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ENVIRONMENTAL & WATER QUALITY OPERATIONAL STUDIES

US Army Corps of Engineers

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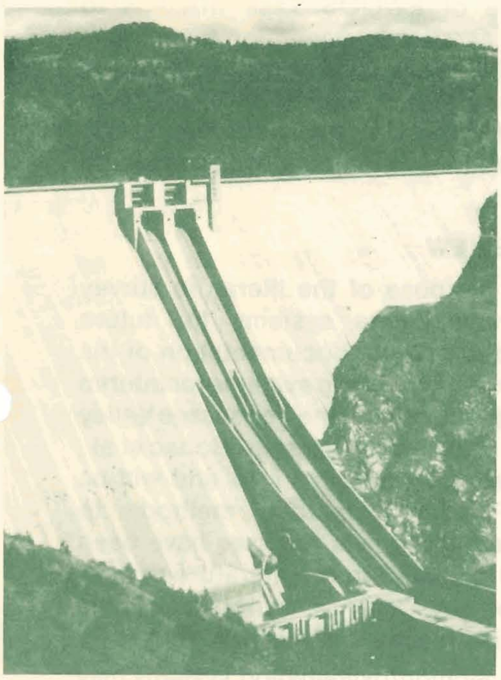

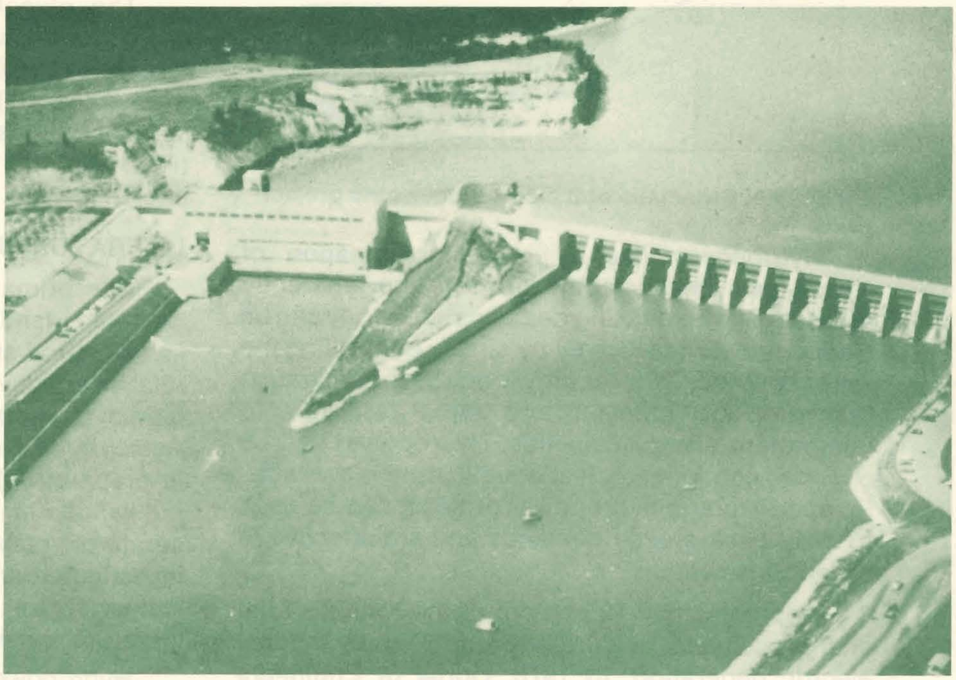

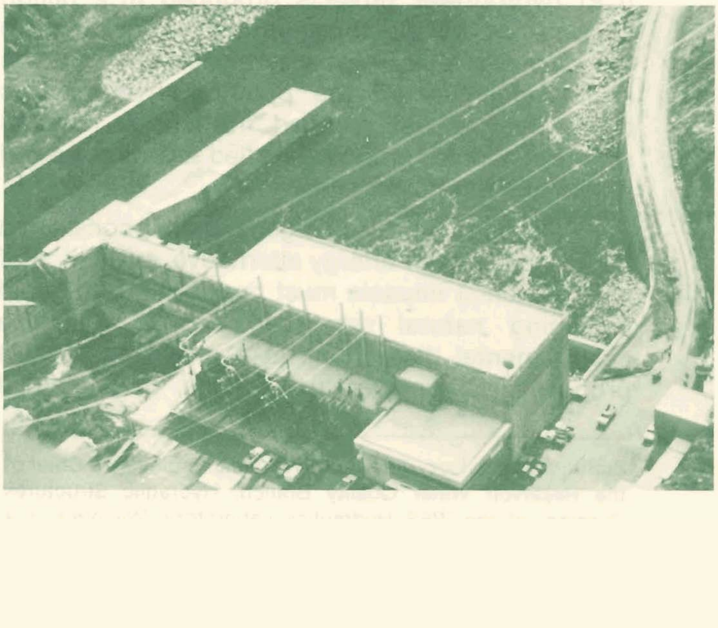

There are several thousand sites in the U.S. with the potential for hydroelectric generation. Care must be taken to develop this energy with minimal damage to natural resources or disruption of the downstream environment. As part of the Environmental and Water Quality Operational Studies (EWQOS), aeration/oxygenation techniques are being developed to avoid releasing water from hydroelectric projects that is low in dissolved oxygen. The results of a search of the literature on reaeration of reservoir releases are described in the following article.

REAERATION OF HYDROPOWER RELEASES

D. R. Smith and S. C. Wilhelms*

One of the Nation's most promising alternatives to using fossil fuels is to supply energy by hydroelectric generation. In hydroelectric projects (Figure 1), water is stored behind a dam, subsequently released through a penstock that directs water through a turbine generator, and then discharged downstream.

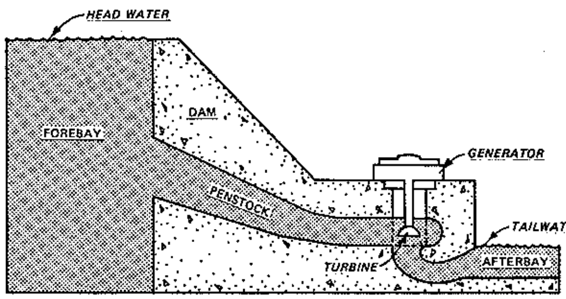

Figure 1. Schematic of typical hydroelectric project

