EWQOS

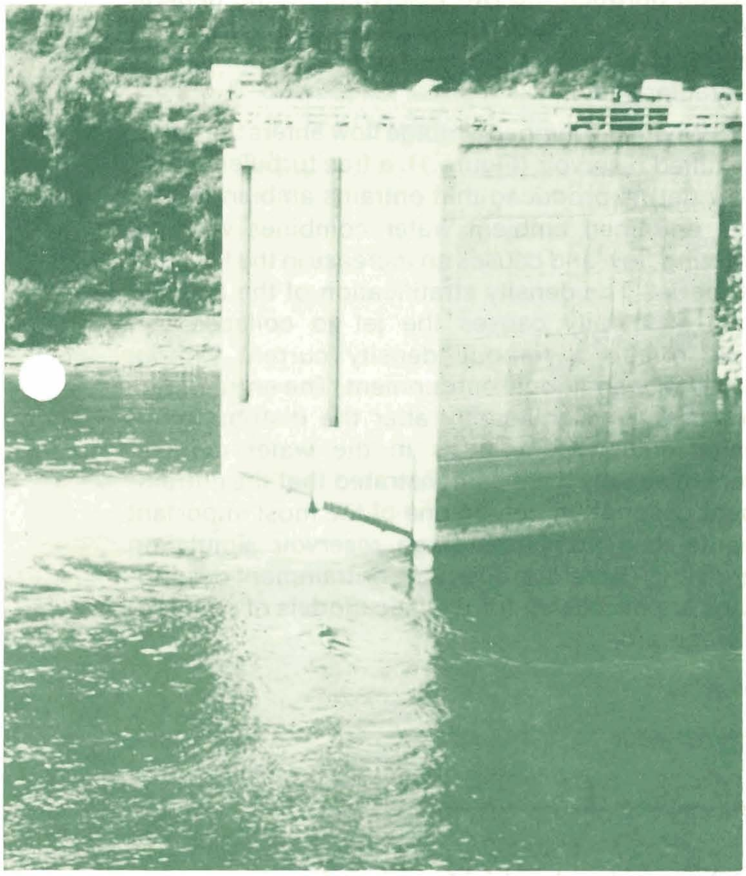
ENVIRONMENTAL & WATER QUALITY OPERATIONAL STUDIES

US Army Corps of Engineers

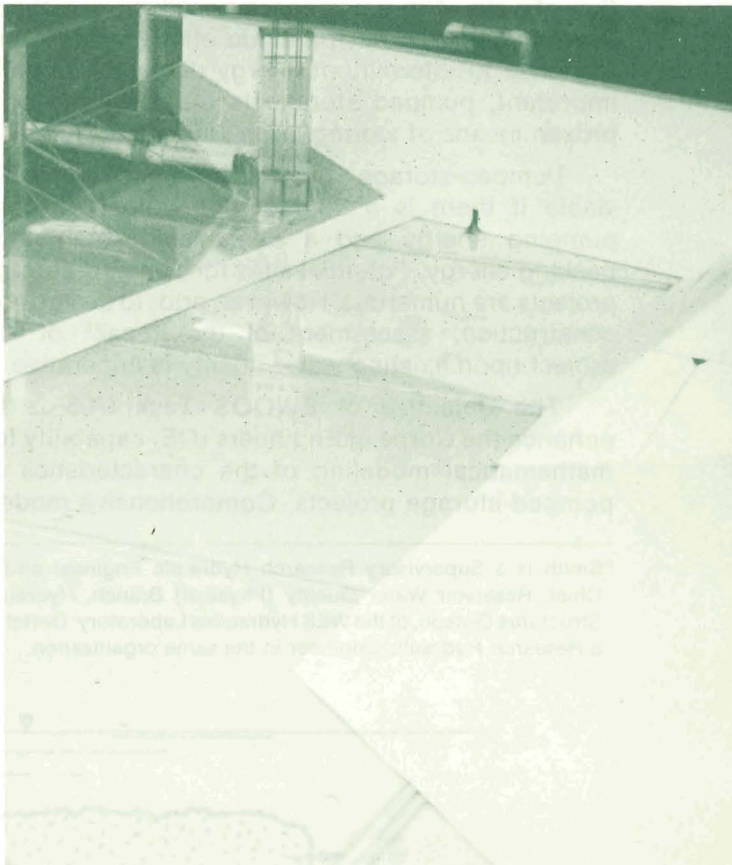
US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

