibility (e.g., reservoirs).

The importance of noneconomic impacts of environmental quality problems associated with Civil Works projects is difficult to determine in a tangible sense. Overall, 264 of the 420 problems (63 percent) had associated noneconomic impacts. These were distributed among public relations (61 percent), legal (17 percent), and aesthetic (22 percent) attributes. Noneconomic impacts contribute significantly towards influencing project feasibility (or acceptability) and operation; consequently, these factors cannot be overlooked in an assessment. In many cases, the noneconomic problem impacts result in economic impacts because of resultant litigations or corrective actions taken to alleviate these impacts.

Economic Impacts

The economic feasibility of a Civil Works project generally predominates unless there are overriding engineering, financial, political, social, or environmental reasons. Economic feasibility of a project is determined by conducting a benefit-cost analysis that is related to project purpose (e.g., flood control, navigation, water supply, etc.). A benefit-cost ratio greater than unity implies economic feasibility, and the project is generally constructed if money is authorized and there are no other constraints on feasibility.

Environmental quality problems may impact the balancing of environmental quality objectives with economic objectives. The minimization of adverse environmental impacts while addressing project objectives may not allow achievement of maximum net project benefits. The attainment of environmental quality objectives during project planning will require additional expenditures for assessment. During engineering and construction phases, attainment of these objectives may result in additional expenditures for design and construction to minimize adverse impacts. During the operational phase, similar increases in expenditures as well as compromises with economic objectives may be required. These additional expenditures may affect the benefit-cost ratio, thus impacting overall project feasibility.

For projects that are operational, corrective actions may well be required to meet environmental quality objectives. These corrective actions will be reflected in increased engineering, construction, or operation costs. In many cases, since the attainment of environmental quality objectives was not included in planning, the impact associated with corrective actions will affect net economic benefits.

Economic assessment of environmental quality problems has the advantage of yielding a tangible (or monetary) result that can be utilized directly in assessing the magnitude of the problems. This is in contrast to noneconomic factors, which yield only an indirect assessment. The economic impacts of environmental quality problems that affect Civil Works projects are summarized in Table 6. The information

Table 6

Documented Economic Impacts of Environment Quality Problems on Civil Works Projects

Project Activity	Economic Impact	Frequency*	Average Cost Thousand $**
Planning (General Investigation and Advanced Planning)	Project-specific studies	5	400/project
	Water-quality data collection	7	60/project
	Coordination with other agencies	2/1	50/yr, 550/project
	Environmental assessment	5	65/project
	Legal	2	100/project
Engineering	Project-specific design studies	1	100/project
	Design modifications or additions	3	130/project
Construction	Construction cost escalation due to delay	4	7250/project
	Loss of benefits due to project delay	-	-
	Additional construction to solve problem	13	585/project
Operation/Maintenance	Loss of benefits	41	130/yr
	Cost associated with corrective action	8	80/yr
	Postconstruction monitoring	23	45/yr
	Increased operations cost	36	80/yr
	Regulatory functions	-	-

* Number of times reported by field input.
** Total documented costs attributable to economic impact divided by frequency.

presented in the table represents a condensation of 109 economic impact items received from the Districts and Divisions on 420 problem statements. Economic impacts were identified as either annual costs or project-related costs, depending on the nature of the input. Annual costs are those representing general items (interagency coordination, operations) or those costs that are expressed on an annual basis (benefits). Project-related costs are those directly related to specific projects; as such, they may not be expressed on an annual basis. Additionally, economic impacts were broken down by the activity that they represent (recognizing that some of these impacts may cross activity boundaries). Additional economic impacts were also identified that were not specifically mentioned in the problem statement input. In assessing economic impacts, both documented and potential, only those costs directly related to environmental quality problems were identified.

The documented economic impact resulted in total costs of $40,000,000 that were project specific and $10,000,000 that were annual costs. To completely examine the potential impact to the entire Civil Works program, the individual projects with environmental quality problems had to be summarized as well as the relationship to the Civil Works program that they represent. Table 7 is a summary of the status of projects included

Table 7

Summary of Problem Statement Input Data

Description	Status, Number (%)				
	General Investigations	Advanced Engineering and Design	Construction	Operational	Total
Projects possessing environmental quality problems with documented problem-cost data	6 (6)	5 (5)	24 (25)	63 (64)	98
All projects possessing environmental quality problems	18 (12)	16 (11)	29 (19)	86 (58)	152
All Civil Works projects (FY 77)	227 (19)	84 (7)	221 (19)	656 (55)	1188

in this study as a function of the input received, and a summary for all Civil Works projects is presented for comparison. The grouping by project status is fairly consistent when compared to the entire Civil Works program. This appears to be logical since environmental quality problems and their associated costs are more readily identifiable during the operational phase of a project. This information was used in assessing trends in economic impacts, since problems tend to be carried over between activities as a project progresses. The economic portion of problem assessment was based on Tables 6 and 7. The following discussion will be oriented to the economic impacts to specific Civil Works activities.

Planning phase

As shown in Table 6, five economic effects were associated with advanced planning of Civil Works projects due to environmental quality problems. The documented and potential costs associated with environmental quality problems for projects in the planning phase are summarized in Table 8. Potential costs were based either on projects in general

Table 8

Economic Impact of Environmental Quality Problems on Planning Activities

Factor	Documented Costs Thousand $		Potential Costs Thousand $		Notes on Potential Costs
	Project Related	Annual	Project Related	Annual	
Project-specific studies	2000	-	2250	-	18 @ $125,000/project
Water quality data collection	420	-	540	-	18 @ $30,000/project
Interagency coordination	500	100	-	1850	$50,000/yr/District
Environmental assessment	325	-	-	2500-5000	10-20% of current annual EIS cost
Legal	200	-	3900	-	39 projects × $100,000/ project*
Total	3495	100	6690	7350-9850	

* See page 87.

investigation that possess environmental quality problems or by appropriate assumptions on representative problems situations based on the current Civil Works status (i.e., legal, EIS). The economic effects associated with the planning phase are described in the following paragraphs.

Project-specific studies. Frequently, during the advanced planning stage of a project, complex environmental quality problems arise. In many cases these problems are specifically related to the project and may not be approached in a general fashion; consequently, a project-specific study is initiated to address the problem. In many instances these studies are usually expensive ($400,000 per project, Table 6). For example, complex physical or mathematical model studies for prediction of water quality impacts are quite frequently required during the planning process.

Because of current requirements to meet economic and environmental quality objectives in water resource project planning, the number of project-specific studies may be expected to rise in the future. Since methodologies are not generally available to address complex environmental quality problems arising from these requirements, these increased planning costs are economic impacts. To obtain potential project-specific planning costs, an average cost of $125,000 was assumed. Potential costs for project-specific planning studies were obtained by multiplying the assumed cost by the number of projects in the general investigations phase possessing environmental quality problems (Table 7).

Water quality data collection. The collection of water quality data during project planning is generally needed for the following purposes: (1) to assess the project impact on water quality and related project purposes (e.g., water supply, fisheries, or recreation); (2) to define potential operational problems; or (3) as input to design if water quality affects the project or its operation. Generally, water quality data are not available in sufficient quality or quantity to accomplish any of the above purposes. Expenditures for water quality data collection vary, but the average reported from field input was $60,000 per project (Table 6). The need for water quality data on projects in the planning phase is expected to increase in the future subject to legal requirements (e.g., Principles and Standards,[4] and EIS preparation). The economic impact due to water quality data collection reflects not only the requirement for data, but the problems associated with collection, interpretation, and management of these water quality data. Potential costs were determined assuming that 50 percent of the documented costs reflected the economic impacts for all projects in the general investigations phase possessing environmental quality problems (Table 7).

Interagency coordination. Coordination with other agencies on project environmental quality problems is required primarily in the planning and operational phases. Interagency coordination may also be required throughout other stages of water resource project development. This coordination usually results in specific requests or suggestions by the other agencies, such as EPA and U.S. Fish and Wildlife Service, for data or information concerning projects being reviewed. These requests involve additional expenditures if the information is not readily available. Generally, these requirements related to interagency coordination must be satisfied prior to proceeding with project development. From the input received from the Districts and Divisions, interagency coordination represents either a continuing annual expense or may be attached to a specific project. The costs associated with specific projects may be quite high depending on the nature of the environmental problem (Table 6). Potential annual costs were determined by assuming a cost of $50,000 per District.

Environmental assessment. The environmental assessment program for Civil Works projects includes all environmental assessments and preparation of environmental impact statements. In many cases these assessments may be performed for projects other than in the planning stages; however, for purposes of this report, all environmental assessment activities were included in the planning phase. Environmental assessment activities are related to specific projects within the Civil Works program, and the average cost for environmental assessments (including EIS's) was $65,000 per project.

The growth in environmental impact statement requirements since the passage of NEPA (PL 91-90) is shown in Figure 14. The initial rise in number of environmental impact statements is attributed to the initial backlog created by the legal requirement. Growth after this period is predominantly due to navigation projects and regulatory permits. A similar trend is evident if expenditures for environmental assessment are analyzed as shown in Figure 15. The two categories with the greatest rate of growth in expenditures are associated with regulatory permits or projects in general investigation.

The cost increase of environmental assessments in terms of average cost per EIS is presented in Figure 16. The average cost for an environmental impact statement appears to peak and then stabilize. These costs have not been corrected to constant dollars, but the trend after correction would be similar to that shown in Figure 16.