Hydropower has a unique combination of advantages. Hydroelectric projects are inherently compatible with peaking demands since they can be stopped or started rapidly by simply controlling the water flow rate. Other energy forms have constraints that preclude efficient and rapid response to intermittent energy demands. Hydropower can be operated continuously if adequate water is available. Pumped-storage hydropower projects can be used to meet peak energy demands and are effective in water conservation.

Approximately 12 percent of the Nation's total energy demand is currently supplied by hydroelectric generation. In 1978, Corps of Engineers (CE) hydropower projects produced 87.2 billion kilowatt-hours of electric energy — the equivalent to the output of 20 average-size nuclear plants. Even so, development of the potential hydroelectric capability has not reached fruition. A national survey conducted in 1980 identified several thousand potential hydropower sites.

Although hydroelectric generation is considered the cleanest major energy alternative, evaluation of environmental impacts must be thorough to avoid damaging natural resources and to minimize environmental disruptions at a proposed site. At proposed hydropower installations, the potential adverse effect most frequently cited is the release of water with low dissolved oxygen (DO) concentrations. This may occur because efficient hydropower design often necessitates relatively deep intakes and naturally occurring reservoir processes tend to reduce the DO at the lower elevations of the lake. Depending upon the magnitude and duration of the DO deficiency, it may be necessary to employ aeration or oxygenation techniques to increase the release DO.