INFORMATION EXCHANGE BULLETIN

VOL E-81-5 AUGUST 1981



ALLEGHENY RESERVOIR



PHYSICAL MODEL OF ALLEGHENY RESERVOIR

Pumped-storage hydropower projects store water in an upper reservoir to be released to generate electrical energy during peak-demand periods and then pump from a lower reservoir back into the upper reservoir during low-demand intervals. Such projects are complex dual reservoir/riverine systems that are difficult to model in order to predict the impact of the project on existing water quality. A hybrid technique that couples experimentally determined data from physical models with a numerical model has been used successfully at WES for several pumped-storage projects (such as Allegheny Reservoir upstream of Kinzua Dam shown above). A good description of the jet entrainment process and the density currents that occur during pumped-storage inflow is necessary for reliable modeling of pumped-storage projects. Actual and model pumped-storage inlet-outlet structures are shown above. General investigations are being conducted at WES to develop entrainment descriptions for generic types of CE pumped-storage inlet-outlet structures. The ongoing study is described in the following article.

PUMPED-STORAGE HYDROPOWER MODELING

*D. R. Smith and M. S. Dortch**

Pumped-storage hydropower is one of the Nation's more promising alternatives for supplying adequate energy during peak demand periods. Pumped-storage hydropower projects use reversible turbines during periods of low energy demand to pump water from a lower to a higher reservoir. Subsequently, water is released through the reversible turbines to generate electrical energy during intervals of peak energy demand.

Hydroelectric projects are inherently compatible with peaking demands since they can be stopped and started very rapidly by simply controlling the flow of water. Alternative energy-producing methods have constraints that preclude efficient and rapid response to intermittent energy demands. Equally important, pumped storage is presently the only proven means of storing large amounts of energy.

Pumped-storage projects are economically viable if there is a source of low-cost off-peak pumping energy and a demand for high-value peaking energy. Potential sites for pumped-storage projects are numerous. However, prior to design and construction, assessment of the impact of the project upon existing water quality is imperative.

The objective of EWQOS Task IA.5 is to enhance the Corps of Engineers (CE) capability for mathematical modeling of the characteristics of pumped-storage projects. Comprehensive modeling necessitates simulation of a complex coupled dual reservoir and/or riverine system. The in situ and released water quality from conventional reservoirs are dependent upon meteorology, hydrology, internal mixing processes, morphometry, reregulating structures, and operational methodology. The pumped-storage system is more complex. One of the reservoirs of a pumped-storage system is usually much larger than the other and normally goes through a thermal stratification cycle, whereas the smaller reservoir usually does not stratify vertically. Relatively large amounts of water are passed between the two reservoirs during generation and pumpback, thus causing mixing and redistribution of thermal and water quality characteristics.

When the pumped-storage flow enters the larger stratified reservoir (Figure 1), a free turbulent shear flow (jet) is produced that entrains ambient water. The entrained ambient water combines with the entering flow and causes an increase in the flow rate of the jet. The density stratification of the ambient pool eventually causes the jet to collapse and change into a tranquil density current without significant additional entrainment. The entrainment process can significantly alter the distribution of water quality parameters in the water column. Recent studies have demonstrated that the entrainment description can be one of the most important inputs to a pumped-storage reservoir simulation model.[1,2] Therefore, adequate entrainment descriptions are necessary for realistic models of pumped-storage projects.

*Smith is a Supervisory Research Hydraulic Engineer and is Chief, Reservoir Water Quality (Physical) Branch, Hydraulic Structures Divison, of the WES Hydraulics Laboratory; Dortch is a Research Hydraulic Engineer in the same organization.