The costs associated with environmental assessment activities

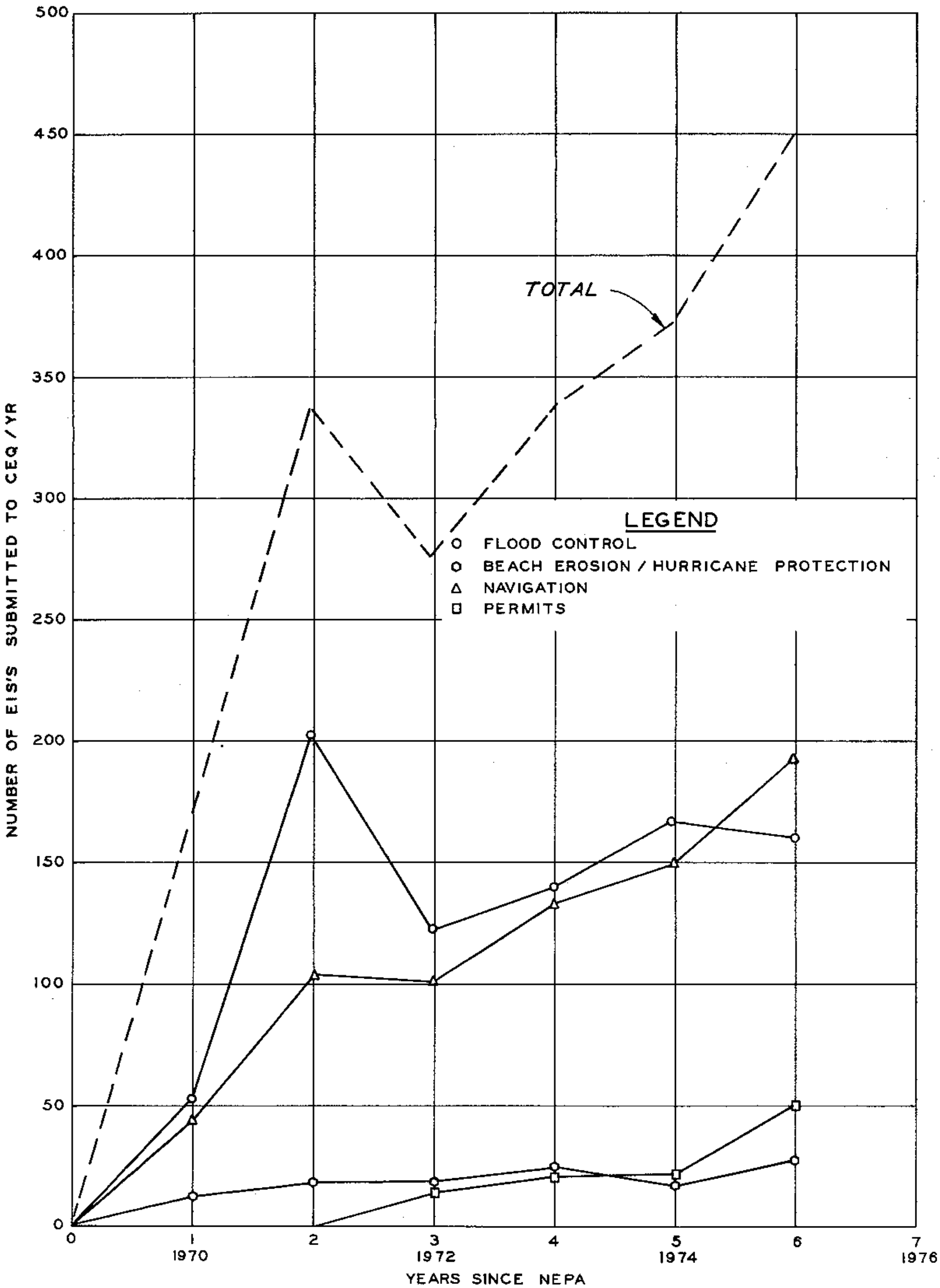

Figure 14. Growth in EIS requirements since passage of NEPA

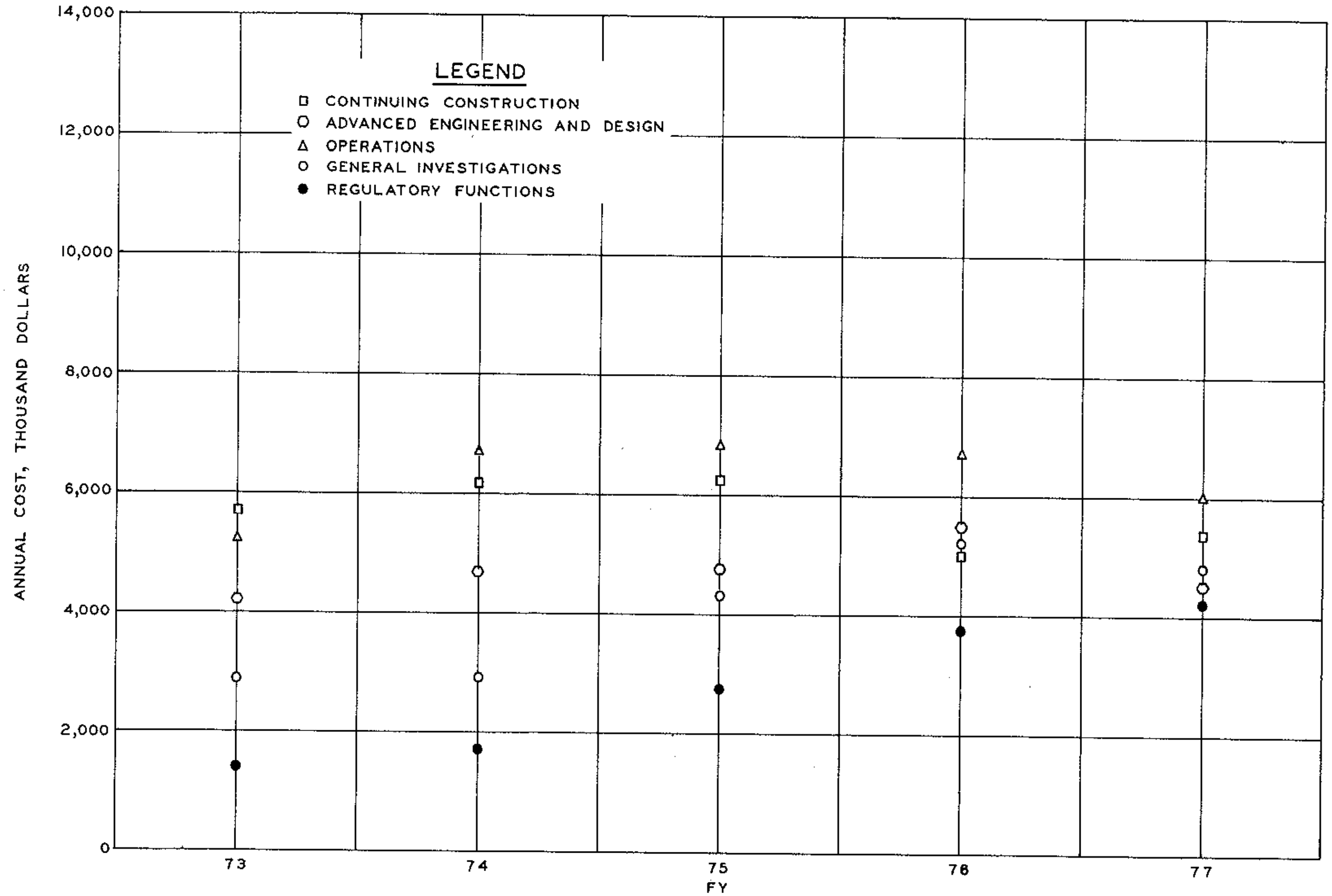

Figure 15. Annual expenditures for environmental assessments

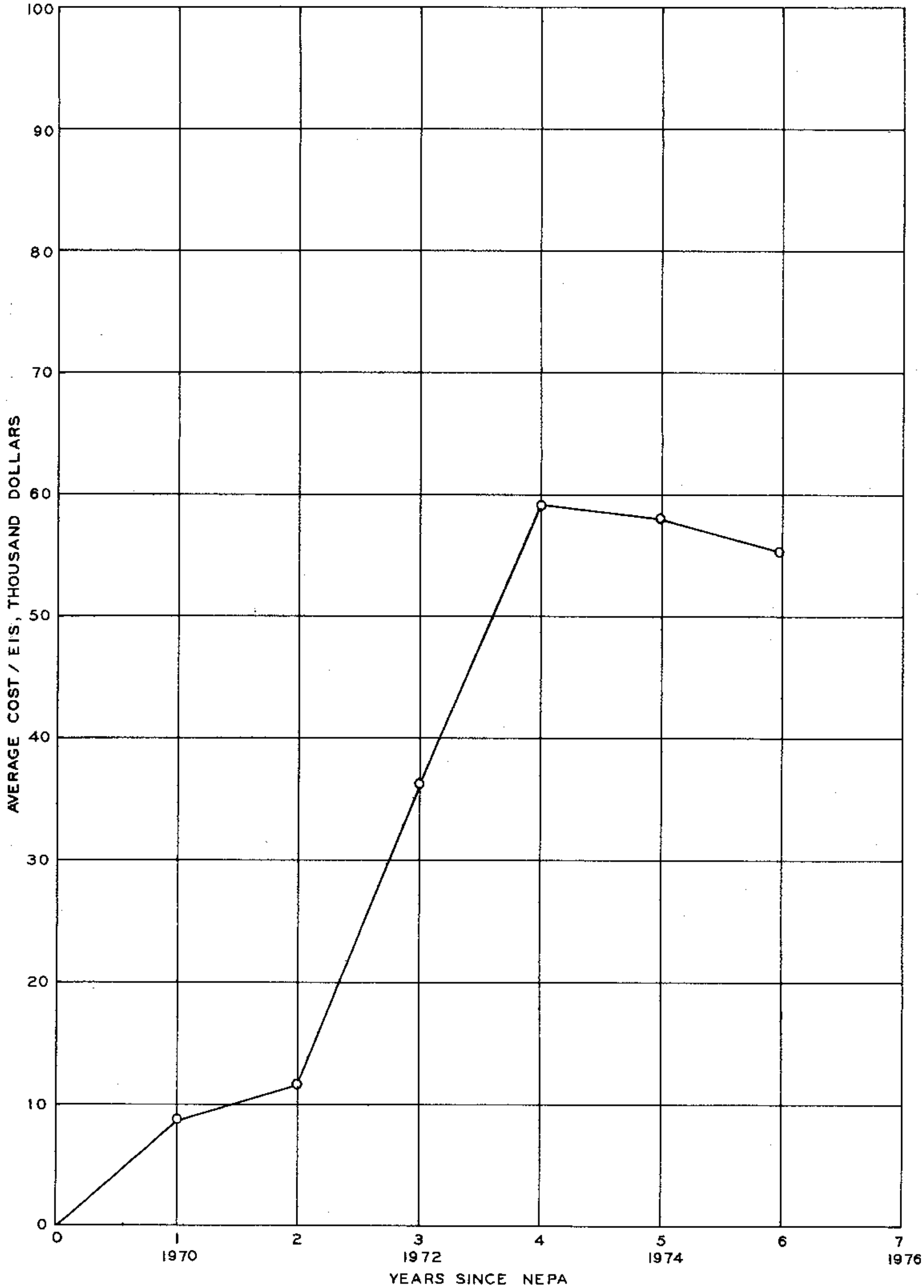

Figure 16. Average annual cost per EIS

within the Civil Works program may be categorized as follows: the costs that represent a base load due to legal requirements and the differential costs associated with preparation of environmental impact statements that are complex and require substantial research or data for completion. It was estimated that the potential cost that represents an economic impact associated with environmental assessment related to Civil Works projects will be 10 to 20 percent of the current environmental assessment costs (i.e., approximately $25,000,000 FY 76).

Legal. Similar to environmental assessment, costs due to litigation concerning environmental quality problems may arise anytime during project history. Legal costs were considered under this section because the input was limited to legal costs during the planning stage. The noneconomic impact of legal problems arising from environmental quality problems related to Civil Works activities has been discussed previously. District and Division input indicated that the average cost due to litigation was $100,000 per project; potential costs for legal problems may be derived by considering all projects that currently possess existing or pending legal problems as shown on page 87.

Engineering phase

Economic impacts on engineering activities due to environmental quality problems stem from project-specific studies and project design modifications. The costs associated with environmental quality problems on engineering activities of Civil Works are summarized in Table 9. All costs are project-associated costs since the design activity was related to specific projects.

Project-specific studies. In the engineering phase, solution of environmental quality problems associated with a project may require a design that is not conventional or that is not generally available. In this case, project-specific studies may be required to develop a design to solve the problems and may result in an engineering cost above that normally required. These costs may be associated with corrective actions as well as to design costs associated with projects in planning. One case was reported involving such a study that cost $100,000.

Potentially, all projects in the advanced engineering and design

Table 9

Economic Impact of Environmental Quality Problems on Engineering Activities

Factor	Documented Costs Thousand $		Potential Costs Thousand $		Notes on Potential Costs
	Project Related	Annual	Project Related	Annual	
Project-specific design studies	100	-	160-320	-	Based on 10-20% of projects requiring studies
Design modifications or additions	390	-	10,010	-	Based on 77 projects @ $130,000/project
Total	490	-	10,170-10,300	-	

phase possessing problems may require project-specific studies, but for purposes of assessing potential costs, 10 to 20 percent of the projects were assumed to require project-specific design studies. These costs are regarded as economic impacts associated with environmental quality problems.

Design modifications. Projects that possess environmental quality problems may require design modifications or additions to solve the problems. Costs will be incurred if problems were not foreseen during project planning and consequent design changes must be made during the engineering phase. Costs may also be incurred for those operational projects requiring corrective actions to meet environmental quality objectives. The cost of these design modifications averaged $130,000 per project. Potential economic impacts should include both costs and represent realistic estimates since environmental quality problems were not identified during the planning stages. The estimates of potential costs were based on the assumptions that all projects in the engineering phase with environmental quality problems (16 per Table 7) will require design modifications and that operational projects with release water quality problems may require these design modifications at the average cost ($130,000 per project). The number of projects placed in the latter category was 61.

Construction phase

Environmental impacts related to environmental quality problems for projects in the construction phase were attributed to cost escalation related to construction delays and additional construction requirements to solve problems. A third factor, delays in realizing project benefits, was considered significant and was added for purposes of assessing economic impact. It is difficult to assess the economic impact for those projects in the construction stages since cost escalations are in part due to inflation and do not represent real costs and delays in realizing project benefits must be determined on a net basis since project costs are also delayed. The first factor, cost escalations, was indeterminable with respect to District and Division input; therefore, no attempt at correction was made.

A summary of the economic impact of environmental quality problems on projects in the construction phase is presented in Table 10.

Table 10
Economic Impact of Environmental Quality Problems on Construction Activities

Factor	Documented Costs Thousand $		Potential Cost Thousand $		Notes on Potential Costs
	Project Related	Annual	Project Related	Annual	
Construction delay	29,000	-	29,000-58,000	-	Based on 5% of costs to complete projects reporting environmental quality problems in engineering or in engineering and continuing construction
Delay in benefits	-	-	-	4770-9540	Based on 1-2% of benefits for those projects in engineering and construction with environmental quality problems
Additional construction to solve problem	7,480	-	18,300-88,920	-	Based on minimum of 61 projects (release water quality problems) @ $300,000/project and maximum of 152 projects @ $585,000/project
Total	36,480	-	47,300-146,920	4770-9540	

Construction delays. Delays in project construction due to environmental quality problems generally are the result of litigation related to an inadequate or a contested environmental impact statement. The resultant cost is due to costs incurred while the project is delayed plus the cost of additional construction that may be required to solve the problem. The project may be deauthorized if the delay is too long, but if the project is eventually constructed, the real increased capital costs are directly attributable to the problem.

The average documented cost for delays was $7,250,000 per project. This represents an average of 9 percent of the total project costs for those projects documented. Economic impact related to construction delays may be estimated by considering all projects in construction or engineering phases that were reported to have environmental quality problems. The potential cost was assumed to be 5 percent of the total cost required to complete these projects.

Delays in benefits. Delays in authorized projects may not only result in increased capital costs, but may also delay realization of project benefits. For any particular project, this factor is not critical since benefits eventually will be realized and costs are simultaneously delayed. However, for all Civil Works projects, if delay for any particular problem becomes continual, project benefits will be effectively lost on an annual basis. Environmental quality problems have recently, and potentially may, affect project benefits on a continual basis. The potential effect on benefits by construction delays may be estimated by considering benefits of authorized projects in engineering or continuing construction phases that possess environmental quality problems. The potential cost, net loss of benefits, was assumed to be 1 to 2 percent of benefits for projects in these stages.

Additional construction. Perhaps the costs that may be most directly attributed to environmental quality problems are those related to corrective actions. Currently, most of these costs are related to structural modification or additions to meet water quality objectives. Other construction costs associated with projects possessing problems were related to those projects that require additional construction due to structural components being affected by upstream water quality. Generally, construction costs associated with corrective actions are related to operational projects, and as such these costs represent economic impacts due to environmental quality problems.

Average cost for construction to solve environmental quality problems was $585,000 per project. Average construction cost to meet water quality objectives alone was $300,000 per project. Documented costs attributed to current environmental quality problems averaged 1.2 percent of the total project cost. Potential costs may be estimated by applying these documented costs to all projects possessing environmental quality problems. A portion of these costs may be offset by benefits accrued in meeting environmental quality objectives, but these benefits cannot be precisely identified at present.

Operation and maintenance activities

The economic effects of environmental quality problems are most dramatically apparent in those projects that are operational. This is true for a number of reasons. First, the effect of environmental quality problems on project purposes can be readily documented for projects in this phase by considering effects on benefits. Second, most of the projects in the operational phase were designed and constructed prior to passage of major environmental legislation, thus environmentally related costs truly reflect economic impacts. Third, the actual problem may be documented. For these reasons, a majority of the projects cited with environmental quality problems were in the operational phase (Table 7). Major cost factors identified include loss of project benefits, operational costs associated with required corrective action, postconstruction surveys and monitoring, increased operation and maintenance costs, and costs associated with problems related to regulatory functions. The last factor is included here because it is normally a function of operations elements in District and Division offices.

