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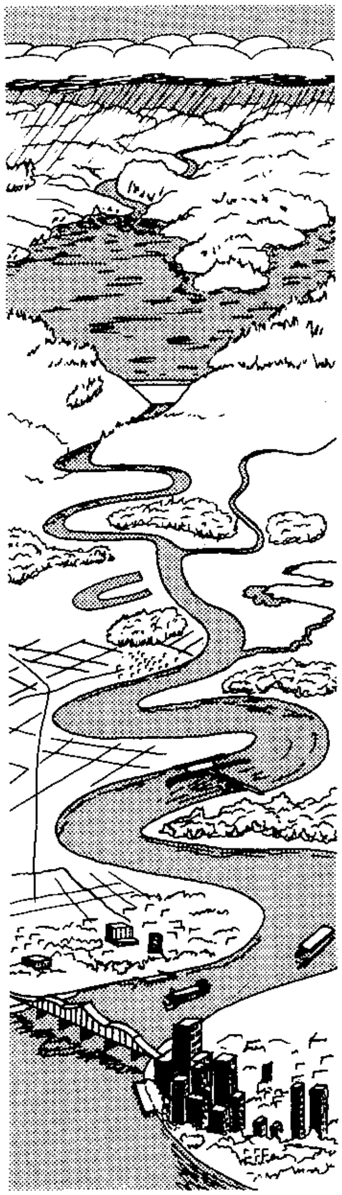

EWQOS
Environmental & Water Quality Operational Studies

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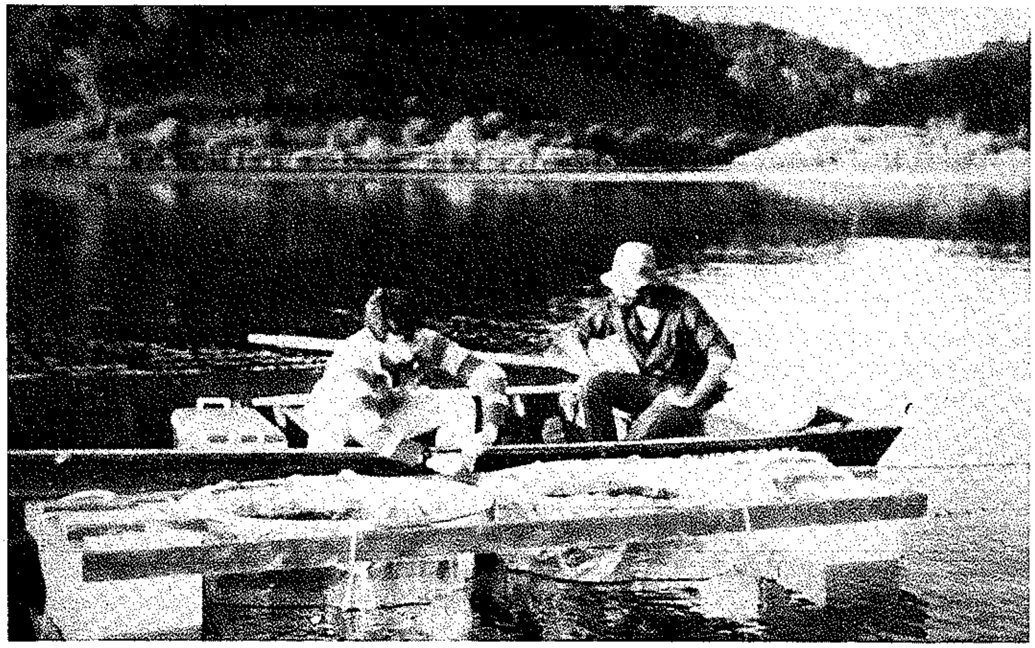


Studies of algal population dynamics in response to manipulated environmental conditions may provide the key to developing ecologically sound algal management programs. The photo above shows enclosures used in the algal experimentation at Eau Galle Reservoir, Wisconsin, that is described in the following article.

ALGAL RESEARCH AT EAU GALLE RESERVOIR

John W. Barko
Ecosystem Research and Simulation Division, EL

In 1981, algal research was initiated at Eau Galle Reservoir, a moderately alkaline eutrophic system in Spring Valley, Wisconsin. The site was selected because of its small size and relatively simple morphometry and the availability of supportive limnological data obtained as part of the Environmental and Water Quality Operational Studies (EWQOS) reservoir field studies.

Eau Galle Reservoir sustains a vigorous and dynamic algal community. Algal biomass ranges from less than 5 g/m^3 (fresh weight) during the winter to as high as 70 g/m^3 during the summer. The seasonal progression of algal growth is characterized by the development of four fairly distinct populations under ice-free conditions (Figure 1): diatoms (Bacillariophyta) during the spring; blue-greens (Cyanophyta) during early to mid summer; dinoflagellates (Pyrrhophyta) and blue-greens during the late summer; and diatoms during the fall.