APPROACH

The objective of EWQOS Task IIA.3 is to develop effective aeration/oxygenation techniques to correct the DO deficiency problem. A literature review (FY 81), system design (FY 82-83), field demonstrations (FY 83-84), and numerical modeling (FY 83-84) are the basic elements of the research effort.

LITERATURE REVIEW

The primary purpose of the literature survey was to identify candidate systems for future investigation and to provide documentation of the relative effectiveness of existing systems for interim guidance. In cooperation with the Tennessee Valley Authority (TVA), the literature search (Bohac et al., in preparation) was initiated in FY 81 and will be published in FY 82. Numerous methods to aerate/oxygenate hydropower releases have been investigated and are cited in the literature review. However, for brevity, only a synopsis of the literature review is presented in this article.

Hydropower aeration/oxygenation systems may be grouped into three general areas: forebay, in-structure, and tailwater systems. Several techniques have been employed in each area:

- Forebay aeration/oxygenation
  - Oxygen injection in the hypolimnion (or in the withdrawal zone)
  - Pneumatic or hydraulic destratification of the reservoir
- In-structure aeration/oxygenation
  - Penstock injection
  - Turbine injection/aspiration
  - Draft tube injection/aspiration
- Tailwater aeration/oxygenation
  - Side stream pumping
  - Mechanical aeration/oxygenation
  - U-tube aerator
  - Reaeration structures

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Forebay systems are designed to enhance the DO concentration of the intake water. Since the water quality usually does not degrade during travel through the hydropower plant, the release water quality is improved. The major disadvantage of air/oxygen injection in the hypolimnion is that the volume of the hypolimnion is relatively large compared to the volume released during generation. This may necessitate a rather large aeration/oxygenation system. However, the oxygen-injection approach has the added advantage of enhancing the water quality of the reservoir and does not decrease the efficiency of the turbines.

Pneumatic or hydraulic destratification increases DO in the lower levels of the lake but has the disadvantage of mixing the entire reservoir and results in the loss of cold water for release, which may not be desirable. Destratification and forebay aeration/oxygenation are being addressed in EWQOS Tasks IIIB.1 and IIIB.4. The results of the initial investigation of these systems were reported in the EWQOS Information Exchange Bulletin Volumes E-80-2, April 1980, and E-81-1, February 1981.

In-structure aeration/oxygenation focused on turbine venting during the 1970's, although compressed air (or oxygen) injection was attempted. In venting systems, air (or oxygen) is aspirated into low-pressure regions that occur in the draft tube of many turbines. Part of the aspirated air (or oxygen) is absorbed as the gas is mixed with the discharge and as it travels down the tube. The fraction absorbed depends upon the initial DO, mass flow rate of air and water, venting geometry, transit time, turbulence level, and the pressure and temperature history during transit through the structure.

Aspiration through existing venting or vacuum-breaker systems normally results in a relatively low DO enhancement. Most vacuum-breaker systems (Figure 2) were designed to allow only enough air into the turbine to prevent cavitation and reduce turbine vibration. Various constrictions often exist that limit air flow. Additionally, the existing ports for air (or oxygen) discharge into the turbine or draft tube may not be strategically located to distribute the air (or oxygen) within the flow. As a result, with the vacuum-breaker system locked open, venting with air usually results in DO increases of less than 2 mg/*l*.

Various modifications to existing venting systems have increased the air flow rate and enhanced gas transfer. In one instance, the air supply line was rerouted to bypass the vacuum-breaker valve. Deflector plates have also been used to increase the vacuum at points on or below the turbine wheel. The deflector plates, usually installed