A summary of the operational economic impacts due to environmental quality problems is presented in Table 11. All cost impacts associated

Table 11

Economic Impact of Environmental Quality Problems on Operations Phase

Factor	Annual Costs, Thousand $		Notes on Potential Costs
	Documented	Potential	
Loss of project benefits	5300	78,780-90,560	Table 14
Costs associated with corrective actions	640	4,880	Based on $80,000/yr for 61 projects reporting water quality problems
Postconstruction monitoring	1035	6,840	Based on $45,000/yr for all projects reporting environmental quality problems
Increased operation costs	2880	12,160	Based on $80,000/yr project for all projects reporting environmental quality problems
Regulatory functions	-	3,540	Based on 10% of FY 77 request for regulatory activities
Total	9855	106,200-117,980	

with operational problems were expressed on an annual basis. It should be noted that these costs were the most frequently documented by the Districts and Divisions; therefore, the estimate of potential cost reflects the most representative sampling of problem-associated costs.

Loss of project benefits. The primary purpose of all Civil Works projects is to achieve one or more water resource purposes that are related to a contribution to public welfare and may be measured in an economic sense as project benefits. These benefits are generally categorized by project purpose and are usually the justification for project construction. Flood control and navigation represent the majority of benefits derived from Corps projects. A summary of the benefits associated with all Civil Works projects is given below.*

Category	Benefit
Cumulative flood damages prevented	47.6 billion dollars
Navigation	1.7 billion tons/year
Water supply (storage)	2,360 billion gallons
Water quality control (storage)	1.1 million acre-ft
Power (installed capacity)	15,700 megawatts
Recreation	352 million days/year

* Source: FY 77 Public Works Committee testimony.

An overall feeling for the trend of benefit classes in the future may be obtained by examining project purposes for a class of projects in the planning, construction, and operational phases. A summary of project purposes for reservoir and multiple-purpose projects is presented in Table 12. Major changes for reservoir projects involve increases in

Table 12

Summary of Purposes of Authorized Reservoir Projects and Authorized Multiple-Purpose Projects with Power*

Type	Phase	Purpose Served, Number (%)								
		Fish/ Wildlife	Flood Control	Recreation	Water Supply	Irrigation	Water Quality Control	Low-Flow Regulation	Navigation	Project Totals
Reservoir	Planning	42 (66)	60 (94)	54 (84)	39 (61)	5 (8)	24 (38)	9 (14)	3 (5)	64
	Construction	74 (64)	117 (100)	113 (97)	43 (37)	12 (10)	48 (41)	14 (12)	2 (2)	117
	Operational	102 (51)	198 (99)	140 (70)	48 (24)	10 (5)	11 (5)	43 (21)	7 (4)	199
Multiple purpose with power	Planning	2 (50)	4 (100)	4 (100)	3 (75)	-	-	-	1 (25)	4
	Construction	7 (77)	7 (77)	8 (89)	1 (11)	2 (22)	3 (33)	-	1 (11)	9
	Operational	22 (37)	44 (73)	58 (97)	13 (22)	17 (28)	9 (15)	5 (8)	38 (63)	60

* Source: Civil Works Historical Project File, FY 75.

the fish and wildlife enhancement, recreation, water supply, and water quality control purposes and a decrease in low-flow regulation as a purpose. The latter decrease is a result of legislative action and current regulatory philosophy reflecting an increased emphasis in water-quality control and decreased emphasis in low-flow augmentation. This trend appears to be similar for multiple-purpose projects, although the low number of projects in the planning and construction phases makes it difficult to draw a definitive conclusion. This trend in benefit (or purpose) categories is significant since these categories are most affected by environmental quality problems.

Effects of environmental quality problems on project benefits may be realized in three ways. First, the problem may directly affect the benefit category (e.g., water quality effects on water supply or recreation). Second, the problem may reduce potential benefits for a project purpose not specifically included in its justification (e.g., eutrophication effects on recreation activities and water supply). Third, the project may affect a benefit category (or purpose) outside the boundaries of the project (e.g., effects of the quality of release water effects on downstream fish and wildlife resources). The average annual loss of benefits attributable to environmental quality problems was $130,000 per project. It is important to consider that a majority of the effects on benefits discussed in this section are related only to operational projects that have documented environmental impacts.

Prior to examining individual benefit categories, a concept of the magnitude of the benefits involved may be obtained from Table 13, which

Table 13

Benefits of Projects Reported as Possessing Environmental Quality Problems

Project Purpose	Annual Benefits Thousand $	Projects Number (%)*	Project Status, Number (%)**			
			Planning	Engineering	Construction	Operations
Fish/Wildlife	15,217	39 (45)	2 (5)	4 (10)	12 (31)	21 (54)
Navigation	86,645	20 (23)	-	4 (20)	6 (30)	10 (50)
Recreation	130,632	72 (83)	4 (5)	10 (14)	26 (36)	32 (45)
Water Quality Control	42,919	21 (24)	-	4 (19)	8 (38)	9 (43)
Flood Control	351,286	81 (93)	5 (6)	9 (11)	24 (30)	43 (53)
Water Supply and Irrigation	75,039	43 (49)	4 (12)	5 (12)	18 (42)	15 (34)
Power	357,588	29 (33)	-	1 (4)	10 (36)	18 (60)
Total	1,059,326	87	-	-	-	-

* Percentage of total number of projects with the designated purpose.
** Percentage of projects with a designated purpose and status.

is a summary of the benefits for those projects cited possessing environmental quality problems. In addition to benefit category, the number of projects and their status are reported in the table. Trends previously established for reservoir and multiple-purpose project purposes appear to be applicable to these projects. Only 87 projects of the 152 projects (57 percent) were included in Table 13 because either the benefit information directly related to projects cited was not readily available or only benefit information prior to 1960 was available and as such was considered unreliable. From this information it is apparent that projects with environmental quality problems represent a substantial monetary value in benefits. The potential effect on project benefits will be considered for certain purposes and related to District and Division input.

Hydropower projects. Hydropower projects represent an increasing source of benefits for Corps projects due to the increasing cost (and demand) for energy, along with their capability to provide peaking power. The growth of hydropower benefits (expressed as megawatts of installed capacity) for CE projects is shown in Figure 17. Because of their flexibility, many hydropower projects are used primarily to provide peaking power; this is particularly true of pumped storage facilities. If releases must be made to accomodate water quality objectives downstream, power-generating capacity may be lost or unnecessary power may be generated. This results in lost revenues from the sale of peak power as well as losses due to requirements to coordinate power loadings. Many operational hydropower facilities do not possess storage or capability for water quality releases (15 percent, Table 12); therefore, loss of benefits may be common if water quality objectives are to be achieved.

Because it is difficult to assess the benefits associated with meeting these water quality objectives (if any), an economic analysis of the alternatives was not possible. The average loss of benefits attributable to this factor by the Districts and Divisions was 1 to 2 percent of the total power benefits for those projects cited by District and Division input. Currently, those hydropower projects with problems related to the quality of the release water account for 12 percent of the total installed capacity of all hydropower projects. Potential costs may be estimated by applying the loss (1 to 2 percent) to the power benefits of projects possessing environmental quality problems (Table 13).

Water supply. Another benefit category of Corps projects that has become increasingly important is water supply. This fact is evident by considering the growth of water supply contracts over the last 30 years (Figure 18). Trends in project purposes indicate that water supply as a purpose will continue to increase in the future (Table 12).

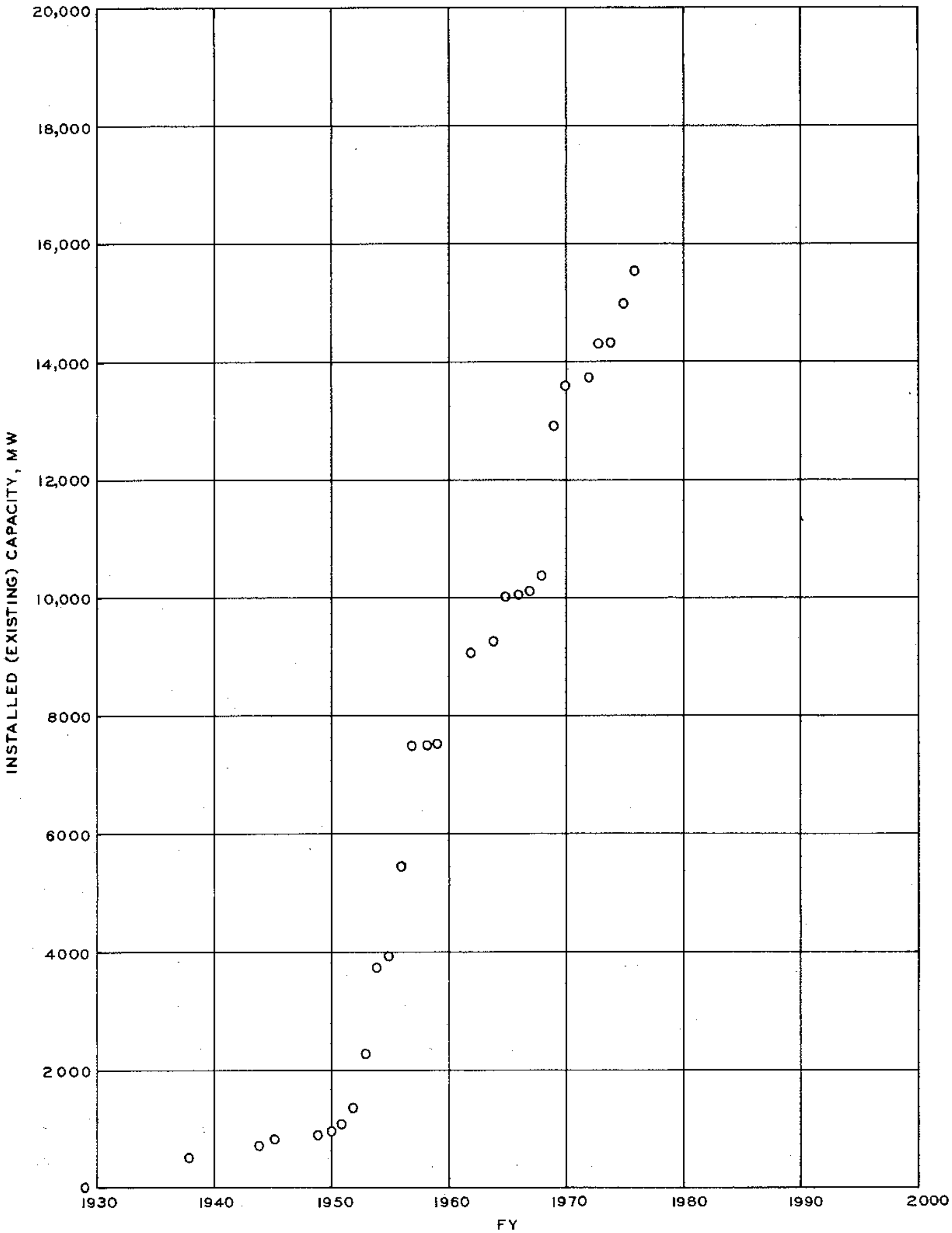

Figure 17. Growth of hydropower benefits for Corps projects

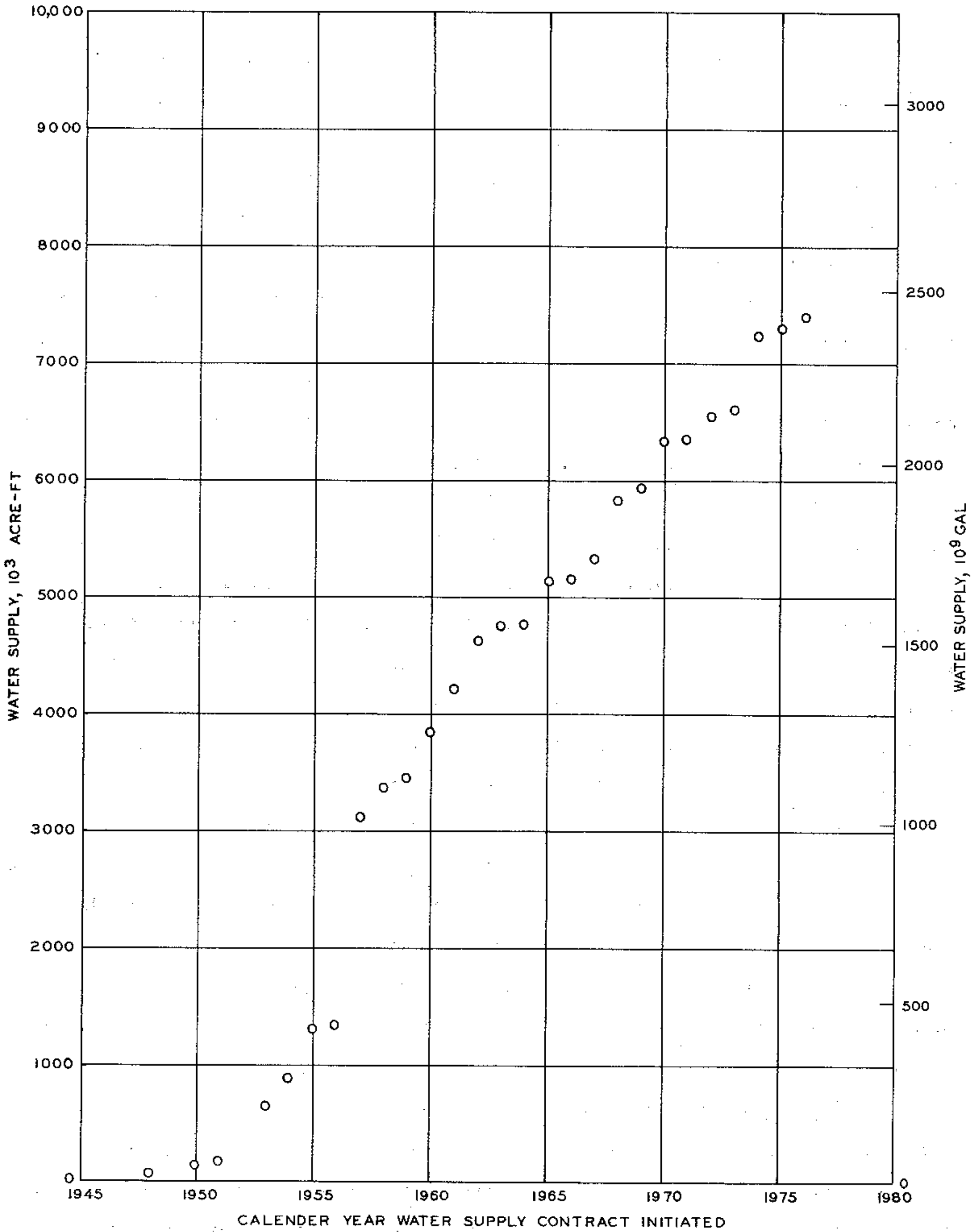

Figure 18. Growth of water supply contracts

The benefits realized from water supply projects are directly related to the quantity and quality of water available over the project life. If the reservoir undergoes accelerated eutrophication or water quality degradation by contaminant input or suffers excessive water losses due to evapotranspiration, a portion of the water supply benefit may be lost. All of the above problems have been documented. Those reservoir projects cited as possessing water quality problems account for 13 percent (300 billion gallons) of the cumulative water supply available at Corps projects. The average cost of water, based on all water supply project contract information, was $0.13 per 1000 gallons. The effect on water supply benefits will be reflected in effective loss of storage for water supply or in additional costs for water treatment to improve quality, thus making alternative supplies more attractive.