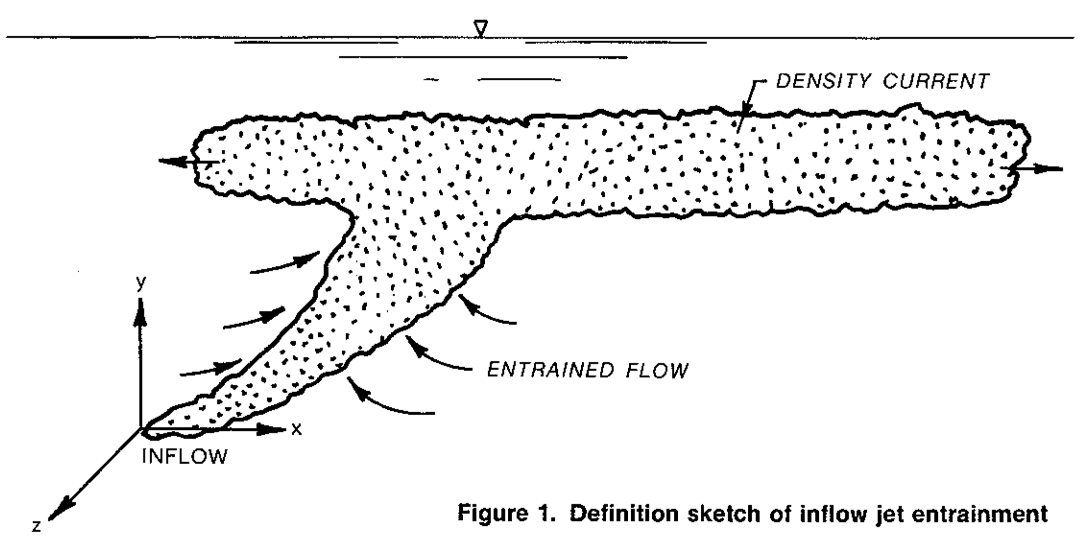


Figure 1. Definition sketch of inflow jet entrainment

RELATED STUDIES

A hybrid technique has been successfully used at the Waterways Experiment Station (WES) for a variety of proposed and existing projects: Richard B. Russell Reservoir,[2,3] Maryville Lake,[4,5] Dickey-Lincoln School Lakes,[6] and Allegheny Reservoir.[1] Basically, the approach involves using a one-dimensional reservoir simulation model that includes algorithms for the selective withdrawal and pumped-storage mixing processes. The algorithms were developed on a site-specific basis from observed flow characteristics that were produced in physical models.

Algorithms developed on a specific project basis yielded excellent results (Figure 2) for the project of interest but should not be expected to have universal applicability. Near-field mixing and withdrawal characteristics are three dimensional and are functionally dependent upon the inlet-outlet geometry, adjacent topography, generation and pumpback discharge rates, ambient stratification, and operating conditions. As a result, the characteristics may vary substantially between generic types of CE structures. Additionally, the flow pattern produced by either generation or pumpback may be different at a particular project for different operating schedules and conditions. For example, at low or nominal flow rates, interaction of the flow with the solid boundaries may have minimal effect. However, at larger flow rates boundary effects may alter the characteristics.

These limitations do not preclude development of improved and more generalized descriptions of both pumped-storage inflow mixing and selective withdrawal flows. Models can be developed, if geometric and hydrodynamic similarity is preserved. The results of the recent efforts on selective withdrawal were reported in Volume E-80-2, April 1980. A synopsis of an ongoing investigation of pumped-storage jets is presented in this article.

APPROACH AND RESULTS

A literature review, parametric laboratory study, field program, and numerical modeling are parts of an investigation designed to develop improved descriptions of the entrainment process and the resulting density current.

The purpose of the literature survey[7] was to identify mathematical descriptions of jet entrainment developed for other applications that might be applicable to pumped-storage projects. Jet inflow characteristics were classified into sixteen idealized flow types predicated upon source buoyancy, boundary proximity, geometry of the jet, and density stratification. The best candidate description for each idealized flow type was identified. Candidate descriptions exist for some of the flow types, whereas for others, potential descriptions can only be assumed. As a result, the reliability of some of the candidate descriptions is questionable. Others appear to have much more promise but will require further investigation and evaluation in laboratory, numerical, and/or hybrid studies.

A parametric laboratory study has been intitiated to investigate the applicability of several entrainment descriptions. Since physically modeling all possible source geometries is not realistic, they will be approximated by slot and/or round orifices and emphasis will be placed upon the flow regimes that are most prevalent in CE impoundments. The descriptions developed from the elementary geometries and the idealized flows will be incorporated into a numerical reservoir simulation model to assess their adequacy.