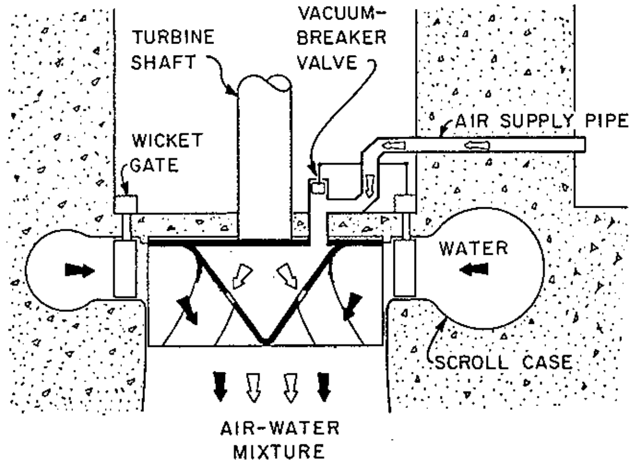


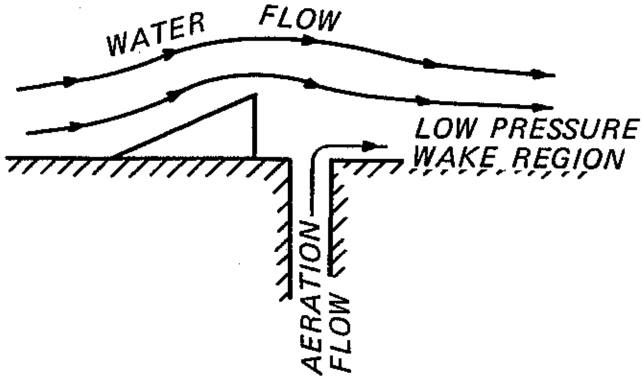
Figure 2. Schematic of a vacuum-breaker system

over existing air ports on the turbine, result in increased aspiration due to the lower pressure in their wake. A typical deflector design and deflector locations are indicated in Figure 3; however, a variety of geometries have been used. In some instances these combined modifications have resulted in DO increases between 3.5 to 4.5 mg/*l*, but in other cases only small increases were observed.

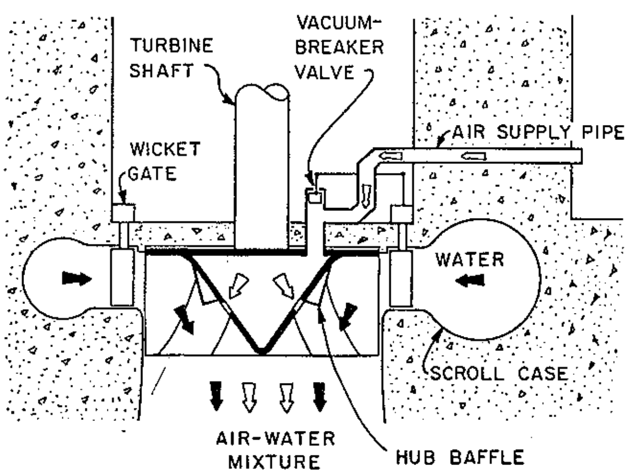
A manifold ring, Figure 4, attached to the periphery of the draft tube liner, has been used to create or enhance negative pressures in the draft tube. Vent holes in the ring are uniformly spaced and are sized appropriately to aspirate air or oxygen uniformly around the ring. DO increases as large as 3.5 mg/*l* have been reported.

Turbine venting has some disadvantages. Turbine efficiency and capacity is usually reduced slightly and dissolved nitrogen concentrations may increase. Turbine efficiency is reduced as a result of both the air flow and by the drag produced by hub or ring baffles. The magnitude of the losses depends upon the baffle geometry, air and water flow rate, and several other variables.