For those projects with documented costs related to loss of water supply benefit due to water quality problems, the benefit loss ranged from 11 to 40 percent of the water supply benefit. Potential costs due to loss of the water supply benefits were assumed to be 30 percent of the benefits for those projects with environmental quality problems (Table 13). This figure was assumed because in many cases the loss of benefit may be complete (i.e., due to presence of toxic contaminants) and because loss of benefits (more attractive alternate supplies) are possible due to increased treatment costs for water.

Recreation. A third benefit category significantly affected by water quality problems is recreation. Recreation is one of the prime benefits of Civil Works projects and contributes greatly to their visibility. The growth of recreation at Corps projects over the last 25 years is displayed in Figure 19. The continual demand for recreation by the public is expected to keep this growth at its present rate. The impact of poor water quality on recreation is generally reflected in poor project aesthetics, which was discussed earlier. A related study on the effects of water quality on recreation benefits concluded that improvement may result in a 45 to 60 percent increase in recreation benefits.[6] Currently, those operational projects with water quality problems account for 34 percent of the total recreation demand at Corps projects.

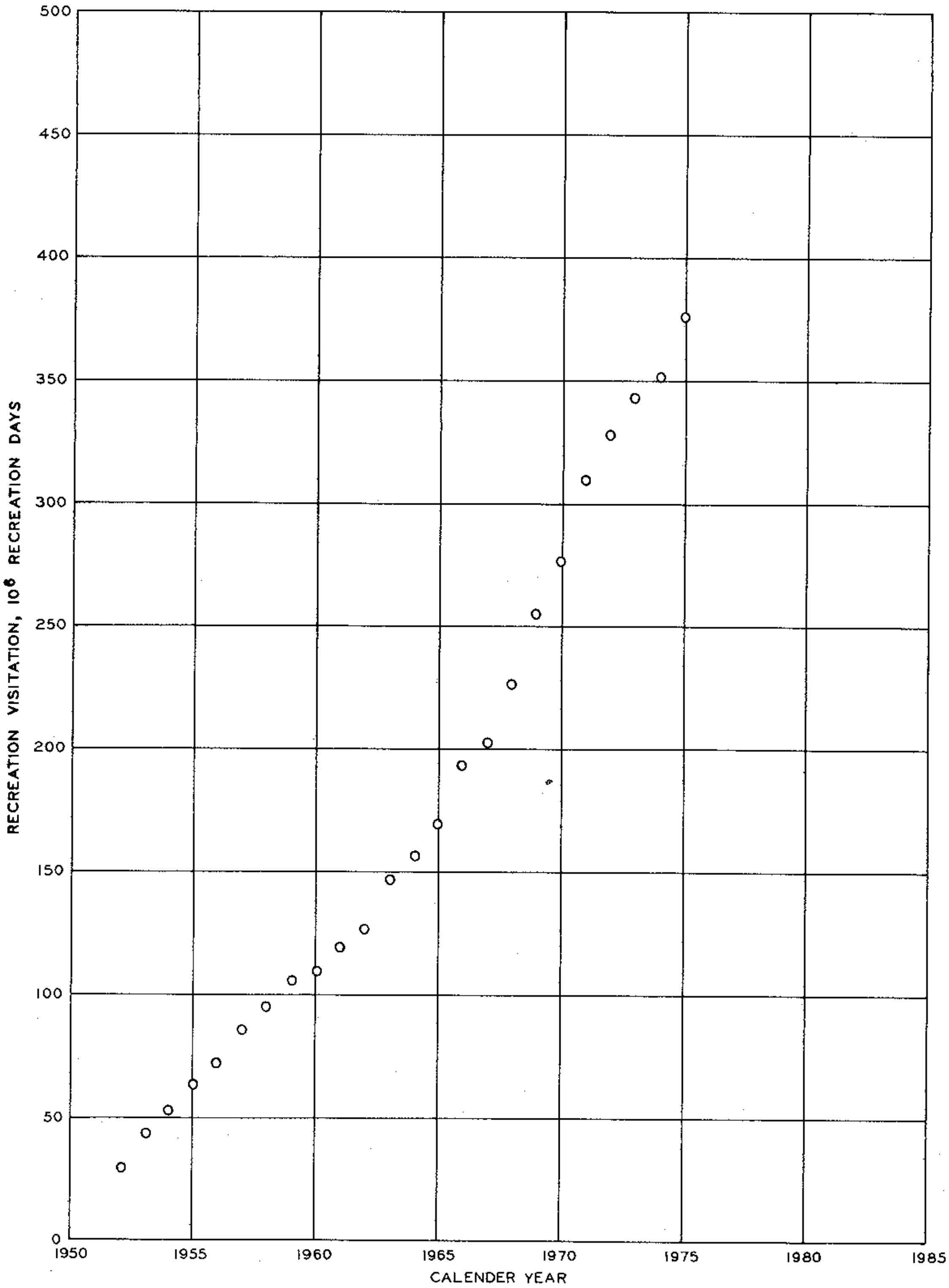

Figure 19. Growth in recreation activity at Corps projects

Another effect on recreation that was commonly cited was the effect of project releases on downstream recreation. Since downstream recreation benefits are seldom included in project evaluation, this would tend to increase the effective loss of recreation benefits.

For those projects with documented costs related to loss of recreation benefits, the benefit loss was equivalent to $0.23 per recreation day affected. A potential cost of $0.35 per recreation day affected was assumed in this study to account for downstream recreation effects; this figure was applied to all operational projects cited as possessing environmental quality problems.

Fish and wildlife. Water quality and environmental impact problems will also directly affect fish and wildlife enhancement benefits. This effect would include those benefits directly related to the project as well as downstream benefits. Loss of fishery benefits may be included as part of the recreation benefits (sport fishing) and will tend to affect the latter. Common factors causing problems are contaminants eliminating reservoir fishery benefits and project releases decreasing (or eliminating) downstream benefits. In several cases, loss of fish and wildlife benefits was complete due to environmental quality problems.

The potential cost associated with loss of fish and wildlife enhancement benefits can only be estimated, and a factor of 0.25 to 0.50 of the fish and wildlife benefits (Table 13) was assumed for economic impact. Effects on fish and wildlife resources need not be necessarily limited to project benefits claimed as enhancement. In many cases affected fish and wildlife resources of a project are replaced through mitigation, or enhancement benefits are not claimed. The effect of environmental quality problems on fish and wildlife resources in this category would not be reflected in a loss in enhancement benefits.

Regional management. The operational need to balance water quality and quantity for Corps projects on a regional or basinwide approach may result in one benefit being lost for a gain in another. Without a method to evaluate the economic feasibility of water resource management alternatives on a basinwide basis, an effective reservoir regulation on a regional basis will be difficult and may result in benefit losses. Navigation benefits are an example of a documented benefit class affected by this problem. If required waterway stages are not maintained due to conflicting water resource requirements, traffic delays may result and the potential for loss of navigation benefits is significant. For purposes of this report, 1 to 2 percent of the navigation benefits for those projects cited as having environmental quality problems (Table 13) was assumed.

Flood-control benefits are another example of an effect by this problem. Flood-control benefits may be lost by allowing the pool to remain at high elevations instead of drawing down to make flood-control storage available. Generally, this conflict arises when recreation benefits or release regulation for other purposes are considered. The potential for losses in this benefit category cannot be directly estimated, and a similar approach (i.e., 1 to 2 percent of flood-control benefits, Table 13) to that used for navigation benefits was assumed for economic impact.

Overall impacts. A summary of the economic impact on project benefits by environmental quality problems is presented in Table 14.

Table 14

Economic Impact of Environmental Quality Problems on Project Benefits

Benefit Class	Annual Cost, Thousand $		Notes on Potential Costs
	Documented	Potential	
Fish/wildlife	1105	3,800-7,600	Based on 25-50% of benefits*
Navigation/flood control	2480	4,400-8,800	Based on 1-2% of navigation and flood control benefits*
Recreation	1265	44,500	Based on $0.35 per recreation-day affected
Water supply	75	22,500	Based on 30% of water supply benefits*
Hydropower	375	3,580-7,160	Based on 1-2% of hydropower benefits*
Total	5300	78,780-90,560	

* Reference Table 13.

Effects on project benefits by environmental quality problems may be realized directly or through attempts to balance project purposes with environmental quality objectives. In the latter case, it is difficult to assess the net effect of benefits because of tradeoffs (e.g., hydropower benefits versus minimum flow releases to meet environmental quality objectives). The economic impacts on project benefits presented in Table 14 generally reflect truly separable costs within the limits of this analysis (i.e., projected loss of recreation benefits does not imply a gain in water supply benefits).

The maximum potential economic impact on project benefits by environmental quality problems ($90,560,000, Table 14) is only 10 percent of the benefits for a portion of those projects documented as possessing problems (Table 13). The actual economic impact may be considerably higher than this, due to the conservative nature of the economic impact analysis on project benefits. Additionally, in many cases input indicated a potential loss of benefits that was not included in problem cost but was documented as occurring.

Costs for corrective actions. The construction costs associated with solving environmental quality problems have been discussed previously. Associated with initial capital costs are operation and maintenance costs for the facilities maintained. From the District and Division input, an average operation and maintenance cost of $80,000 per year associated with corrective actions was obtained. The potential costs due to this factor may be determined by applying the same reasoning used earlier to obtain potential construction cost impacts (Table 10).

Postconstruction monitoring. As legal requirements to meet environmental quality objectives are imposed on Civil Works projects, the requirements for monitoring will increase. Monitoring requirements for projects are related to requests for information from regulatory or other State and Federal agencies and to the need to assess the success of corrective actions taken at projects. Operational monitoring for water quality and other environmental impacts were cited as an important cost impact. The average cost associated with this monitoring effort was $45,000 per year per project. Potential monitoring costs may be estimated by applying this average cost to all projects that were cited as possessing problems and at the upper limit may be required for all operational Civil Works projects.

Increased operation costs. Second to the effect on project benefits, increased operation and maintenance costs were the most frequently cited cost impact. Since most operational Civil Works projects were constructed prior to passage of major environmental legislation, this impact is somewhat expected. Projects constructed prior to major environmental legislation generally do not have provisions for attaining current environmental quality objectives; consequently, corrective actions will increase operational costs or will require expenditure of operation and maintenance funds for potentially major rehabilitation.

The average cost impact due to environmental quality problems was estimated as $80,000 per year per project. Determination of the potential impact of this cost factor may be approached by examining trends for operational costs for projects in various categories.

Figure 20 is a plot of the average of the last five years' operation and maintenance costs versus number of years in operation for those reservoir projects cited as possessing problems. The average cost ($390,000 per year) was almost double the average for all operational reservoir projects ($210,000 per year). While this number may be related to project size (i.e., larger projects were documented in District and Division input), it certainly does support the documented average cost input. Costs were used as obtained in this analysis; as such no attempt to bring costs to a constant-dollar basis was made. There does appear to be a slight relationship with the age of the project in that newer projects demonstrated a larger cost variation and somewhat higher cost. A similar analysis was conducted on the multiple-purpose projects with power that were cited as possessing problems (Figure 21). In this case there was a decrease in operational costs from the average, but the number of projects considered makes it difficult to establish any definite trends.