To complement the numerical study, a field study program was executed. Between May and December 1979, biweekly profiles of temperature, dissolved oxygen, pH, and conductivity were obtained at Carters Lake, Georgia. The duration of the study was sufficient to ensure that the data-

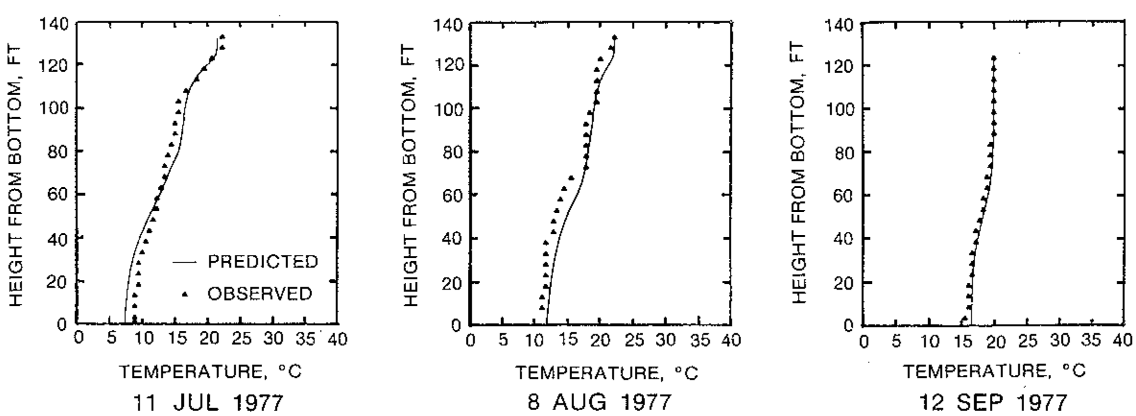


Figure 2. Comparison of predicted and observed temperature profiles at Allegheny Reservoir

collection program covered a wide range of reservoir and operating conditions. Profiles were obtained during periods when the pumped-storage hydropower capability was used both frequently and infrequently. Most of the stratification cycle from strong stratification (summer) through weak stratification (fall) was sampled.

The adequacy of the candidate algorithms is being investigated by incorporating them into the reservoir simulation model, which includes the entrainment process, and subsequently comparing the predicted profiles with the profiles obtained at Carters Reservoir. Preliminary results indicate that some of the descriptions will yield good agreement. As indicated in Figure 3, the predicted profiles have the correct trends and the predicted temperatures closely approximated the observed. Additionally, the general effects of pumped-storage operations were reproduced. For example, the thermocline tends to be deeper during pumpback and turnover occurs earlier with pumped-storage hydropower operations.

Realistic simulation of pumped-storage reservoirs cannot be accomplished without simulation of the entrainment process. To illustrate this conclusion, simulations were executed assuming no entrainment into the pumpback jet. As indicated in Figure 3, the temperature distributions predicted without entrainment were significantly different from the observed data or from the results predicted with entrainment.

The results indicate that improved and more generalized entrainment descriptions can be developed and used for impoundments that have structural or source geometries consistent with idealized descriptions. As descriptions for various