Diatoms are generally much less objectionable than either blue-green algae or dinoflagellates, because the

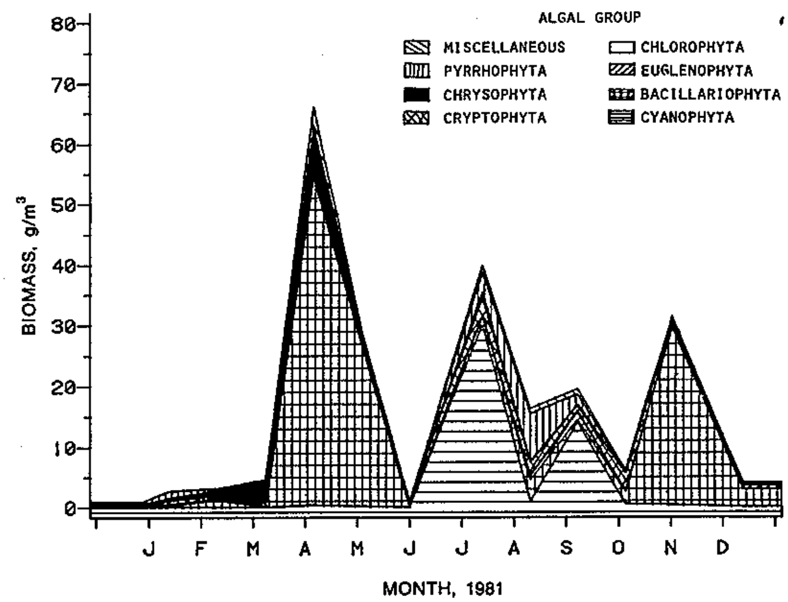


Figure 1. Seasonal distribution of total phytoplankton biomass by group sampled from 0 to 3 m at an openwater station in Eau Galle Reservoir in 1981

former do not form surface scums and are more readily utilized by consumer populations (i.e., zooplankton). At Eau Galle, it would be desirable to extend the growing season of diatoms, while reducing densities of blue-green algae and dinoflagellates.

In situ experimentation involving the use of large polyethylene enclosures was initiated in 1982 to examine the feasibility of manipulating phytoplankton populations in Eau Galle. Treatments have included modifications of water chemistry (nitrogen, phosphorus, silica, and inorganic carbon concentrations), pH alterations, mixing, and zooplankton exclosure. Preliminary results suggest that additions of silica + nitrate-nitrogen may be effective in extending the occurrence of diatoms beyond spring into midsummer. This is particularly encouraging, since the collapse of diatoms and simultaneous development of nitrogen-fixing blue-green algal populations typically occur during early June when both silica and dissolved inorganic nitrogen concentrations are at their lowest in Eau Galle.

Related studies of algal population dynamics in response to experimentally manipulated environmental conditions will continue through the summer of 1983 at Eau Galle, with corroborative laboratory research conducted concurrently at the Waterways Experiment Station. It is anticipated that results of this undertaking will be useful in formulating an ecologically sound algal management program for Eau Galle Reservoir. Results may be applicable to other CE reservoirs, providing an environmentally acceptable technique for nuisance algae control.