To establish possible trends in operation and maintenance costs for those projects cited as possessing problems, the increase in FY 75 operational costs over the average for last five years was analyzed. These values were plotted as a function of project age and are presented for reservoir and multiple-purpose projects with power in Figures 22

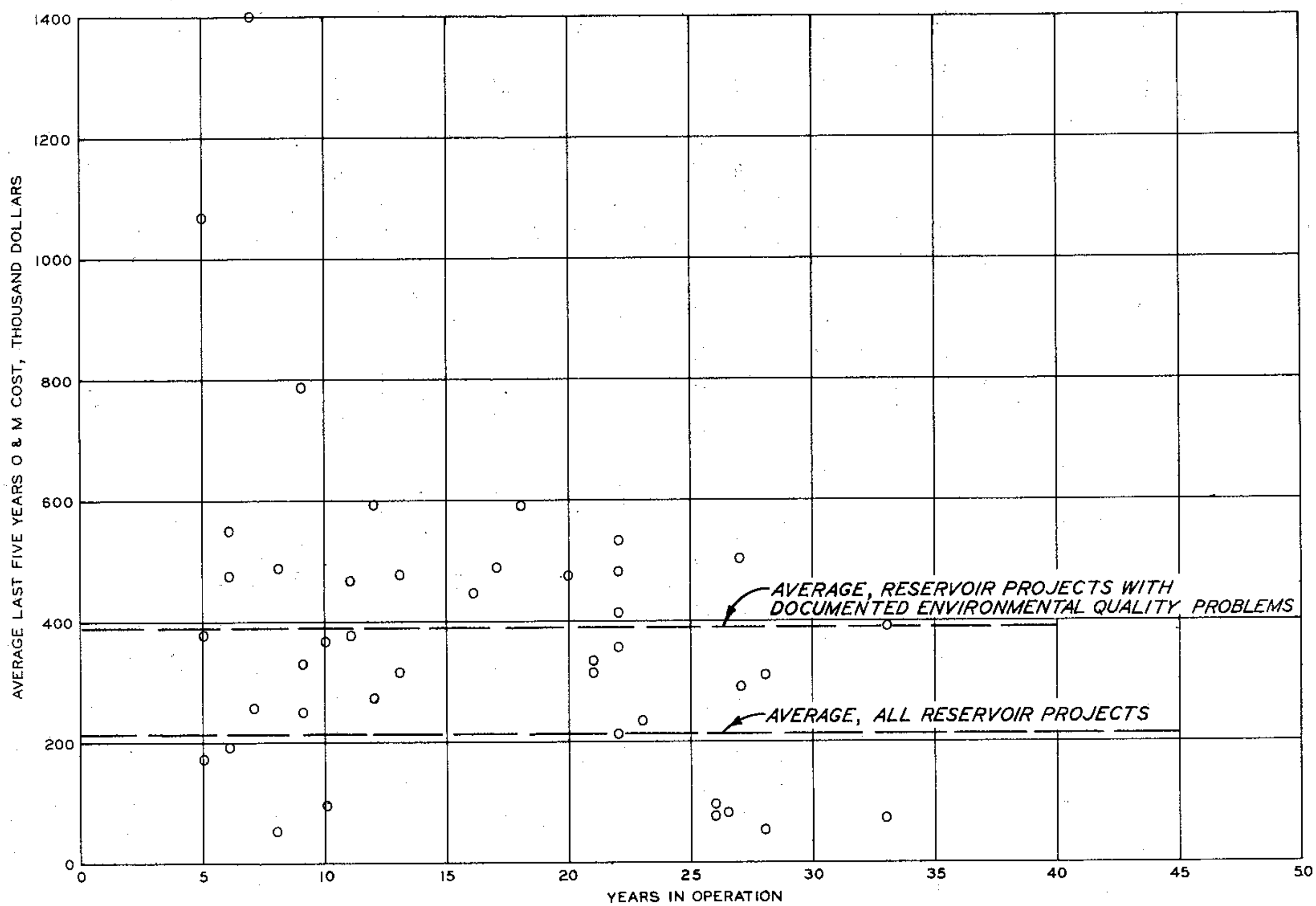

Figure 20. Five-year average operating and maintenance costs for reservoir projects possessing problems versus number of years in operation

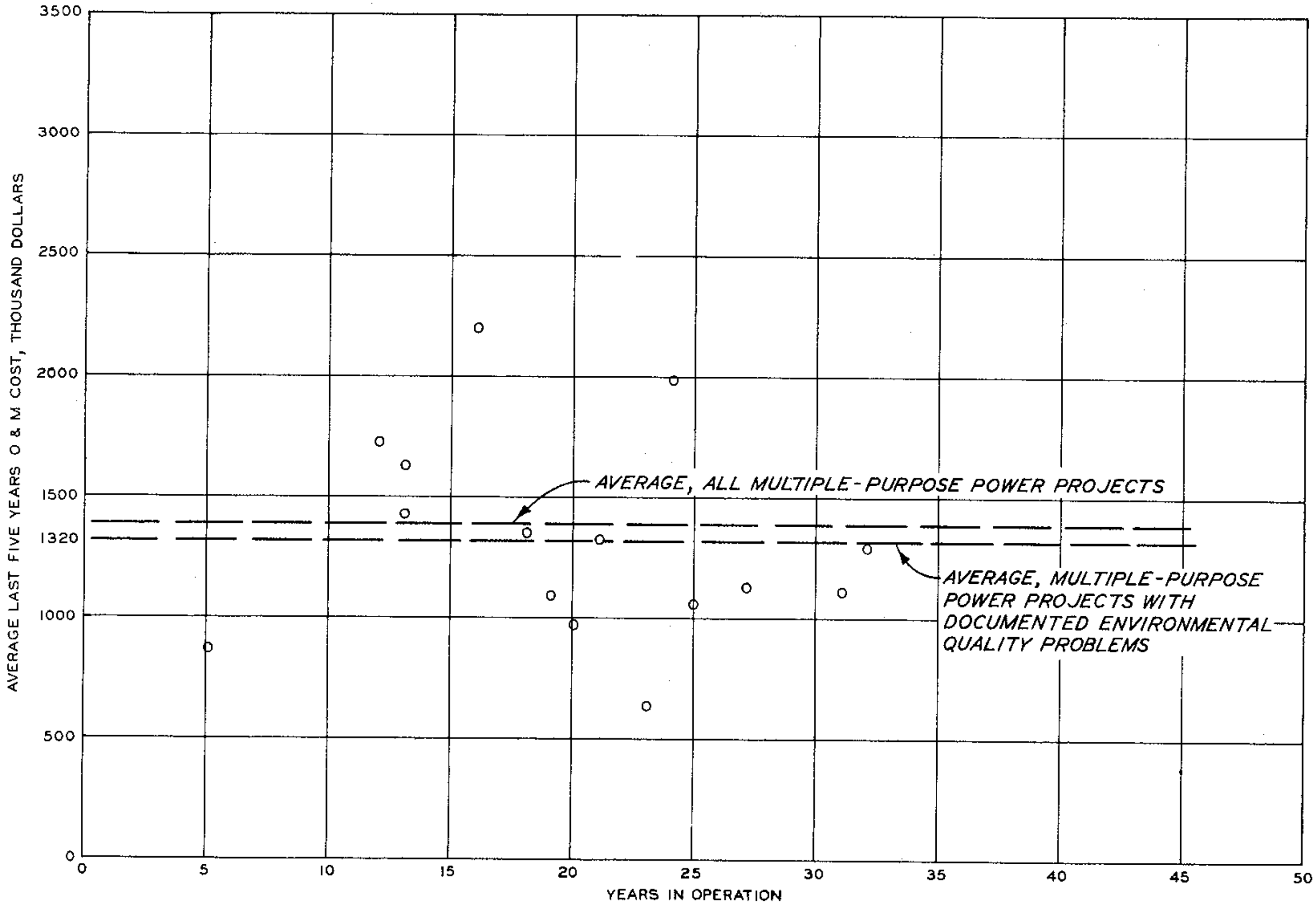

Figure 21. Five-year average operating and maintenance costs for multiple-purpose projects possessing problems versus number of years in operation

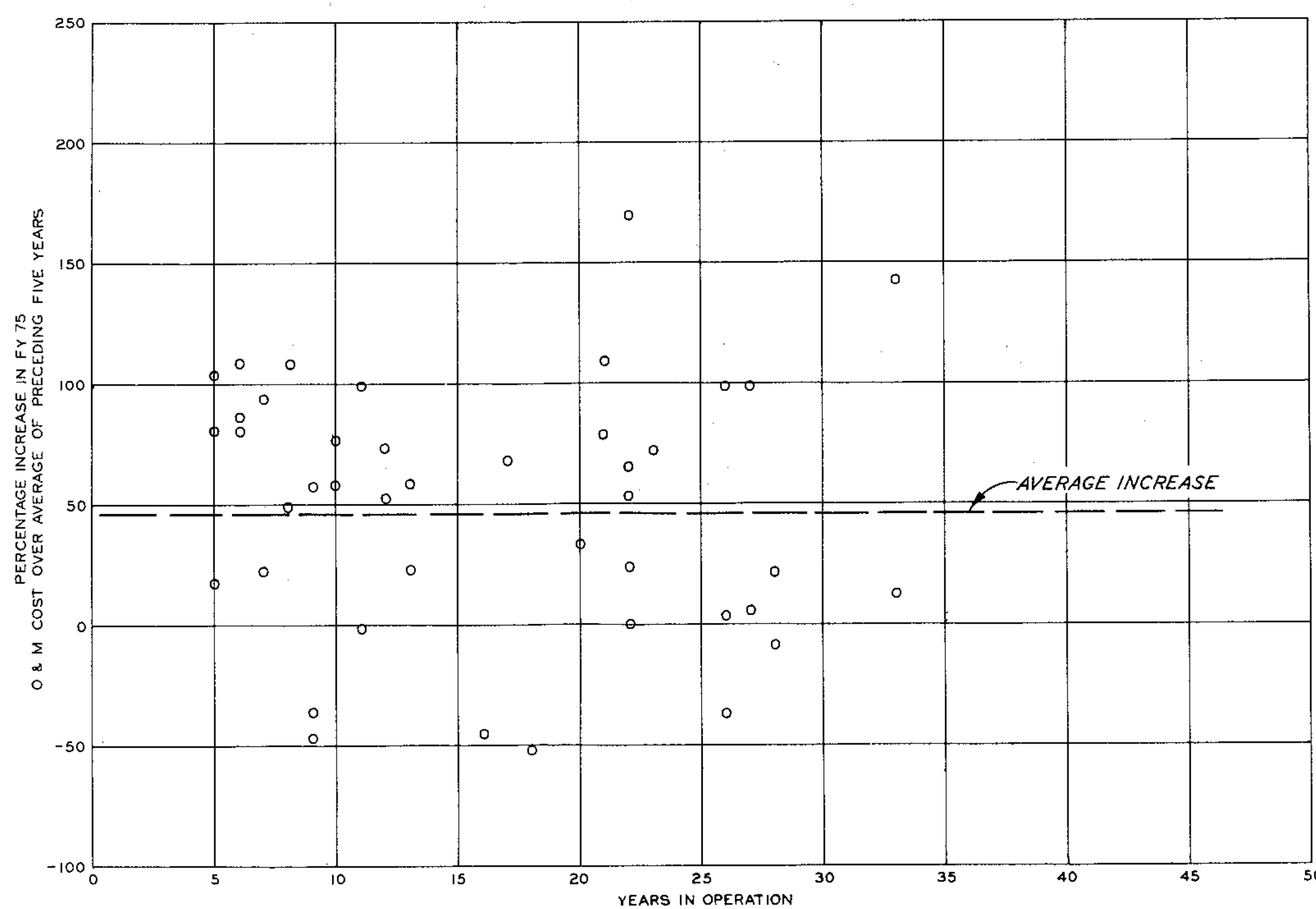

Figure 22. FY 75 operational costs of reservoirs possessing problems compared with the 5-yr average increase as a function of project age

and 23, respectively. The results of this analysis were not conclusive, although it does appear that costs are increasing and, in the case of power projects, may be related to project age.

From the above analysis, the potential effect of water quality and environmental impact problems on increased operation and maintenance costs of the Civil Works program is substantial. The potential cost will be estimated by applying the documented cost ($80,000 per year per project) to all projects cited as possessing environmental quality problems.

Regulatory functions. Although an economic impact on the regulatory functions of the Civil Works program was not documented, it did occur in sufficient frequency in problem statement input to be considered in this section. Current estimates of the regulatory functions of the Corps include the processing of approximately 30,000 Section 404 and Section 10 permits at a cost of $21,000,000 annually. The Districts and Divisions documented many problem areas relative to permit processing and a cost impact is to be expected. The magnitude of the potential economic impact related to regulatory functions should be based on a differential cost and not costs related to achieving legal requirements. It was assumed that 10 percent of the current cost of the regulatory program represents this potential cost.

Summary of Economic and Noneconomic Impacts

A summary of the economic impact of water quality and environmental impact problems by Civil Works activity is presented in Table 15. Economic impacts are related either to specific project costs or to annual costs; both costs are entirely separable. The documented costs are approximately $10,000,000 and $40,000,000 for the annual and project categories, respectively. The maximum potential costs are approximately $137,000,000 and $164,000,000 for the annual and project categories, respectively.

The potential economic impacts were based on projects cited as possessing environmental quality problems. It can be assumed that all

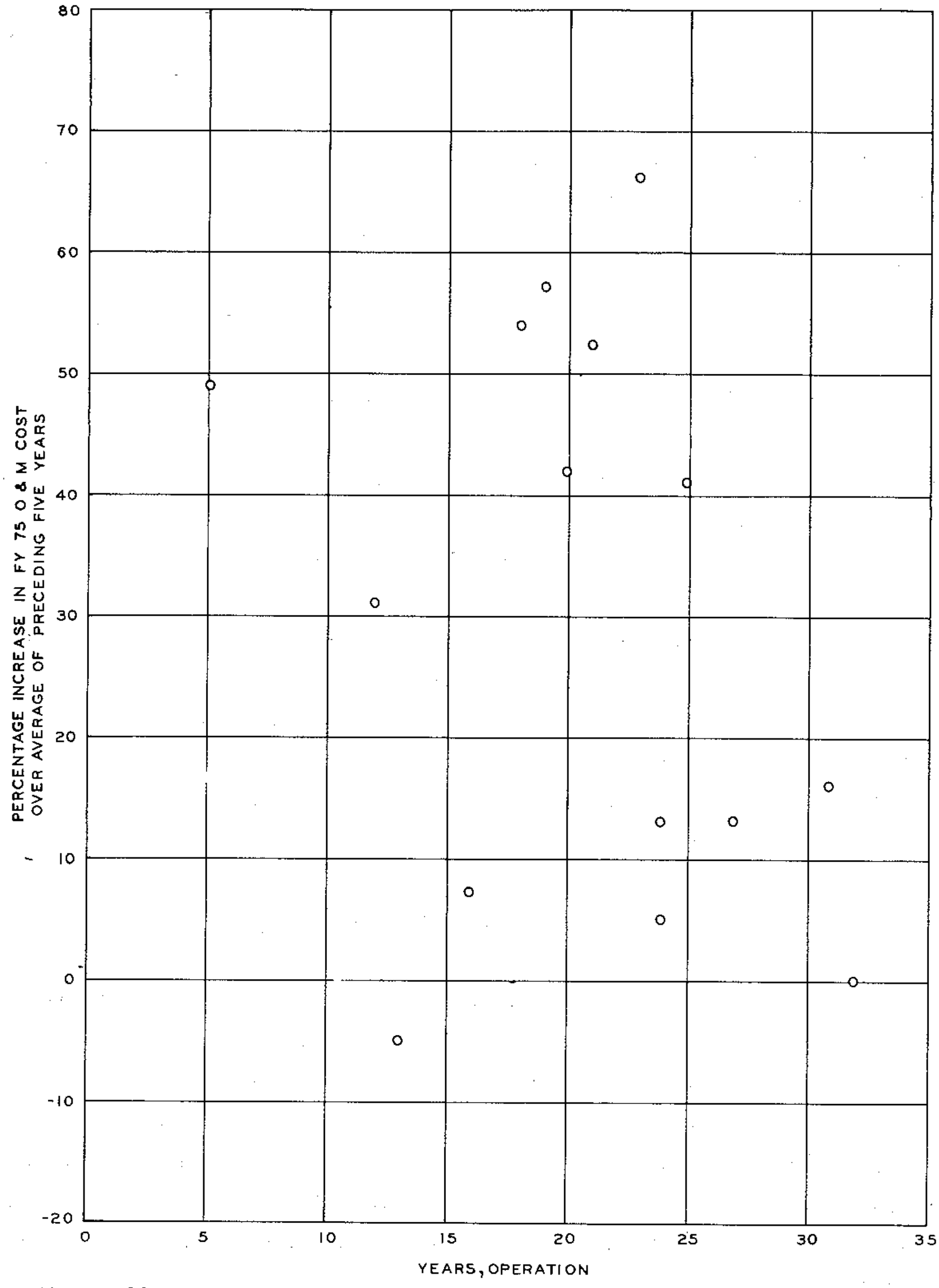

Figure 23. FY 75 operational costs of multiple-purpose projects possessing problems over the 5-yr average increase as a function of project age