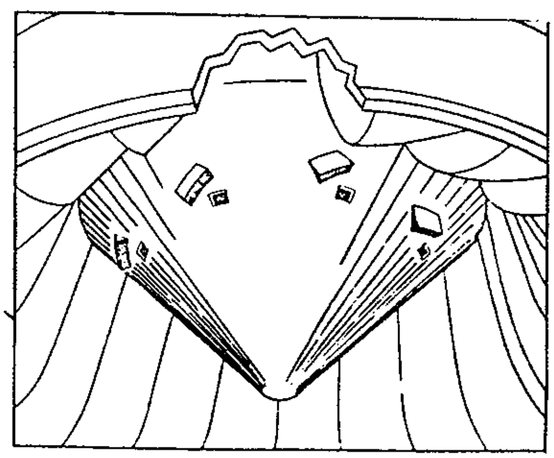
For the oversized hub baffles with no air admission at Norris Lake, Tennessee, energy losses were reported to be a little more than 2 percent over the usual operating range and capacity losses of about 3.5 percent at maximum turbine output. With air flow rates of 3 percent of water flow, energy losses increased about 1 additional percent, and full-gate capacity losses increased an additional 2 percent. Also at Norris, aeration with a temporary ring baffle resulted in a 2- to 4-percent loss in generating efficiency and capacity. These losses are essentially a head loss; consequently, the percent loss associated with these processes tends to decrease with increasing head.



a. Deflector plate design



b. Location of hub baffles



c. Distribution of baffles on hub

Figure 3. Sketch of deflector design and location

Turbine venting tests with the vacuum-breaker valve blocked open at J. Percy Priest Reservoir, Tennessee, and Allatoona Reservoir, Georgia, resulted in releases with nitrogen saturation of 112 and 117 percent relative to the respective surface conditions. Nitrogen uptakes with bypass lines or

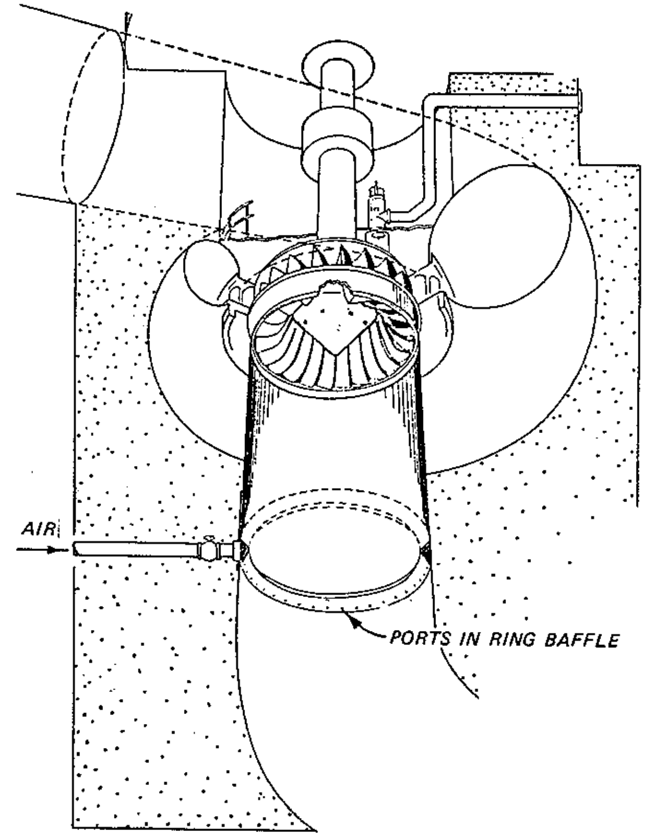


Figure 4. Schematic of ring baffles installed in draft tube

baffle designs have not been reported. However, the results obtained at J. Percy Priest Reservoir and Lake Allatoona with relatively low air flow rates suggest the potential for increasing the nitrogen concentration if the ratio of air to water flow is significantly elevated.

Historically, compressed air injection into flow regions at (or above) atmospheric pressure has not received significant attention and an adequate data base does not appear available for quantitative evaluation of its effectiveness. The technique has been investigated predominantly for hydraulic conditions that do not permit an aspirating type of turbine venting. If efficient forced air injection systems with small holes or jets distributed around the draft tube could be developed, they would eliminate the losses produced by the presence of baffles. Preliminary results from European investigation and analysis by TVA indicate that only small inexpensive blowers would be required. Additionally, it has been speculated that forced air injection would be equally effective at either high- or low-head dams. TVA has planned tests at Norris Dam in FY 82.