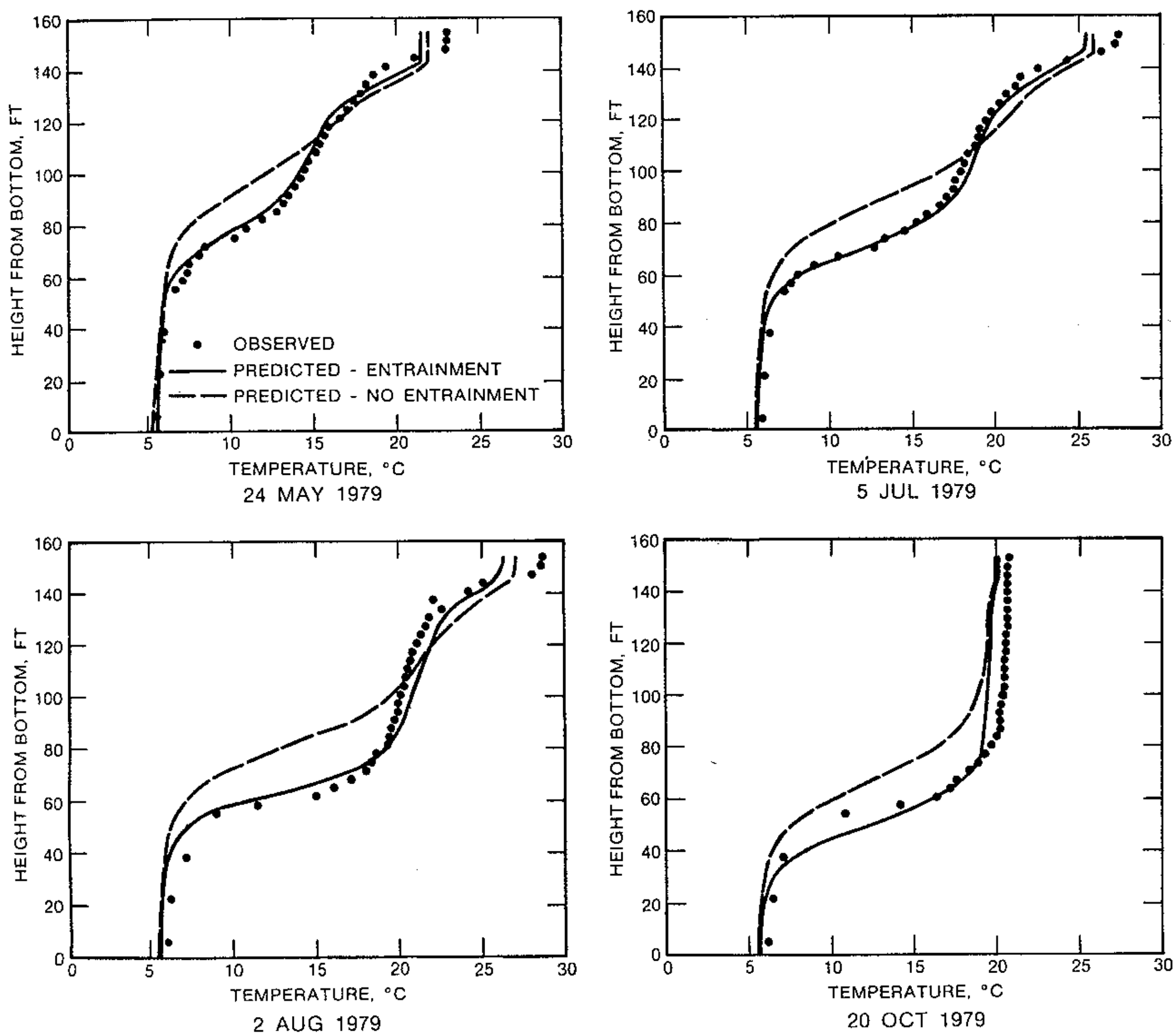


Figure 3. Comparison of observed temperature profiles with predicted temperature distributions (Carters Lake, Georgia)

geometries and flow regimes are developed, the algorithms will be made available for inclusion in reservoir simulation models.

Many CE impoundments will not be consistent with the idealized assumptions because they may have more complex source geometries, intermittent or continuous near-field topographical interaction with the inflow jet, or interaction with complex boundaries. In these cases, approximating complex reservoir and structural source geometries by rectangular or round orifices will not suffice. As a result, large errors could occur if idealized conditions are assumed. In such instances, the hybrid (physical-numerical models) approach discussed earlier is recommended to select and/or calibrate the most appropriate entrainment descriptions and if necessary to develop alternate descriptions. In either case, the generalized research will result in more expedient convergence to the appropriate description.

The results of these studies will be applicable for planning studies, evaluation of structural and operational modifications at existing reserovirs, effective operation of existing reservoirs, and design and operation of future CE water resource projects.

REFERENCES

1. Dortch, M.S. 1981 (draft). "Investigation of Release Temperatures for Kinzua Dam, Allegheny River, PA," Technical Report, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
2. Smith, D. R., et al. 1981 (draft). "Evaluation of In-Reservoir Cofferdam on Richard B. Russell Reservoir and Hydropower Release," Technical Report, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
3. Fontane, D. G., and Bohan, J. P. 1974. "Richard B. Russell Lake Water Quality Investigation; Hydraulic Laboratory Investigation," Technical Report H-74-14, December 1974, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
4. Fontane, D. G., et al. 1977. "Marysville Lake Hydrothermal Study: Report 1," Technical Report H-77-5, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
5. Dortch, M. S. 1978. "Marysville Lake Hydrothermal Study: Report 2, 2250 MW-Project, Hydraulic and Mathematical Model Investigation," Technical Report H-77-5, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
6. Dortch, M. S. et al. 1976. "Dickey-Lincoln School Lakes Hydrothermal Model Study," Technical Report H-76-22, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.
7. Roberts, Philip J. W. 1981. "Jet Entrainment in Pumped-Storage Reservoirs," Technical Report E-81-3, prepared by School of Civil Engineering, Georgia Institute of Technology, for the U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