Table 15

Summary of Economic Impact of Environmental Quality Problems

Phase	Documented Costs, Thousand $		Potential Costs, Thousand $	
	Annual	Project	Annual	Project
Planning	100	3,495	7,350-9,850	6,690
Engineering	-	490	-	10,170-10,330
Construction	-	36,480	4,770-9,540	47,300-146,920
Operations	9855	-	106,200-117,980	-
Total	9955	40,465	118,320-137,370	64,160-163,940

projects with problems or potential problems were not identified in the input; therefore, this estimate is probably conservative. Additional input may tend to lower average costs used for estimating potential costs, but this effect would probably be offset by increases in project-specific costs, and certain projected annual costs (e.g., operational costs, loss of benefits). Furthermore, factors used to determine potential impacts were chosen in such a manner as to present a conservative viewpoint.

One factor significantly affecting potential costs associated with environmental quality problems is the rate at which problems are transmitted from engineering and construction phases to operations. Problem costs associated with projects in engineering and construction are primarily project related; conversely, those costs in operations are annual costs. Delay in implementing solutions to specific problems may or may not significantly impact engineering or construction costs (these costs may be incurred to solve the problem regardless), but will cause operational costs to increase.

On a direct extrapolation, 30 percent of the projects with problems were in the engineering or construction activities; consequently, the maximum potential annual operational cost may rise by a factor of 1.6 to $165,000,000 (considering lost benefits and increased operational costs only, Table 11). To place this in perspective, the last figure is approximately 30 percent of the total operations and maintenance budget request for Civil Works in FY 77. Additionally, projects in engineering and construction cited as possessing problems account for approximately 25 percent ($4,500,000,000) of the balance required to complete all projects in these activity categories. This implies that a considerable investment may be made in projects that potentially will have environmental quality problems.

Another factor that may influence the economic impact is new starts within the Civil Works program. Since documented problems are currently reflected in 13 percent of the projects in the Civil Works program, it may be assumed that this trend will hold for new starts if present practices continue. This hypothesis is probably conservative since changes in environmental quality objectives probably will continue to increase requirements. Depending on the number of new starts initiated, the resultant economic impact could be significant.

The impact of environmental quality problems associated with the Civil Works program has both noneconomic and economic implications. Noneconomic impacts were documented for 63 percent of the problems received. The economic impact, in terms of total costs (project related plus annual), ranged from a documented $50,000,000 to a potential of $301,000,000. Due to increasingly higher environmental quality objectives, identifiable impacts may be expected to increase in the future unless solutions to these problems can be found. The benefits of a research program to address documented problems would be a reduction in impacts. All impacts will not be totally alleviated, but noneconomic impacts along with those economic impacts reflected in annual costs should be reduced.

PART V: RESEARCH REQUIREMENTS

Introduction

District and Division needs associated with environmental quality problems generally are directly related to the problem situations described earlier. The needs may be classified into two broad categories: diagnostic techniques necessary for assessment of environmental quality and design or management procedures for corrective actions to solve or minimize problems previously discussed. Both of these categories are directly related to achieving environmental quality objectives while meeting project purposes. Because the project purposes are achieved through many classes of projects (Figures 4 thru 10), the development of the diagnostic techniques or corrective procedures to meet District and Division needs is complex.

Those needs related to diagnostic techniques generally involve procedures for assessment, prediction, or simulation of impacts; data collection, interpretation, and analysis; and planning procedures (choice of alternative projects or activities) to reduce problem severity. The main concept in satisfying these needs through research is to develop generalized procedures that could be brought to bear on many of the problems discussed in the problem investigation section (Part III).

Those needs related to corrective actions generally involve structural modifications or additions, operational procedures, or new engineering design techniques to solve problems while maintaining project purposes. Guidance is needed for the design, selection, and application of water resource engineering concepts to environmental quality problems. These needs primarily address operational projects, although they may be used in the project planning phase. To ensure that past, present, and future research satisfies these needs, comprehensive field verification of methodologies is mandatory. Without field verification, the credibility of results of research is questionable, the degree of application is small, and attainment of success is not ensured.

The research requirements discussed in this part of the report are responsive to the problem areas related to current practices that were identified in the problem investigation (Part III).

Dissolved Oxygen

A limited number of approaches and procedures are available for the amelioration of problems associated with low dissolved oxygen levels in reservoirs, reservoir releases, and waterways. Information is available for hypolimnetic oxygenation of very small bodies of water, but little information is available for large bodies of water.[7] Artificial destratification techniques for water bodies have been developed and applied,[8-13] but the application to large reservoirs has been limited. General guidance suitable for case-by-case application needs to be developed for various means of in-reservoir aeration and destratification. Such guidance must address cost effectiveness, system efficiency, operational criteria, and resultant effects on overall water quality objectives.

Reaeration of reservoir waters as they are released from a project has been attempted to meet downstream dissolved oxygen objectives. At hydropower projects where large volume rates of water are released, reaeration using injection of either pure oxygen or air has been attempted on a limited basis.[14-16] The need exists to determine whether in-reservoir aeration or through-structure reaeration is most appropriate for hydropower projects. Figure 24 shows reaeration alternatives available for application to hydropower projects.

For nonhydropower projects, the degree of reaeration that occurs through various types of outlet structures must be determined. Present information is limited.[17] Design criteria must be developed for new projects to ensure that adequate reaeration is attained through outlet works. For existing projects there is a need for developing means by which reaeration can be attained through either operational or structural modifications.

Another consideration is the reduction of oxygen-demanding materials in reservoirs and waterways. This reduction may be accomplished

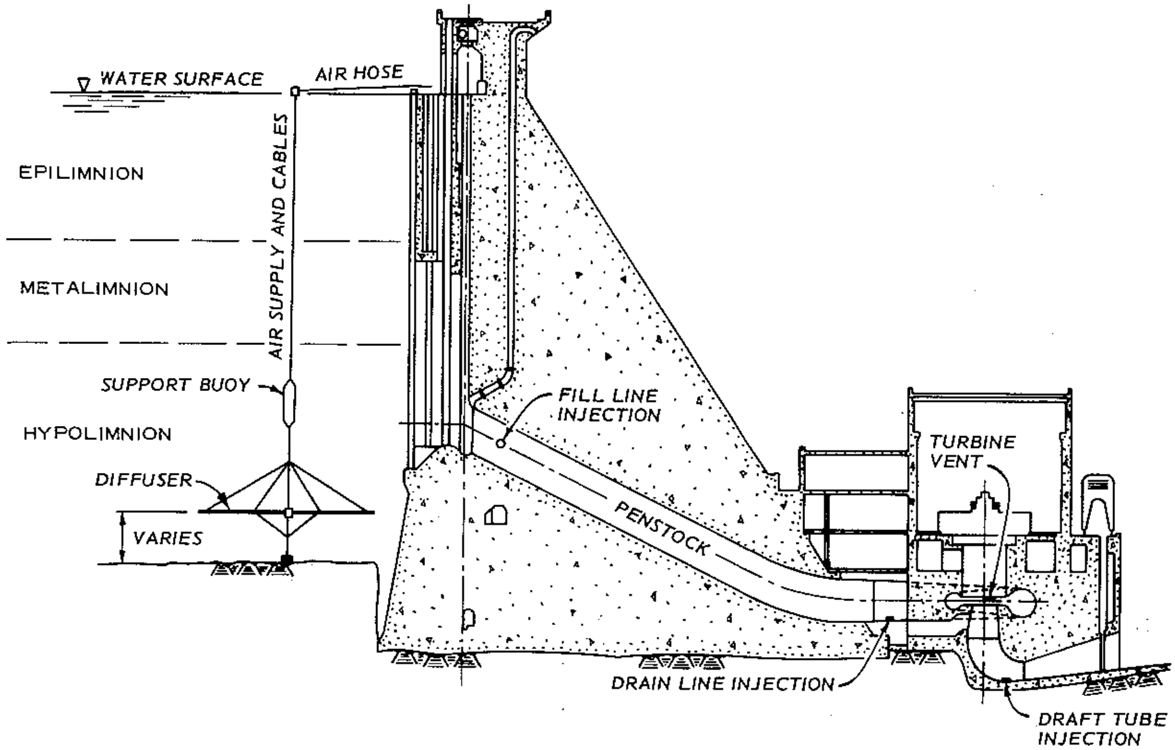

Figure 24. Reaeration alternatives for hydropower projects

in several ways: diversion of waters containing oxygen-demanding substances,[18] appropriate clearing and site preparation prior to reservoir filling, or flushing during initial stages of impoundment. Alternatively, procedures may be used in reservoirs to avoid the release of waters that possess low oxygen levels, as for example, through the use of selective withdrawal from various levels of water in an impoundment.[19]

While attempts are being made to achieve reasonable dissolved oxygen objectives in connection with Corps waterways activities, present technology does not generally provide information on when and how to apply reaeration methodologies to existing projects in a cost-effective manner or how to design and operate planned waterways projects to achieve dissolved oxygen objectives.[17]

The importance of various sources and sinks of dissolved oxygen in reservoirs and the influence of project operations on the dissolved oxygen balance needs to be better understood so that potential problems can be avoided. Procedures are needed for quantifying the effects of project operational schemes on the dissolved oxygen in reservoirs. This should include the chemical and biological interactions coupled with hydrodynamic aspects of reservoir operations.

Additional research efforts notwithstanding, improved coordination and cooperation between Federal, State, and local agencies should minimize the deleterious effects of oxygen-demanding loadings from upstream watershed activities.

Nutrients and Eutrophication

Although the Corps is not responsible for and cannot control many watershed activities that contribute to eutrophication, the Corps is responsible for and does control project design and operation. Furthermore, the Corps' significant responsibilities and capabilities for the construction, operation, and maintenance of reservoirs and waterways offer great potential for a major role in the restoration of eutrophic waters.

The capability to predict the eutrophication potential of reservoirs and resultant effects on project purposes is needed for the planning, engineering and design, and operational phases of Corps activities. Where appropriate data are available, mathematical modeling techniques are presently being used with limited success in predictive evaluations of nutrient loadings and eutrophication potential.[20] However, these models lack sufficient resolution and require extensive field verification. Mathematical techniques for predicting eutrophication potential show promise, but are currently in their infancy from the standpoint of general application.

In addition to the need for prediction during the project planning phase, operational information for controlling eutrophication at existing impoundments is also required. Supplementing mathematical simulations, a current approach to the evaluation of reservoir eutrophication potential includes procedures such as laboratory algal bioassays and the use of loading analyses. Since each procedure contains assumptions and limitations, there is a need for the refinement of existing procedures and the development of techniques for evaluating eutrophication potential in reservoirs.

Excessive inorganic macronutrients alone cannot produce the characteristics associated with eutrophic conditions unless other environmental factors are suitable for high rates of biological productivity. The most important of these factors is light penetration through the water column. Since most reservoirs receive significant loadings of essential nutrients from watershed sources, turbidity is often the most common environmental factor limiting excessive algal growth. Adverse symptoms of eutrophication occur most frequently in regions where surface waters have low concentrations of naturally occurring suspended solids.

To date, the primary research emphasis on problems associated with eutrophication has been aimed at identifying the factors and sources causing eutrophication and evaluating restoration and control strategies for natural lakes. Many of the approaches for problem management and control that have shown significant potential for application to natural lakes are technically inappropriate and impractical for use on large reservoirs. In evaluating the potential effectiveness of restoration techniques, it is important to understand the fundamental hydrodynamic and ecological differences between reservoirs and natural lakes. Reservoir operational alternatives, which to some extent may allow the selective routing and in some cases retention of large inflows of nutrients and suspended solids, offer significant potential for the control and management of problems associated with eutrophication. However, for practical and effective structural design and operational guidance to be developed, a definitive understanding of the factors and interactions that control excessive algal blooms and associated problems of eutrophic reservoirs must be obtained. Restoration concepts such as project operational alternatives or the removal of nutrient-rich or contaminated sediment by dredging should be evaluated by long-term field demonstration studies.

Although microorganisms (bacteria and algae) can effectively absorb large quantities of nutrients from water, their use is economically impractical because of the elaborate and expensive techniques required to harvest them.[21] Vascular aquatic vegetation absorbs large amounts of nutrients[22] and is relatively easily removed, thus constituting a potentially effective means of reducing the nutrient content of reservoir waters. Although there has been much conjecture regarding the nutrient-removal capabilities of different types of vegetation, there is little definitive information in this area.