Tailwater systems in general have received little attention over the last decade in comparison to forebay and in-structure systems, although various tailwater aeration/oxygenation systems have been investigated both in Europe and the United States. The efficiency, operating cost, and capital investment vary considerably depending both on the project and respective techniques.

A comprehensive review of tailwater systems is beyond the scope of this synopsis because of the diversity of the systems. For details, the reader is referred to reviews by King (1970), Knapp (1975), and Volkart (1979). However, it should be noted that tailwater aeration/oxygenation techniques are often incompatible with hydropower design and/or operation of typical CE or TVA impoundments.

SUMMARY

No single hydropower reaeration system is universally perferred. In general, for CE impoundments, either forebay or in-structure aeration/oxygenation systems would be superior to tailwater aeration/oxygenation. However, the particular technique to be employed must be evaluated on a site specific basis.

Recent hydropower reaeration studies have focused on turbine venting. The effectiveness and the problems encountered with various venting designs have been documented. Generally, blocking the vacuum-breaker system open will result in DO increases of up to 2 mg/*l*. Bypassing the vacuum-breaker valve may result in DO increases between 2.5 and 3 mg/*l*. Baffle designs can result in DO uptakes on the order or 4 mg/*l*. Potential problems are increased nitrogen concentration, a decrease in turbine efficiency and capacity, and head loss and cavitation caused by the deflectors during non-venting periods. Several engineering solutions have been proposed to mitigate or eliminate the reduced efficiency and cavitation problems. The nitrogen supersaturation problem can be resolved only after additional data are obtained for quantification.

FUTURE WORK

The literature review will be published to provide documentation of existing systems for interim guidance. Predicated upon published data and coordinated with TVA, candidate systems for future investigation and development will be identified. After any necessary redesign, these candidate systems will be evaluated under prototype conditions. Design procedures will be developed for the most promising systems, detailing the effect on efficiency and nitrogen saturation. Subsequently, numerical models will be developed to predict the release water quality based upon the performance of the system and intake water quality.

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Knapp, G. L. (editor). 1975. "Aeration of Natural Waters," Office of Water Resources Research, U.S. Department of the Interior, Washington, D.C.

Volkart, P. 1979. "Stream Aeration Methods of Oxygen Application of Water Turbines," Research Institute for Water Engineering, Hydrology and Glaciology, Swiss Technical University in Zurich, Switzerland.

ENVIRONMENTAL ENGINEER MANUAL SERIES PLAN

F. Douglas Shields, Jr. and Raymond L. Montgomery*

Over the last decade, increasing awareness of the importance of environmental quality has resulted in major federal legislation. The mandates of these laws have been amplified by Corps of Engineers (CE) policies and regulations. New information needed to incorporate environmental considerations into the planning, design, construction, maintenance, and operation of water resources projects is being produced by programs of research at CE laboratories.

Effective use of the results of this research is dependent on timely transfer of technology from research and development (R&D) personnel to field office engineers and scientists. Application of the results of environmental research programs to management and development of resources will eventually lead to improved environmental quality.

TECHNOLOGY TRANSFER

What is the most effective method of technology transfer? Corps R&D personnel currently use several methods to transfer technology to the field:

- Engineer manuals (EMs)
- Engineer circulars, engineer technical letters, and engineer pamphlets

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- Limited consulting services and one-stop R&D assistance
- Technical reports and other technical publications such as journal articles
- Workshops and training courses

Each method has its strengths and limitations, depending largely on the audience involved. Although all of the methods are being used to provide technical guidance in environmental matters, in the future major emphasis will be placed on reviewing and indexing results of ongoing research programs in a special series of EMs.