ALGAL MANAGEMENT—AN UPDATE

John W. Barko*

Algae are an essential component of lacustrine ecosystems. These organisms are responsible for the synthesis of organic materials, providing much of both the structure and energy upon which other components of these systems are dependent. Yet, when the production of algal cells exceeds or becomes asynchronous with the capacity of the ecosystem to utilize this resource, excessive algal populations may occur.

Dense algal populations occur in many Corps of Engineers impoundments with documented regularity. The excessive growth of algae is frequently associated with an advanced state of eutrophication and is symptomatic of a variety of limnological conditions favoring high algal population densities.

In addition to obvious reductions in the aesthetic quality of reservoirs supporting excessive algal biomass, the decomposition of algal mass can result in drastic reductions in dissolved oxygen and the formation of potentially toxic organic residues. Algal-related water quality problems are a source of considerable public concern related to the use of reservoir resources.

PAST EFFORTS

In cooperation with the University of Nevada and the U.S. Environmental Protection Agency (EPA), a survey was undertaken in 1979 to compile information on existing methods of algal control.**

Despite the large number and diversity of algal

**Barko is a Research Biologist assigned to the Ecosystem Research and Simulation Division of the WES Environmental Laboratory.*

***Refer to WES Technical Report E-80-1, "A Compilation of Common Algal Control and Management Techniques," by Jeffrey J. Janik, William D. Taylor, and John W. Barko.*

control methods identified during the survey, none of these methods appear to adequately provide long-term control. Historically, most control methods have been applied only after the occurrence of an algal bloom and normally require reapplication because of their short-term effectiveness. Methods providing long-term control (if only on a seasonal basis) are essentially nonexistent.

Major conclusions and recommendations forthcoming from the 1979 survey are summarized below:

- There should be a change in emphasis from controlling algal problems after they arise to determining their causes and implementing a preventive program.
- There is a need for improving phytoplankton surveillance and analysis programs using standard techniques.
- Better knowledge of the time course of development of algal blooms will allow a more prudent and effective application of control methods (particularly chemical).
- Innovative methods of algal control as alternatives to the use of chemical algicides need to be developed because of the high cost, short-term effectiveness, and toxicity associated with the latter.

As an extension of the earlier survey work, a workshop was conducted jointly with the EPA in 1980 to review state-of-the-art techniques for algal management and control, to establish the functional availability and limits of these various techniques, and to determine the future direction of related developmental research.* Twenty-seven individuals from State, Federal, and private institutions participated in the workshop, which consisted of formal reviews of approaches or perspectives, plenary discussions, and formal panel deliberations related to algal management and control. Areas considered either formally or informally during the workshop included:

- Biological approaches:
  - Biomanipulation
  - Phycoviruses
  - Phycobacteria
  - Grazing
  - Extracellular metabolites
- Chemical approaches:
  - Selective algicides
  - Nutrient diversion and inactivation
  - Treatment of nonpoint nutrient sources
- Physical approaches:
  - Algal removal
  - Artificial destratification
  - Aeration
- Synthesized approaches
- Historical synopsis of algal problems
- Perspectives in algal control

Major conclusions and recommendations forthcoming from the 1980 workshop are summarized below:

1. The causes of algal problems are not fully understood. However, it is known that most lacustrine systems undergo a natural succession promoting the eventual inevitability of algal problems.

2. Systematic and extensive evaluations of the effectiveness of algal management techniques should be made. The limnological characteristics associated with the maximum effectiveness of the various techniques should be determined.

3. To properly design algal management and control programs, it is necessary to know why an algal problem is a problem; i.e., what beneficial use of water and its associated water quality requirements are being interfered with. Water quality requirements for specific beneficial uses should be determined so that algae management and control programs can be properly designed to meet them.