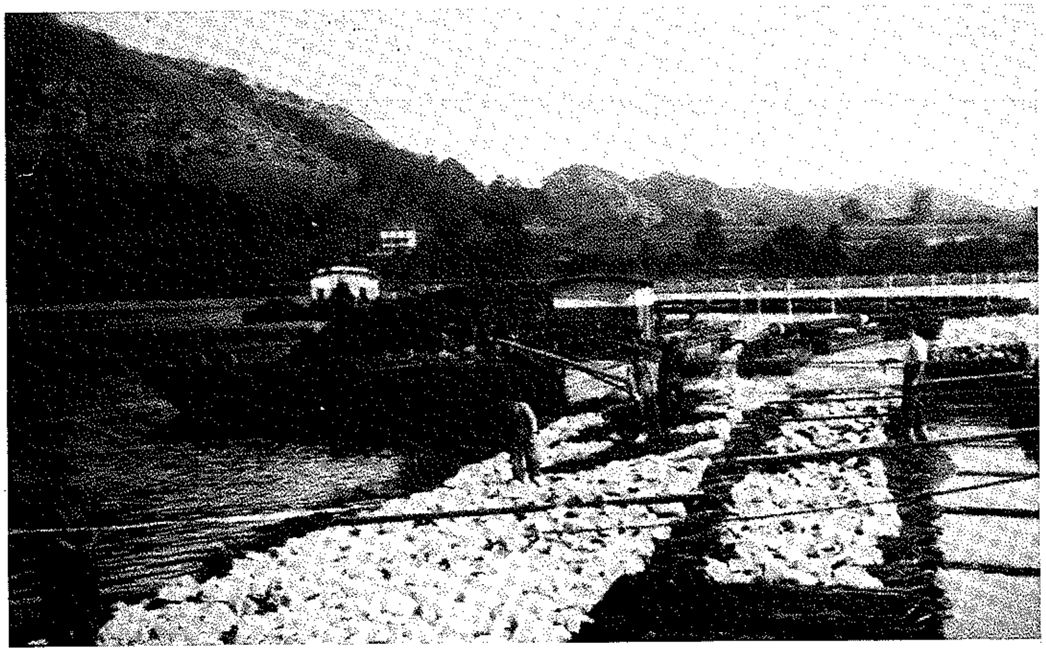
DIKE FIELD MEETING

F. Douglas Shields, Jr.
Environmental Engineering Division, EL

Forty-four individuals representing seven Corps District offices, two Division offices, the states of Illinois and Missouri, and the U.S. Fish and Wildlife Service met at WES on 6 January for a day-long workshop on various environmental aspects of dike fields. There were seven presentations, each followed by questions and answers and general discussion. The program is summarized in Table 1.

Presentation of the EWQOS Waterway Field Study findings regarding lower Mississippi River dike fields was a highlight of the meeting. At low river stages, the dike fields provide areas of low velocity and soft substrate that are populated by fish and macroinvertebrate communities quite similar to those found in abandoned channels. Dike fields and dike structures provide valuable habitats to the riverine ecosystem. However, many of the dike fields are filling with sediment.

Although the Corps has practiced dike notching extensively on the Missouri to reverse or reduce dike-field sediment accretion, some evidence



Early dike construction along the upper Mississippi River around the turn of the century required labor-intensive procedures to build dikes of willow mattress and stone. These dikes have since been submerged following construction of locks and dams. Environmental aspects of present-day dike fields were the subject of the meeting described in the article that begins on page 2. (Photographs courtesy of Mr. Robert Whiting, St. Paul District.)

Table 1. Program for Workshop on Environmental Aspects of Dike Fields, 6 January 1983

Welcome and Introduction	Mr. Doug Shields WES Environmental Lab
Dike Design Research at WES	Mr. Charles Elliott WES Hydraulics Lab
Missouri River —Structure Modifications	Mr. Tom Burke Kansas City District
Habitat Value of Upper Mississippi River Dike Fields	Mr. Robert Whiting St. Paul District
Habitat Value of Lower Mississippi River Dike Fields	Dr. David Beckett WES Environmental Lab
Environmental Guidelines for Dike Fields	Mr. Carey Burch Versar, Inc.
Case Studies:	
Lower Mississippi River —Leota Dike Field	Dr. Robert Dolan University of Virginia
Missouri River —ABC Dike Field	Dr. Michael Stevens Consultant Boulder, Colorado

indicates that notches in lower Mississippi River dikes might produce undesirable habitats characterized by higher velocities and shifting sand and gravel substrate. These conditions are typical of the relatively unproductive main channel.

Two additional methods (besides notching) for keeping dike fields open were discussed. Manipulation of the basic dike-design parameters holds some promise, but additional dike field modeling will be required to identify specific dike-field configurations that will consistently produce desirable environmental conditions. There is no conclusive evidence to suggest that lower Mississippi River dike fields must fill in with sediment to be effective river trainers. However, dike fields must frequently be located in natural depositional areas such as point bars. Another unexplored concept for keeping dike fields open is to periodically open notches in dikes to flush out sediment deposits and later close them to produce pools with more ecologically valuable low-velocity conditions.

The final three presentations consisted of summaries of the findings of an information review contract conducted under EWQOS Project VI. Mr. Carey Burch is the principal investigator for the contractor, Versar, Inc., and Drs. Stevens and Dolan are consultants retained by Versar. Prior to the meeting, Corps personnel scheduled to attend the seminar were supplied draft copies of the Versar report for review and comment.

Comments offered by Corps personnel on the Versar draft report and oral discussions at the 6 January meeting will be incorporated in the final report. The final report should be useful to Corps personnel who are responsible for managing ecological resources associated with major open-river waterways.

EWQOS FIELD REVIEW GROUP MEETING

The fourteenth meeting of the Field Review Group (FRG) for EWQOS was held at the Waterways Experiment Station during 7-9 December 1982. The FRG was established at the initiation of EWQOS to provide field-office input into program planning, to review progress and technology development, and to assist in planning technology transfer activities. During the entire history of the EWQOS program, the FRG has provided valuable input and support of program activities and during the later stages of the program is expected to play a key role in technology transfer. Major purposes of the fourteenth meeting were for program personnel to present options for technology transfer activities and for the FRG to provide input on the desirability and effectiveness of the options as a basis for development and implementation of a technology transfer plan for EWQOS.

The key elements of any technology transfer activity include documenting research results, informing users, training, assisting users, and maintaining technology.

Documenting research results may take a variety of forms including reports, manuals, and journal publications. Goals may vary depending on the type of documentation, but providing comprehensive guidance for problem solutions, establishing technical credibility of program results, and documenting the results are the primary objectives.