The frequent occurrence of algal blooms in eutrophic waters has prompted the development of various chemical algicides for use during the last half century.[23] Algicides, like chemical substances used in the control of pest species, are rather unspecific in their targets and have been used somewhat indiscriminately in the past.[24] Although planktonic algal populations are naturally kept in check by herbivorous zooplankton, this balance is upset in eutrophic reservoirs where blooms of blue-green algae often occur. Blue-greens are notoriously less palatable than other algae to herbivirous zooplankton.[25] This may be an important factor in causing their increased abundance relative to that of the more palatable algal representatives. Parasitism and grazing of blue-green algae by various microbiological agents have been demonstrated under natural conditions (see References 26 and 27 for reviews). The practical use of specific parasites to control noxious algal populations has been researched to only a limited extent[28] and remains a potentially productive area of pursuit.

Problems with excessive nutrient enrichment and dissolved oxygen demands in reservoirs frequently are most intense during the first few years of impoundment. New reservoirs not only are subjected to allochthonous loadings, but also generate a significant internal loading and oxygen demand from the decomposition of inundated herbaceous plants, litter, and topsoil. The decomposition of woody plant material such as trees probably is not a significant cause of eutrophication and low dissolved oxygen because of the very slow rate of degradation. Effective preimpoundment clearing and site preparation policies cannot be formulated because sufficient information is not available on the relative importance of various materials as dissolved oxygen sinks and nutrient sources following inundation. Definitive studies on these problems need to be conducted so that preimpoundment clearing guidance would reflect equal concern for reservoir water quality, fisheries habitat, and recreational opportunities.

Contaminants

The Corps has the responsibility for planning, designing, constructing, and operating water resource projects in a manner consistent with environmental quality objectives and other national interests. In areas where available information is inadequate, the Corps must develop the understanding, techniques, and guidance required to meet environmental quality objectives consistent with project purposes.

Guidelines are required to assess the environmental impacts of specific contaminants and their effect on authorized project purposes and permitted activities. The capability is required to evaluate both short- and long-term effects since certain contaminants (mercury, chlorinated hydrocarbons, etc.) are capable of bioaccumulation and transmission through food chains to valuable sport and commercial fish species and to man. Methods are also needed to predict the fate and effects of contaminants in Corps projects in order to make adequate assessments of environmental impacts and for consideration in project design. Procedures are needed to reduce adverse environmental impacts associated with contaminants in both planned and existing projects. Examples of information that needs to be developed include the prevention of mobilization of contaminants from sediments into project waters and possible in-project restoration techniques that could be implemented to avoid potential or existing contaminant problems. The need exists to evaluate project operational alternatives that can be used to alleviate contaminant-associated problems.

Major sources of contaminants to Corps projects are stormwater runoffs, natural mineral deposits, and point sources of wastewater (i.e., municipal or industrial effluents). The degree to which these sources may affect projects that are planned or operational must be understood. Relationships between storm events and contaminant loadings need to be developed. Procedures for determining the availability and potential impact of naturally occurring contaminants (e.g., heavy metals) at project sites are required during the planning and design stages. Predictive techniques are required to determine the fate of inflowing contaminants and the effect of operational alternatives on their impact. The significance of various contaminants to project purposes (e.g., recreation, water supply) should be examined and related to project planning and operation.

Current research on heavy metals has principally been concerned with their interactions with biological and chemical components of the environment. Interactions involving metals include sequestering by organic compounds of both natural and manmade origin,[29-31] accumulation by aquatic biota,[32-39] and biological transformations from various inorganic forms to organic and other inorganic compounds.[40-53] Ridley and Symons[54] briefly considered reservoir destratification as a means of keeping impoundments aerobic, thus preventing anaerobic metal solubilization from occurring. Present methodology for handling these contaminants is severely limited. Operational procedures must be developed for restoration of projects or to reduce impacts of heavy metals on project purposes.

Man's activities cause a vast array of organic compounds to move into natural waters.[55-58] Many of these materials are strongly resistant to natural degradation processes and may cause adverse environmental impacts. The decomposition or lack thereof of man-made and man-manipulated organic compounds has been the subject of much research. Compounds that have received close scrutiny include pesticides, PCB's, and phenol movement and degradation.[2,24,58-78] LaRiviere[79] and Ridley and Symons[54] examined organic waste management in surface waters and impoundments, respectively. Procedures are required to assess the impact of organic contaminants on project purposes, and corrective actions need to be identified to reduce or eliminate the effects of the contaminants on projects. Since many organic contaminants are associated with stormwater inflows, operational techniques are needed to control their entry into project areas. Possible techniques that should be considered include diversion, removal, or treatment to reduce the availability of organic contaminants.

Current research on microbial contaminants has been concerned with enumeration of waterborne pathogens in water (References 80 and 81 and many others) and with the factors influencing survival of pathogenic and nonpathogenic fecal organisms in natural waters.[82-86] This research may require supplementation by considering project effects on microbial contaminants prior to developing guidelines for managing Corps projects having microbial water quality problems and resulting losses of recreation benefits.

Requirements relative to contaminants involve diagnostic techniques for assessing effects on projects during planning and operation and corrective actions. Presently, corrective actions that have been verified by field studies are virtually nonexistent. Similarly, diagnostic procedures are not readily available to support project planning and development of operational alternatives.

Prediction and Evaluation Techniques

Major requirements

The ability to realistically predict and assess the effects of engineering activities on the environment is among the highest priority needs of Corps District and Division offices. These requirements span the entire spectrum of Civil Works activities and involve a variety of environmental habitats including reservoirs, waterways, watersheds, floodplains, wetlands, and urban areas. Examples of major requirements are described in the following paragraphs.

Engineering and design. Environmental consideration during advanced engineering and design of Civil Works projects require the use of reliable predictive techniques capable of providing precise evaluations of alternatives for structural design and operation. Examples include the design of reservoir outlet structures, spillways, stilling basins, locks, water supply intakes, etc. The evaluation of the alternatives usually involve the analysis of a variety of meteorologic and hydrologic conditions and must consider existing and future watershed activities that might alter the quality of project inflows, possible future changes in in-lake and downstream water quality and fishery objectives, and water user requirements. The Corps has been designing and constructing projects that have the capability to withdraw water selectively from multiple levels within a stratified reservoir. The purpose is to provide the capability for meeting various downstream water quality objectives and also to provide flexibility in managing in-reservoir water quality.

Previous Corps research has provided design guidance for some aspects of simplified selective withdrawal systems. The need exists to increase this knowledge to include other important considerations that cannot presently be evaluated. Such items as side intakes, multiple horizontal intakes, and large intakes need to be evaluated relative to withdrawal characteristics. Figure 25 is a generalized schematic of a selective withdrawal structure. Appropriate outlet works configuration

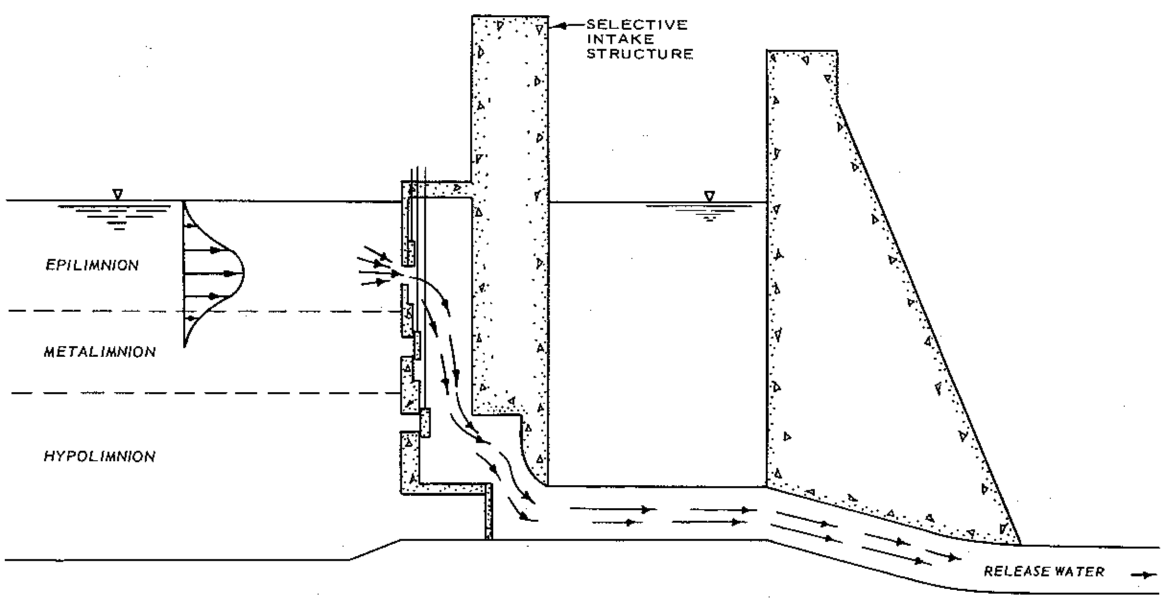

Figure 25. Generalized schematic of a selective withdrawal structure

and design considerations need to be developed to meet environmental objectives. The effects of unsteady flows (pulsating releases) on selective withdrawal characteristics must be determined to provide guidance on operational constraints. Structural means need to be developed where water quality objectives are not being met due to the inability to release waters from various levels within the reservoir.

General investigations and project planning. Methodologies capable of providing semiquantitative predictions and evaluations of planning alternatives are required in the early stages of Civil Works projects. Research requirements include development of procedures to conduct preliminary assessments of environmental impacts, make predictions of future changes in water quality and other environmental conditions resulting from changes in population, land use, etc., and conduct evaluations of the suitability of existing and future water resources for water supply and recreational purposes.

Project operations. The operation and management of existing projects to satisfy multiple purposes and environmental objectives are increasingly difficult responsibilities. Predictive techniques capable of simulating project operations and evaluating management alternatives are required to operate projects and to minimize detrimental effects. These techniques must also be capable of addressing the management of both chronic problems that may develop at existing projects because of structural limitations and unexpected acute problems such as result from accidental spills of contaminants.

Environmental impact statement preparation. NEPA requires that both short- and long-term impacts of engineering alternatives, including no action, be predicted for all major water resources projects. This evaluation should include consideration of both local and regional impacts and the cumulative impacts of multiple projects. Predictive modeling techniques along with reliable environmental baseline data are needed for the simulation of important environmental changes that might occur in the future under various alternatives.

Basin planning and management. A variety of Civil Works activities including water resources system management, floodplain information studies, urban studies, and basin planning require the evaluation of overall changes in land use and the hydrologic resource in terms of suitability to meet water quality, water supply, recreational, and ecological objectives. This implies the ability to simulate and predict changes in basinwide hydrology, project operations, land use, waste treatment levels, and aquatic and terrestrial ecology. Predictive tools required to accomplish various aspects of these evaluations effectively are inadequate or nonexistent.

Regulatory functions. Corps responsibilities for regulatory functions established under Section 103 of PL 92-532 and Section 404 of PL 92-500 have greatly increased the need for predictive methodologies for environmental evaluation. The environmental effects of proposed activities on the water quality and ecology of navigable waters and wetlands must be evaluated before permits can be issued. Cost-effective and accurate evaluation of large proposed projects and the cumulative impact of multiple smaller projects has and will continue to result in increasing field office requirements for predictive ecological modeling techniques.

Simulation techniques

Mathematical modeling. Increasing demands for environmental impact evaluation and the need to evaluate environmental consequences of a growing list of hazardous contaminants have resulted in technical requirements for predictive modeling far exceeding the existing state-of-the-art. In the case of mathematical water quality and ecological modeling, the existing state-of-the-art has left a major gap between the biologically complex models developed primarily by universities as part of the International Biological Program,[87,88] the relatively simple water quality models developed primarily by consulting engineers,[89] and the relatively reliable and moderately complex hydraulic and hydrologic simulation techniques.[90] The existing state-of-the-art on one hand requires field data far in excess of those that can be reasonably expected for practical field application and, on the other hand, is inadequate to provide reliable predictions for many required evaluations.

Physical modeling. In many cases, mathematical predictive techniques are limited by an understanding of and an ability to quantify rate process and interactions among chemical, biological, and other environmental variables. In these cases, physical modeling techniques may be required to provide the required prediction or the understanding and data necessary. Both hydraulic and ecological processes may be studied using physical models.

Physical hydraulic model studies are frequently required for extremely dynamic situations such as hydropower projects, locks and dams, etc., to assist in providing an understanding of circulation patterns, density-stratified flow, entrainment, and withdrawal zones. Because of the costs involved in constructing such models, the use of highly distorted scaling has been employed. This results in significant cost savings over undistorted physical models, but it poses problems in extrapolating results to field situations.

Certain hydrodynamic characteristics as well as energy exchanges at the water surface due to wind and meteorological effects are not adequately considered by present modeling techniques. Therefore, seasonal changes in model stratification required for long simulations and predictions of far-field conditions are not adequate. Improvements in these techniques and definitive field verifications are needed.

Laboratory ecological simulations in the past have been based primarily on kinetic principles involving the use of well-mixed reactors (chemostats). Since real residence times must be maintained in studying biological and chemical rates, hydraulic similitude in the usual sense is not possible. If similitude with respect to residence time and process rates is maintained, simulation results can be extrapolated to field situations by consideration of volume-to-volume and area-to-area scaling relationships. A major limitation to existing laboratory simulation techniques is the lack of demonstrated ability to independently, but simultaneously, control important physical environmental variables such as turbulent mixing, thermal stratification, and light penetration.

Recent and ongoing research efforts are directed at making major improvements in physical modeling techniques. However, these improvements need significant evaluation and field verification prior to routine application to field problems as is the case with mathematical modeling techniques.

Model application. A mathematical model whose formulation adequately embodies the mechanisms, interactions, and complexities of a water resources system under one condition does not necessarily embody all of the critical considerations necessary to simulate system behavior under different conditions. In most cases, modeling techniques in current use were developed and immediately applied to field situations where predictions of future conditions were required. In most of the applications, model verification was not possible.

In cases where so-called "verification" was attempted, it usually has consisted of calibrating or tuning the model to a portion of an existing data set, predicting the system behavior for the next few steps, and comparing predicted and observed results. This approach does not constitute a valid verification of a model's ability to provide reliable predictions of future changes in system behavior resulting from modifications in project design or operation, meteorological conditions, contaminant loadings, land-use changes, etc. Field evaluation and verification of modeling techniques in a truly predictive mode are essential for providing improved and reliable tools for field application.