4. Algicides provide cosmetic treatment of algal problems. Copper is still the agent of choice; however, because of the considerations of cost and toxicity, copper sulfate is being replaced by chelated and synergistic formulations of copper for control purposes. The development of chelated and synergistic formulations of copper-based algicides should be continued.

5. Many algal management and control techniques, other than those involving the use of toxicants, have been utilized successfully by State agencies; however, their application is expensive and the results from their application are often unpredictable.

6. The direct removal of algae by mechanical means is presently not economical for managing and controlling algal problems in large bodies of water. Low-energy mechanical devices for movement of surface algal scums from localized nearshore high-use areas should be developed.

7. The effects of reducing the supply or availability of nutrients on algal community structure is not fully understood. Accordingly, the effects of dilution/flushing of nutrients on algal community structure and abundance should be more adequately determined.

8. Artificial aeration/circulation may reduce algal biomass and cause shifts of populations dominated by blue-green algae to populations dominated by more desirable algae. However, the

Complete proceedings of the workshop were published as Technical Report E-81-7.

results of applying this algal management and control technique have been neither consistent nor predictable. Design criteria for the application of aeration/circulation techniques to lacustrine waters for algal management and control should be developed. The manipulation of thermocline levels as an algal management and control technique should be more fully developed and evaluated.

9. Treatment of water bodies with alum and related compounds can precipitate phosphorus in the water column and inhibit the release of phosphorus from bottom sediments. However, detailed information is needed relative to the toxicity, dosage requirements, effectiveness as an algal management and control technique, and efficient application of these compounds to water bodies.

10. Biological processes that change algal community species composition and abundance do occur naturally, but have rarely been deliberately induced by man to control the abundance and composition of algal populations. Biological methods have the potential for providing low-cost, self-sustaining means to manage and control algal abundance and community composition. Techniques to biomanipulate algal populations should be developed. A better understanding of the grazing potential of zooplankton populations should be obtained. Work should include the determination of the size spectrum of particles (bacteria to macroalgae) potentially available to grazers in natural waters. Methods of stimulating the growth of herbivorous zooplankton should be developed.

11. Biomanipulation of algal populations through the use of viral or bacterial pathogens holds promise as an effective algal management and control technique. To date, these techniques have been limited to laboratory and small-scale pond experiments; practical application of such techniques in nature appears to be 5-10 years in the future. Work should be continued on the development of phycoviral and phycobacterial pathogens for algae control.

ONGOING RESEARCH

In 1981, algal research was initiated at Eau Galle Reservoir, a small, eutrophic, moderately alkaline system in Spring Valley, Wisconsin. Currently, examination of the composition and abundance (by species) of phytoplankton and determinations of related limnological characteristics are being conducted at six stations in Eau Galle with a 2-week sampling frequency. Emphasis is being given to meteorological and hydrological events and to littoral-pelagic processes that may influence phytoplankton density and community composition on a seasonal basis. As the data base becomes more informative, hypotheses will be developed concerning phytoplankton-regulating mechanisms in the reservoir. It is anticipated that experimental work designed to examine these hypotheses will be initiated in 1982. Experimental work will draw heavily on the conclusions and recommendations formulated during the 1980 workshop.

Help! Help!

If you haven't returned the poll letter that was the last page of Volume E-81-4 and if you want to continue to receive this information exchange bulletin —

DO IT NOW (please)

EWQOS REPORTS

U. S. Environmental Protection Agency. 1981. "Proceedings of Workshop on Algal Management and Control; 9-12 March 1980, Pacific Grove, California," Technical Report E-81-7, prepared for the Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Walburg, C. H., et al. 1981. "Water Quality, Macroinvertebrates, and Fisheries in Tailwaters and Related Streams; An Annotated Bibliography," Technical Report E-81-8, prepared by the U. S. Fish and Wildlife Service for the Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Walker, W. W., Jr. 1981. "Empirical Methods for Predicting Eutrophication in Impoundments; Report 1, Phase I: Data Base Development," Technical Report E-81-9, prepared for the Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

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.

TILFORD C. CREEL
Colonel, Corps of Engineers
Commander and Director

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180
OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300
WESAR

POSTAGE AND FEES PAID
DEPARTMENT OF THE ARMY
DOD-314
FIRST CLASS