Informing users of available technology is a very necessary activity. Recommended methods include publishing the information exchange bulletin, compiling computerized databases for information searches and retrieval, circulating publications listing, and presenting briefings. Critical steps in this element include informing as many users as possible (including managers and decisionmakers) and maintaining interagency coordination.

Training is essential to technology transfer, particularly for innovative techniques and for complex technologies such as application of mathematical models. While not necessary for all program products, it is required for many program products. Specific EWQOS-related training needs are being identified and training aids developed to interface with formal training efforts within the Corps.

User assistance, usually required for any technology, ranges from answering simple questions to detailed assistance on specific problems. This assistance is already provided within EWQOS, and activity is expected to increase dramatically in the future.

Maintenance of developed technology and products is essential to correct deficiencies or errors, to provide current technology, and to minimize response time in bringing products to bear on the solution of those problems that were identified and addressed by EWQOS or those problems that may emerge after completion of the program.

The FRG input on all key elements of technology transfer was received during the meeting and will provide the background and basis for establishment of a technology transfer plan. Support for EWQOS technology transfer activities was a consensus recommendation of the FRG.

RIVERINE WATER QUALITY MODELS

Aaron Stein
Ecosystem Research and Simulation Division, EL

EWQOS Work Unit 1C.3, "Improve and Verify Riverine Water Quality and Ecological Predictive Techniques," was designed to provide tools for CE resource planners and managers to evaluate the effects of man's activities on river systems. Several specific projects are included within the unit and are described in the following article.

EVALUATION OF SELECTED 1-D MODELS

An evaluation of five of the most commonly used one-dimensional (1-D) stream water quality models was performed by the United States Geological Survey (USGS) under the direction of and with funding from WES. The results of this evaluation were reported by McCutcheon (1982).

The report contains brief reviews of the literature concerning 1-D water quality models, description of five specific models, selection of the database used to evaluate the models, and assessment of the need for further study.

Models included in this evaluation and comparison were a modified Streeter-Phelps model called the USGS Steady-State Stream Water-Quality Model, the Southeast Michigan Council of Governments' version of the QUAL II Model, the Water Quality for River-Reservoir Systems (WQRRS) Model, the MIT Transient Water-Quality Network Model, and the Velz Method.

Figure 1 is an example of the type of comparison of the models predictive capabilities contained in the report. It shows that each of four models predicted similar dissolved oxygen levels under the conditions studied.

Recommendations concerning model usage and descriptions of model accuracy are contained in the report. The study will assist engineers and scientists in evaluating which of the four models is most suitable for their particular application requirements.

DYNAMIC 1-D HYDRAULIC AND WATER QUALITY MODEL

A 1-D, branching, dynamic hydraulic and water quality model has been developed for WES by Bedford, Sykes, and Libicki (1983). This model, a new version of a model originally developed for the Ohio Environmental Protection Agency, is referred to as CE-QUAL-RIV1. The model has the capability of simulating dynamic events such as storm flows and hydroelectric generation on highly controlled river systems. The hydraulic simulation is based on an implicit solution technique that is more accurate, stable, and less expensive to use than the more commonly used explicit techniques found in many existing models.

The water quality portion of the model includes the traditional quality parameters such as dissolved