Engineer Manuals. Research programs and their documentation tend to be organized subject to investigational or resource constraints, and thus the information needed by a particular user may be scattered through a number of technical reports, journal articles, and other documents. EMs are attractive because they gather and index the existing body of information, both that which is long established and that derived from recent research, in a form convenient to the Corps user.

With the increase in output from environmental R&D efforts, there is a need to ensure that research results are translated into action items for the Corps field offices. This is particularly true in the environmental and water quality areas where little technical guidance in the form of Corps publications is available for field use. In other disciplines (e.g., soils and hydraulic design), EMs are already available that provide a logical place to publish R&D output. Accordingly, the environmental and water quality R&D programs, and specifically EWQOS, are being oriented toward producing chapters or sections for existing EMs and entire manuals for a newly established Environmental Engineer Manual (EEM) series. The purpose of the new series is to provide environmental engineering procedures necessary for Corps projects.

EMs normally synthesize tried-and-true information and establish standard procedures without the lengthy derivations, documentation of experimental methods, and justification of conclusions found in technical reports. Newly hired personnel may use EMs for training and familiarization while managers may consult EMs for standard policies and procedures, sources of additional information, checklists of required considerations, and recommended studies for a particular type of project. Establishment of the EEM series points to the growing expertise of the Corps for meeting environmental quality objectives as part of its Civil Works missions.

Environmental Engineering Manuals. The Waterways Experiment Station (WES) has been assigned overall coordination responsibility for developing the EEM series. Table 1 lists the schedule for EEM production. The EEMs will complement the hydraulic EMs having similar titles by providing the environmental considerations required for project planning and design. The list will be modified if events warrant. The EEM series will incorporate appropriate research results, state-of-the-art information, and field office experience.

TABLE 1. SCHEDULE FOR ENVIRONMENTAL ENGINEERING MANUAL SERIES

EEM Title	Estimated Draft Completion Date
*Reservoir Water Quality Analysis	Jan 1983
Environmental Engineering for Deep-Draft Navigation Projects	Sep 1983
*Environmental Engineering for Shallow-Draft Waterways	Jan 1984
*Environmental Engineering for Flood-Control Channels	Sep 1984
Environmental Engineering for Coastal Shore-Protection Projects	FY 1985
Environmental Engineering for Coastal Flood-Control Projects	FY 1985
Environmental Engineering for Small Boat Basins	FY 1986

*Manuals to be produced under the EWQOS Program.

Environmental sciences are young and rapidly expanding fields of knowledge, and major advances in many topics addressed by the EEMs are expected to occur after initial publication of the manuals. Accordingly, the EEMs will be expanded and revised at fairly frequent intervals. In some cases, the original documents will contain gaps to be filled as ongoing research efforts are completed. Despite the information gaps that exist, the EEM series will be produced in a timely fashion because of the priority needs of CE field office personnel for easy-to-use environmental technology.

The EEMs will not be cookbooks that answer all environmental questions for every project. Instead they will identify major considerations that should be taken into account when conducting Corps activities relating to a specific project type. Recommended procedures for conducting environmental studies will be described in order to aid field office personnel in identifying potential environmental problems and studying alternative solutions.

Reservoir Water Quality. The Reservoir Water Quality EEM will be the first produced and will draw on findings of EWQOS Projects I-III and the reservoir field studies. Although the limnology of natural lakes has been documented for some time, there is no similar compilation available on the limnology of reservoirs.

This manual will be a valuable guide for CE personnel concerned with reservoir water quality. The general purpose will be to assist CE Division and District personnel in developing water quality objectives; in particular, it will be used by persons preparing environmental impact statements or environmental assessments, reservoir release studies, eutrophication analyses, general design memoranda, water control manuals, and the like.

The manual will introduce the basic physical, chemical, and biological characteristics of reservoirs that affect reservoir and release water quality and will review basic types of project designs and operational schemes. Reservoir water quality sampling and data analysis will be discussed in some detail with special attention given to formulation of sampling objectives and sampling program design. Appendices will deal with physical and mathematical modeling, site preparation, closure water quality, and other special topics.