Reservoir and riverine modeling. In general, the state-of-the-art of reservoir and riverine modeling is considerably advanced over that of watershed, terrestrial, wetland, and estuarine modeling in terms of field application to water quality and ecological problems. However, even in the case of reservoir modeling, significant improvements are needed to meet existing requirements.

Reservoir water quality and ecological models available for practical application are one dimensional. Conceptually promising two-dimensional hydrodynamic models have recently been developed.[90] Field verification of the hydrodynamics of these models and incorporation of quality subroutines are considered to be high-priority research needs. Reliable two-dimensional quality models are essential for evaluating many types of reservoir projects, predicting the unconservative behavior of contaminants and waterborne pathogens as they move through a reservoir or waterway, and evaluating effects of watershed and floodplain land uses.

Other specific research needs for reservoir and stream models include the following:

- The capability to simulate anaerobic conditions and related phenomena including dissolved oxygen deficits, nutrient and contaminant regeneration, and the production of noxious gases.
- Improved techniques for simulating the accumulation and melt of ice and snow on water surfaces.
- Field verification of wind-mixing algorithms.
- Improved techniques determining suspended solids routing and sedimentation.
- Techniques for evaluating the fate and consequences of contaminants such as heavy metals and pesticides.
- Improved techniques for predicting and describing reservoir inflow under stratified conditions.
- Techniques for simulating dynamic project operations such as power peaking, pumpback storage, and selective withdrawal during flood-control operations.
- Techniques for considering the effects of emergent and attached aquatic plants on water quality and biological productivity.
- Improved techniques for simulating stream biology.
- Development of a basic understanding of and techniques for predicting the survival and reproduction of waterborne pathogens.
- Improvements in techniques for simulating the aquatic food chain necessary for reliable predictions of impacts on stream and reservoir fisheries.

Other approaches

In addition to simulation modeling techniques, holistic and statistical approaches for making environmental predictions are being applied to Corps field problems. Some of these techniques, such as the nutrient loading-lake response method developed for evaluating the eutrophication potential of natural lakes,[91,92] as presently formulated and applied are not applicable to reservoirs. These and other techniques, such as regression equations for predicting reservoir fisheries,[93,94] are potentially useful for certain types of environmental predictions. In almost all cases, modification for application to Corps activities and field evaluations are required.

Examples of research requirements

Generalized examples of research requirements for development of reliable modeling techniques include:

- Improved understanding of and ability to quantify and simulate important quality/quantity processes involved in watershed storm runoff.
- Techniques for evaluating effects of changes in flood frequencies and durations on floodplain ecology.
- Techniques for predicting the effects of changes in salinity distributions on estuarine ecology caused by inland water resources regulations and coastal construction activities.

Reservoir Operations

The relationship of various reservoir operation alternatives to environmental quality objectives as they relate to pool elevations and release requirements has been determined to a limited extent. The impact of fluctuating pool elevations on littoral zones and benthic communities must be established to develop regulation procedures that minimize this impact and subsequent impacts on reservoir productivity. Methods should be developed to reduce the aesthetic impact of fluctuating pool elevations and improve recreational and wildlife management strategies affected by pool elevation changes. A possible technique is the establishment of vegetation along the shoreline that is resistent to inundation. Data and guidance is required on the effect of various frequencies and durations of inundation on selected vegetation that would enable field offices to establish proper vegetative cover. This technique would also serve to reduce bank erosion caused by pool elevation fluctuations. Data are required on the environmental impacts of various reservoir-filling schedules to select an adequate schedule that will produce a minimum adverse impact. Alternative filling schedules should be weighed against various clearing and construction methods to develop guidance on the most economic means to achieve reservoir filling while meeting project purposes and environmental quality objectives.

Research is required to develop guidance on minimum release requirements from reservoirs. Primary emphasis should be placed on meeting project purposes while fulfilling downstream environmental quality objectives and demands. A generalized procedure should be developed that may be applied to specific reservoir sites. Variables include velocity and depth of flow, seasonal requirements, desirable downstream ecology (including fishery resources), streambed characteristics, and other parameters deemed important. Initial guidance can probably be provided through a comprehensive literature survey but will have to be supplemented by long-term field studies. For those projects in the planning stages, this guidance will complement existing methods to determine storage allocations and outlet works design. For operational projects, the guidance will serve to resolve conflicts between project purposes and demands for releases to meet a variety of downstream objectives (i.e., recreation, fisheries).

Another consideration comparable to minimum release requirements is effects of flow variations on the downstream environment, particularly in the case of hydropower projects and, in some cases, for flood-control projects. Data are required to permit the operation of these projects in a manner that minimizes adverse environmental impacts from fluctuating release flows. In the case of operational projects that have limited storage or structural flexibility to regulate flow variations, guidance for alternative operations or project modification may be required.

Data Collection, Management, and Interpretation

Sample collection, field and laboratory analyses, and data quality control and management are areas in which guidelines must be developed that ensure the acquisition of adequate and reliable water quality and environmental data. These data are basic requirements for environmental impact assessments, project planning, and postconstruction monitoring. Guidelines related to data collection should reduce problems associated with design of sampling programs, selection of reliable analytical facilities, and development of data management systems to meet these requirements. A majority of these needs can be provided by application of existing technology to specific Corps activities.

Examples of guidelines include uniform methodologies for establishing objectives, sampling design (sample number, frequency, and location), statistical treatment, proper sampling equipment, field and laboratory analysis procedures, and sample preservation and transportation techniques. Implementation of these guidelines could then be accomplished by developing training courses for principal investigators, analytical coordinators, and field sampling technicians. Analytical quality-control methodologies are presently available through the EPA, the U. S. Geological Survey, and other Federal agencies; however, these methodologies would have to be modified somewhat for Corps use. Guidelines of a chemical-analytical nature should include manuals for field and laboratory analyses, quality-control procedures delineating statistical and analytical techniques necessary to ensure data precision and accuracy, and standards of technical performance.

Concurrently, with the establishment of guidelines, standard contracting policies should be developed to ensure conformity. This is particularly important in view of the fact that the major percentage of laboratory analyses for the Corps are performed under contract with commercial testing companies and universities or by agreement with Federal and State laboratories. Such policies would allow the judicious selection of competent regional laboratories with the appropriate equipment, instrumentation, and personnel necessary to meet requirements for water quality information, EIS preparation, and model input and verification data.

To maximize the utility of project data, a management system should be developed that would permit retrieval, analysis, and display of data as needed in connection with project activities. Standardized formatting and storage procedures would increase the availability of the data and reduce redundancy in collection programs.

The data collection and management procedures described herein are within the state-of-the-art and, as such, do not require substantial research. However, a major thrust in the areas of interagency coordination, management, and technology transfer is needed.

Environmental Assessment

The Corps is responsible for determining the environmental impact of all its proposed Civil Works activities and for evaluation of alternate project plans based on their effect on environmental quality. Research is required to identify environmental quality objectives, to determine data requirements for their assessment, to develop procedures for evaluating alternative plans based on their environmental impacts, and to standardize impact assessment procedures.

Identification of environmental quality objectives

Environmental quality objectives may be addressed during the planning phase by an environmental assessment or environmental impact statement. Since it is impossible to collect all data or to address all alternatives, guidance is required to identify the data that are required to determine the potential for adverse environmental impact during the planning of water resource projects. A comprehensive assessment procedure is required by field offices to adequately address the environmental aspects of various project types. Examples of information currently required in these activities include the historical/archaeological value of a site; the environmental impacts of bank erosion, incremental reservoir filling, and navigational project effects on groundwater; values of coastal, estuarine, and riverine habitats; alternative ecosystem stability and diversity indices and their relationship to projects; and climatic changes resulting from projects that yield water bodies having large surface areas.

Data requirements

One approach toward identifying data requirements is postproject monitoring to determine the environmental impacts of various project categories. This needs to be coordinated with preproject studies to allow development of a method that can be used during the planning process. In this manner those data that are required, sampling programs, and evaluation techniques may be determined in the planning process to address potential environmental impacts. The relationship between projects and among project categories must also be investigated to identify commonalities that can be advantageously employed during the planning process.

Evaluation of alternatives

If the data requirements can be fulfilled, the next logical step would be the development of methodologies to predict adverse environmental impacts of Civil Works projects. These predictive methodologies are required to address environmental quality objectives during resource planning and to make a complete evaluation of all alternatives. Post-project surveys (field studies) would serve as primary tools in developing and verifying these predictive techniques.

In any resource planning approach, the economic benefits (with and without the project) must be identified and compared to project costs. This becomes important in relationship to environmental quality objectives because the economic objectives and environmental quality objectives must be compared and the benefits of achieving environmental quality objectives must be determined. Decisionmaking procedures are needed to compare environmental quality and national economic plans. In many cases the environmental benefits of various Civil Works projects are not known, nor is a procedure available to evaluate these benefits in relationship to other project purposes. A prime example of this is the effect of various waterways construction procedures (e.g., dikes, revetments, training structures, etc.) on habitats. Research directed toward quantifying environmental quality benefits would facilitate alternative evaluation and promote a general understanding of Civil Works projects and their interrelation with the environment.

Standardized assessment procedures

A fundamental requirement of the assessment process is a standardized procedure. Currently, no applicable standardized procedures exist that apply to performing environmental assessments. The development of such procedures is critical if uniformity in the planning process and resolution of alternative plans are to be achieved within the Civil Works program.

Several purposes can be served by a standardized assessment methodology. A methodology could ensure that all factors that should be considered in alternative selection are included in the analysis. It would aid in identification of data needs and would assist in determination of priorities for allocating resources for data collection. Most importantly, a methodology would provide a framework for the evaluation of alternatives on a common basis and could assist in developing mitigation measures. Important components of the methodology should be prediction of anticipated changes in an environmental variable, determination of scale or magnitude of a specific change, and application of weight or importance of any change.

Water Resources Management

Research requirements in the area of water resources management include the development of improved methods for multi-project operation, basin water resources planning, and the balancing of project purposes with environmental quality objectives on a regional basis. These methods will contribute substantially to improving the compatibility of water resources projects with environmental quality objectives both from an operational standpoint and during planning phases for future projects.

Guidance on multi-project operations requires the development of procedures that account for simultaneous project operation on a regional (or basinwide) basis. Procedures to evaluate the effect of operation of a project on subsequent (downstream) project purposes and means to balance a variety of project purposes on a regional basis should be developed. These techniques should examine the effects on individual project purposes, regional and/or project-specific environmental quality objectives, and methods for quantifying the relationship between costs and environmental quality objectives. The procedures should be implemented in a fashion to allow adaptation to daily operational needs, long-term requirements or assessments, and planning studies.

Many Corps activities involve the complete water resource development of a river basin. During the planning process, information is needed on the cumulative environmental effects of all projects within the basin. Without such information, the impacts of proposed projects may not be adequately addressed and the evaluation of alternative plans is difficult. Additionally, cumulative impacts become critical in regulatory functions where many permits are issued for a particular region or area. Research and development to address cumulative impacts will allow District and Division offices to plan resources development activities while minimizing adverse environmental impacts on a region.

Information on the value, from both a quantitiative and qualitative sense, of meeting environmental quality objectives should be developed for the spectrum of Civil Works activities. In this manner, environmental quality objectives may be placed in perspective with other project purposes and the merits of balancing these objectives with project purposes can be determined on a regional as well as project-specific basis. This information, when coupled to procedures for describing the quantity and quality of the water resource on a regional basis, will permit improved project planning and operation.

Riverine Environmental Impacts

Many of the activities of the Corps that take place in the riverine environment involve construction for flood control and/or navigation or regulatory activities related to contiguous wetlands. The environmental impacts of these activities are poorly defined and extensive field investigations will be required to provide guidance relative to such activities in the riverine environment. High priority research needs involve the evaluation of the impact of navigation structures, effects of navigation traffic on riverine ecosystems, and the environmental impacts of alternate waterways structures for flood control or navigation. These research needs will serve to establish a relationship between waterways activities and environmental quality objectives.

The effects of dikes and revetments on riverine habitats and consequent effects on fisheries should be examined. Studies should include consideration of benthic communities, effects of these structures on fish spawning and nursery areas, and localized effects on water quality. The end products would be improved design guidelines for the construction of these structures to minimize their environmental impact. Information on backwater areas required includes exchanges between backwater areas and the main stem river, productivity, wildlife usage, and the effect of flooding cycles. The environmental impacts of navigation traffic need to be quantified, primarily the effects on sediments and their resuspension. Key factors involved include impacts on productivity, backwater areas, aquatic organisms, and water quality. The environmental impacts of locks and dams and their operation should be quantified. This information would be useful during planning for increased navigation capacity as well as for operation of existing structures. The impacts of these navigation structures on riverine ecosystems and water quality should be evaluated prior to establishing planning or operational guidance compatible with environmental quality objectives.

The quantity and quality of information available on the riverine environment as it is affected by Corps activities is minimal. This is in direct contrast to environmental quality problems involving reservoirs, where some effects have been well documented and quantified. By necessity, this means that the research requirements for waterways are more fundamental and will involve an extensive data collection effort. Additionally, this means that generality in the approach to waterways environmental quality problems must be sacrificed to some degree to address high priority problems.

Summary

The research requirements discussed in this chapter represent high priority needs of the Corps from the survey of District and Division problems. The research requirements are in direct response to the environmental quality problems presented and represent a departure from the current state of knowledge concerning these problems. A complete research program to address all of these needs would be monumental in scope and is not advisable at the current time since many of the interrelationships between problems are not adequately defined. Furthermore, environmental quality problems are subject to significant change dependent on the assigned missions of the Corps, policy, and legal requirements. The research program outlined earlier in this report narrows the scope of the needs presented in this chapter to address the primary environmental quality problems faced by the Corps. The end products of this program will be improved planning, design, construction, and operational procedures (diagnostic methods and corrective actions) to address environmental quality objectives in a manner compatible with project purposes.

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