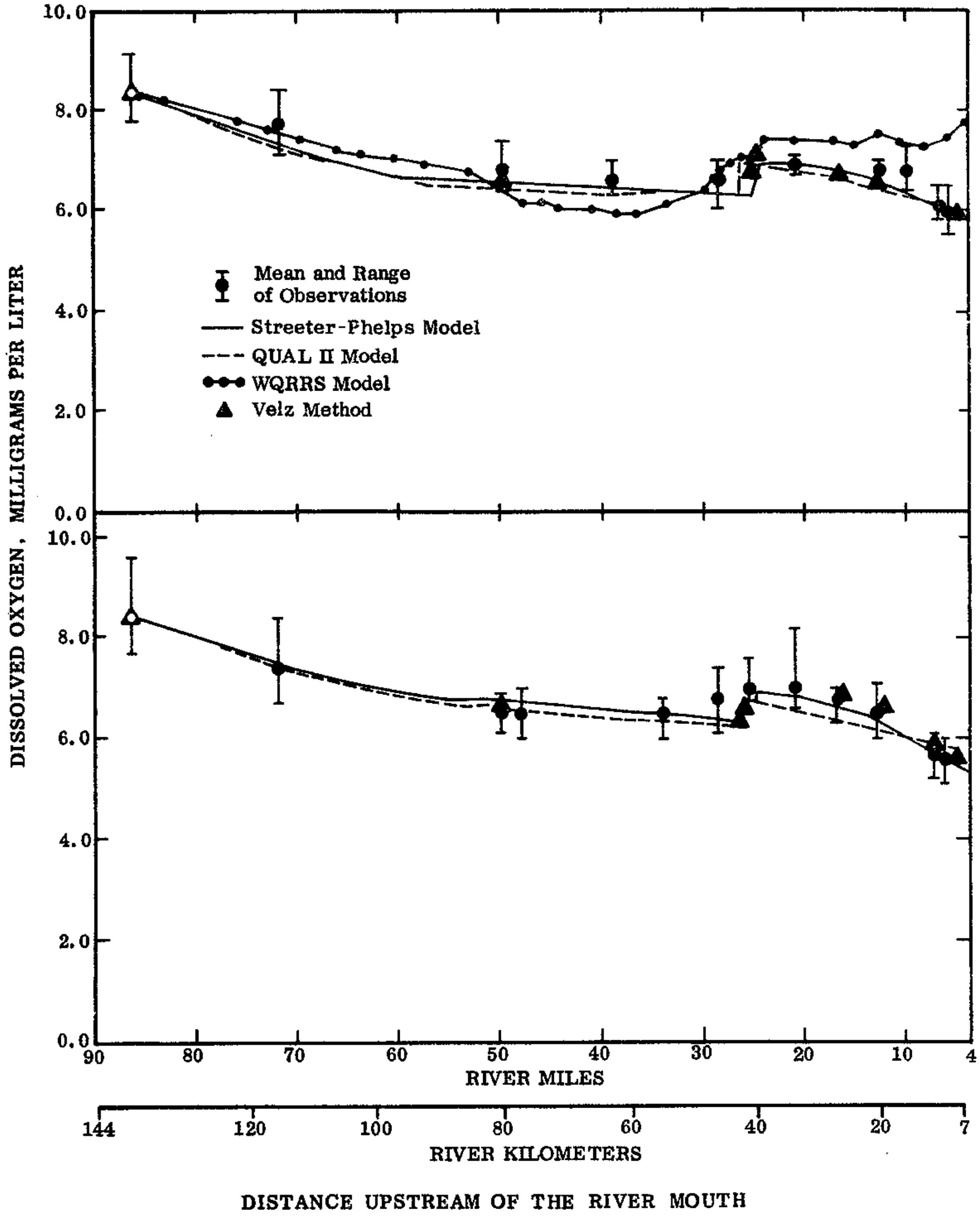


Figure 1. Observed and predicted dissolved oxygen concentrations, Willamette River (McCutcheon 1982)

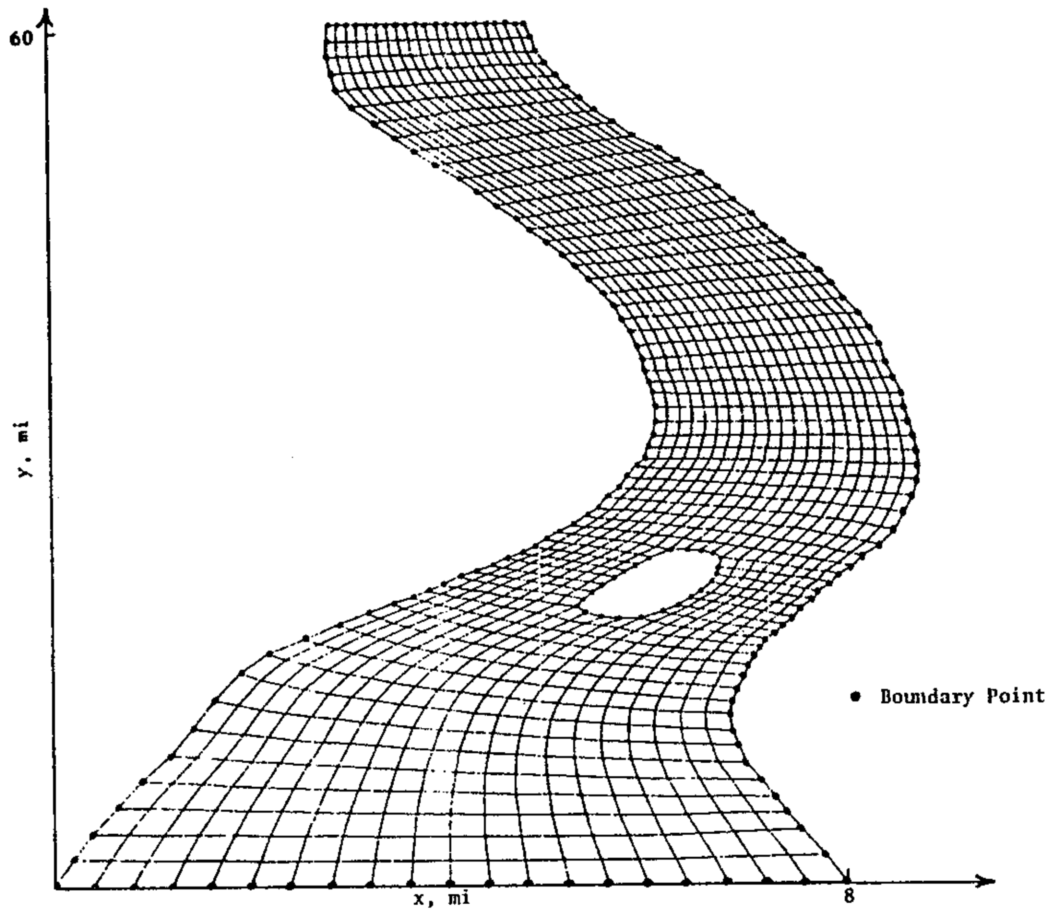


Figure 2. Boundary-fitted coordinate system for a multiple connected region (Johnson 1980)

oxygen and the nitrogen cycle. However, the coefficients and rates used are functions of stream turbulence. This is a new concept in riverine water quality modeling that will increase the accuracy and flexibility of model usage. The CE-QUAL-RIV1 model will be documented and made available during the current fiscal year.