Shallow-Draft Waterways. The Shallow-Draft Waterways EEM will address environmental aspects of planning, designing, constructing, operating, and maintaining shallow-draft waterway projects that include features such as locks and dams, cutoffs, streambank protection, dikes and other river training structures, ice retention structures, channel excavation, dredging, and disposal of dredged or fill material. Discussions of dredging and dredged material disposal will be brief since these topics are covered in detail by the EM 1110-2-5000 series and a new EM, presently in draft stage, entitled "Dredging and Dredged Material Disposal."

The shallow-draft manual will be based on the findings of EWQOS Project VI and waterways field studies and other CE research efforts such as wetlands and aquatic plant control. Typical morphological, physical, chemical, and biological characteristics of waterway systems will be reviewed, as will hydraulic design aspects. Adverse environmental impacts of waterway project features will be identified, and promising methods for reducing these impacts will be presented.

Current knowledge of the environmental aspects of waterway operation will be summarized including aquatic plant control, dredging, habitat development, and the effects of boat traffic on ecology and water quality. Considerations for conducting environmental studies on major waterways including special requirements for biological and water quality sampling will be discussed. Appendices will deal with modeling and other special topics.

Flood Control Channels. The Flood Control Channels EEM will address environmental aspects of modification of natural streams to increase flow-carrying capacity by channel excavation, clearing and snagging, channel paving, and building levees and floodwalls. This EEM will be largely based on information review performed under EWQOS Project VI. In the absence of extensive field work and laboratory experiments, a major source of information about methods for reducing adverse impacts of channel projects will come from the experiences of CE District offices. The EEM will provide a synthesis and condensation of the experiences of a large number of individuals working in diverse situations.

Typical channel projects will be described and the major characteristics of stream systems will be reviewed. Environmental impacts of various types of channel modification will be presented, and methods for reducing these impacts and design criteria for these methods will be described. Recreational, aesthetic, and fish and wildlife features appropriate to flood control channels will be discussed. Considerations for conducting environmental studies on streams too small for commercial navigation will be identified. Appendices will deal with special topics and case studies.

PRODUCTION OF EEMs

Each EEM will receive input and review from a number of contributors due to the multidisciplinary nature of the subjects covered. A coordinator has been assigned for each manual to ensure timely completion of the task and a smooth final draft. DAEN-CWE will have the overall management, approval, and publication responsibilities for the EEM series. To ensure all available information is incorporated into each manual, several coordination meetings among personnel from the various CE R&D organizations are being held and an environmental manual advisory group composed of representatives from the two participating Waterways Experiment Station laboratories, Environmental and Hydraulics, has been formed.

SUMMARY

The Corps has pursued national environmental quality objectives by initiating a program of research and development. Application of the results of this effort to CE activities depends on effective technology transfer to field office personnel. Several methods of transfer are available and will be used, including EMs. A special series of EEMs will be produced to concentrate and index the tremendous body of information on environmental aspects of CE water resources projects. These manuals will serve as training documents, road maps, and checklists for field office personnel. The establishment of the EEM series highlights the increasing role environmental quality considerations are playing in water resources development and management by the CE.

This bulletin is published in accordance with AR 310-2. It has been prepared and distributed as one of the information dissemination functions of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from EWQOS can be rapidly and widely disseminated to Corps District and Division offices as well as other Federal agencies, state agencies, universities, research institutes, corporations, and individuals. Contributions of any type are solicited from all sources and will be considered for publication as long as they are relevant to the objectives of EWQOS, i.e., to provide new or improved technology to solve selected environmental quality problems associated with Civil Works activities of the Corps of Engineers in a manner compatible with authorized project purposes. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Mahloch, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Mississippi 39180, or call AC 601, 634-3635.

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