2-D RIVERINE MODEL

The major emphasis of Work Unit IC.3 is the development of a two-dimensional (2-D), vertically averaged riverine water quality model called CE-QUAL-RIV2. The model will simulate traditional water quality variables such as temperature, dissolved oxygen, the nitrogen cycle, phosphorus, algae, and fecal coliform and various arbitrary conservative and nonconservative constituents. CE-QUAL-RIV2 is based on VAHM, a vertically averaged hydrodynamic model developed by Johnson (1980). Like VAHM, CE-QUAL-RIV2 is based on a numerical scheme called boundary-fitted coordinates, developed by Thompson et al. (1977). This technique allows the simulation of complex geometries such as meandering river systems using simple and inexpensive mathematical tools.

The boundary-fitted coordinate technique transforms complicated geometries to rectilinear domains where finite difference techniques are easily applied. Figure 2 shows a typical riverine grid generated for use with a boundary-fitted coordinate scheme. Notice that the physical river boundaries are exactly coincident with the boundaries of the simulation grid. This eliminates the necessity of using costly and time-consuming interpolation schemes in the simulation process and represents a significant improvement in riverine models. Such grids can be generated routinely for complex real-world river geometries. Documentation of CE-QUAL-RIV2 and workshops on its use are scheduled for FY 1985.

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LOCALIZED MIXING TO ENHANCE RESERVOIR RELEASE QUALITY

Jeffery P. Holland
Hydraulics Structures Division, HL

PROBLEM DEFINITION

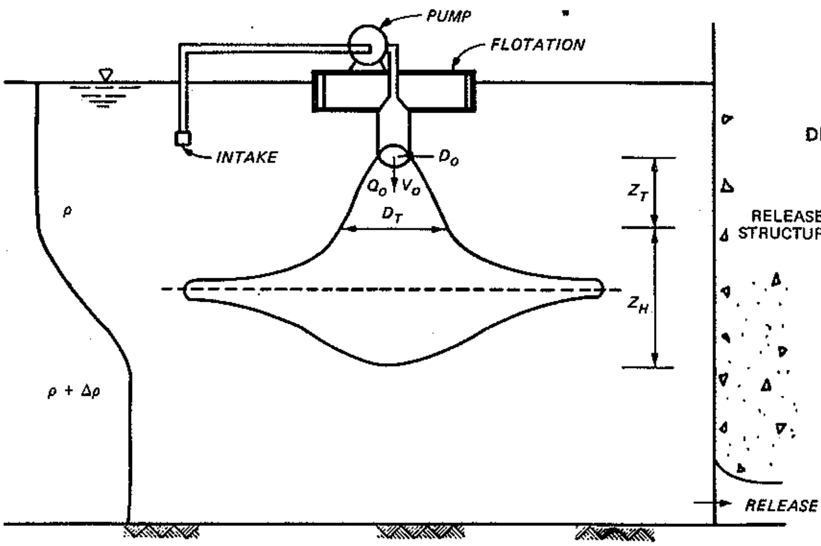
During the late spring or early summer months, many CE reservoirs become thermally stratified. The subsequent density stratification inhibits vertical mixing in these reservoirs, resulting in the formation of three vertical strata in the reservoir. The epilimnion, the upper region, contains warm low-density water that is generally high in dissolved oxygen (DO) concentration, due to surface exchange and wind mixing, and is usually considered high quality. The region of rapid temperature change just below the epilimnion is called the thermocline or metalimnion. The hypolimnion, the lowest region of the reservoir, consists of cooler high-density water that, due to stratification and oxygen demand, is often low or deficient of DO.

Stratification may present a downstream water quality problem for reservoirs with low-level release outlets. The water released from these outlets, which will be either predominantly or completely hypolimnetic, may be of generally poor quality due to oxygen deficiency. Further, during certain periods of the year, these waters may become anoxic, resulting in the release of high concentrations of reduced iron and manganese and hydrogen sulfide.

Several solutions have been considered to improve the water quality of these releases. Artificial destratification, hypolimnetic oxygenation, structural modification, and localized mixing are all feasible approaches. Artificial destratification of the entire reservoir destroys either most or all of the stratification within the reservoir, and hypolimnetic oxygenation and structural modifications are generally expensive alternatives. Conversely, localized mixing is designed to destratify the reservoir in the vicinity of the release structure and field applications of this concept for small impoundments have shown it to be a simple, cost-effective approach to improve the quality of low-level releases (Garton and Peralta 1978, Dortch and Wilhelms 1978). It is, in fact, the simplicity of localized mixing that promotes its cost effectiveness.

CONCEPT

The concept of localized mixing near the release structure is shown in Figure 1. A downward vertical jet composed of epilimnetic water transports high-quality water downward into the hypolimnion. This jet can be formed in a number of ways, ranging from the use of an axial flow propeller located in the epilimnion (Garton and Peralta 1978) to the use of a surface pump with an epilimnetic intake and outflow as shown in Figure 1. Regardless of the mechanism, the jet is designed with adequate initial momentum to penetrate to the level of the release outlet in the hypolimnion. A portion of the transported epilimnetic water will then be withdrawn from the reservoir along with a quantity of hypolimnetic water, thus diluting the



DEFINITION OF TERMS USED IN FIGURE 1:

Q_o, V_o, D_o = VOLUME FLUX, VELOCITY, DIAMETER OF JET AT THE OUTLET
D_T = DIAMETER OF JET AT THERMOCLINE
Z_T = DISTANCE FROM JET OUTLET TO TOP OF THERMOCLINE
Z_H = PENETRATION DEPTH BELOW TOP OF THERMOCLINE
ρ = EPILIMNETIC DENSITY
$\rho + \Delta\rho$ = HYPOLIMNETIC DENSITY
$\Delta\rho$ = ABSOLUTE DIFFERENCE BETWEEN EPILIMNETIC AND HYPOLIMNETIC DENSITIES

Figure 1. Definition schematic of localized mixing application (the withdrawal zone from the outlet is not shown)

hypolimnetic outflow and improving the release quality. The quantity of epilimnetic water required for transport will depend on the quality desired for the given release and the qualities of both the hypolimnion and epilimnion. Obviously, the poorer the hypolimnetic quality, the larger the quantity of epilimnetic water required to enhance, or dilute, the hypolimnetic release in order to obtain a desired release quality.

While a number of important parameters have been identified for localized mixing (Busnaina et al. 1981), it is imperative that two general conditions be met:

a. The epilimnetic jet must penetrate to the level of the release outlet. If the jet fails to penetrate to this level, the improvement of release quality will be lessened. Further, penetration of the jet beyond the outlet represents a waste of energy that reduces the cost effectiveness of the method. In certain cases, such as for bottom outlets, overpenetration may disturb bottom sediments and degrade rather than improve release quality (personal communication, J. E. Garton, Professor of Agricultural Engineering, Oklahoma State University, Sept. 1979).

b. The volume of epilimnetic water jetted into the hypolimnetic withdrawal zone must be sufficiently large such that the flow-weighted average of epilimnetic and hypolimnetic qualities is equal to the desired quality of the total release. This process of augmenting the quality of the release with an epilimnetic component is referred to as dilution of the release.

An effective localized mixing device, then, must provide adequate initial momentum and volume flux to transport an adequate epilimnetic volume to a prescribed hypolimnetic elevation. Initial design guidance has been developed for localized mixing systems as a part of the EWQOS Task IIIB.1, "Improvement of Reservoir Destratification/ Mixing Technique." Holland (1982), using laboratory test results, quantified penetration of the epilimnetic jet as measured from the thermocline down into the hypolimnion. Moon et al. (1979) developed initial guidance on the ratio of pumping rate to release required to achieve a given dilution factor. These research results may be used to obtain the initial design of a localized mixing device for a given set of reservoir conditions. A brief overview of these results are presented in this article. For a thorough review of the assumptions inherent in these works, the references cited should be consulted.

RESEARCH RESULTS

Jet Penetration and Dilution

The quantification of jet penetration depth was determined from laboratory experiments that idealized reservoir stratification as two layer. The upper layer was considered to be low-density (ρ) epilimnetic water that resided over a high-density ($\rho + \Delta \rho$) hypolimnion. Epilimnetic water was assumed to comprise initial volume of the downward vertical jet. Within the epilimnion, the jet was characterized as a nonbuoyant jet and the classical analysis of Albertson et al. (1950) was

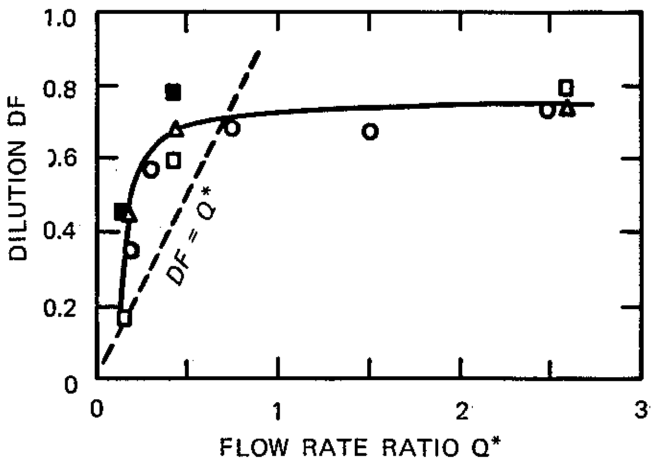


Figure 2. Dilution DF as a function of Q*, the ratio of epilimnetic volume flux pumped to total volume flux released

used to quantify the densimetric Froude number of the jet at the thermocline. Subsequently, using dimensional arguments and the results of 100 laboratory tests, the penetration of the jet into the hypolimnion was related to the densimetric Froude number at the thermoline by the expression

$$\frac{Z_H}{D_T} = 1.66\ F_r - 0.66 \qquad (1)$$

where

Z_H = depth of penetration into the hypolimnion as measured from the top of the thermocline, ft

D_T = diameter of the jet at the thermocline, ft

F_r = densimetric Froude numberof the jet at the thermocline

Moon et al. (1979) have given guidance on the practical dilution of a hypolimnetic release by an epilimnetic jet. Based upon a comparison of the ratio of the volume flux of the epilimnetic water released to the total release volume flux DF and the ratio of the epilimnetic flux pumped to the total release flux, Moon et al. showed that a maximum dilution of 80 percent was practical (Figure 2). Further, for epilimnetic pumping rates greater than one half the release rate, no increase in dilution was observed. While the range of data and test conditions is limited to Moon et al. (1979), their results combined with the penetration results discussed above are sufficient for an initial design.

System Design

A localized mixing system may be designed for a given reservoir stratification, release rate, required downstream release quality, and hypolimnetic and epilimnetic qualities. This design is incorporated in the following general procedure:

a. Specify the downstream release water quality objective.

b. Determine the thermal distribution in the reservoir.

c. Predict the withdrawal zone established by the known downstream release flux (Smith and Dortch 1983).

d. Compute the epilimnetic volume flux that must be withdrawn to result in the specified quality of the given downstream release based on mass balance criteria.

e. Compute a dilution factor DF based upon results from step *d.* If all the epilimnetic volume pumped is assumed withdrawn, DF equals the value from step *d* divided by the total release flux.

f. Compute the initial pumping rate from Moon et al. (1979).

g. Specify depth of penetration required. This depth is usually to either the outlet center line or an elevation representing a percentage of the withdrawal zone thickness.

h. Compute the initial jet characteristics from Equation 1 and Albertson et al. (1950) work.

Holland (1982) used this procedure to size a localized mixing system for the reservoir conditions shown in Figures 3 and 4. For these conditions, Holland determined that a pump located 2 ft below the surface should pump 22 cfs of epilimnetic water into the hypolimnetic withdrawal zone to achieve a DO content of 6 mg/ℓ for a 100 cfs release. The reader is referred to Holland (1982) for an in-depth analysis of this design.

SUMMARY

Localized mixing is often a viable method of enhancing the water quality of releases from low-level hypolimnetic outlets. A jet of good-quality epilimnetic water penetrates the zone of withdrawal where it is released with a quantity of hypolimnetic water, thereby enhancing the quality of the total release volume. Although enhancement is a function of several parameters, two conditions are necessary to promote successful localized mixing:

- The epilimnetic jet must penetrate to the level of the outlet or to well within the withdrawal zone.
- The jet must provide sufficient volume of epilimnetic water to effectively dilute the hypolimnetic release component and thereby enhance the total release quality.

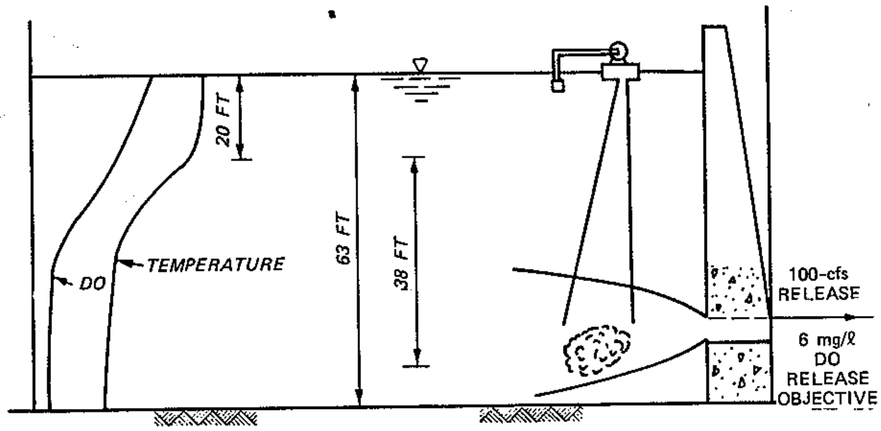


Figure 3. Definition schematic for example reservoir localized mixing design where the thermocline is 20 ft below the water surface and the jet was designed to penetrate 38 ft below the thermocline (the detailed DO and temperature distributions are given in Figure 4)

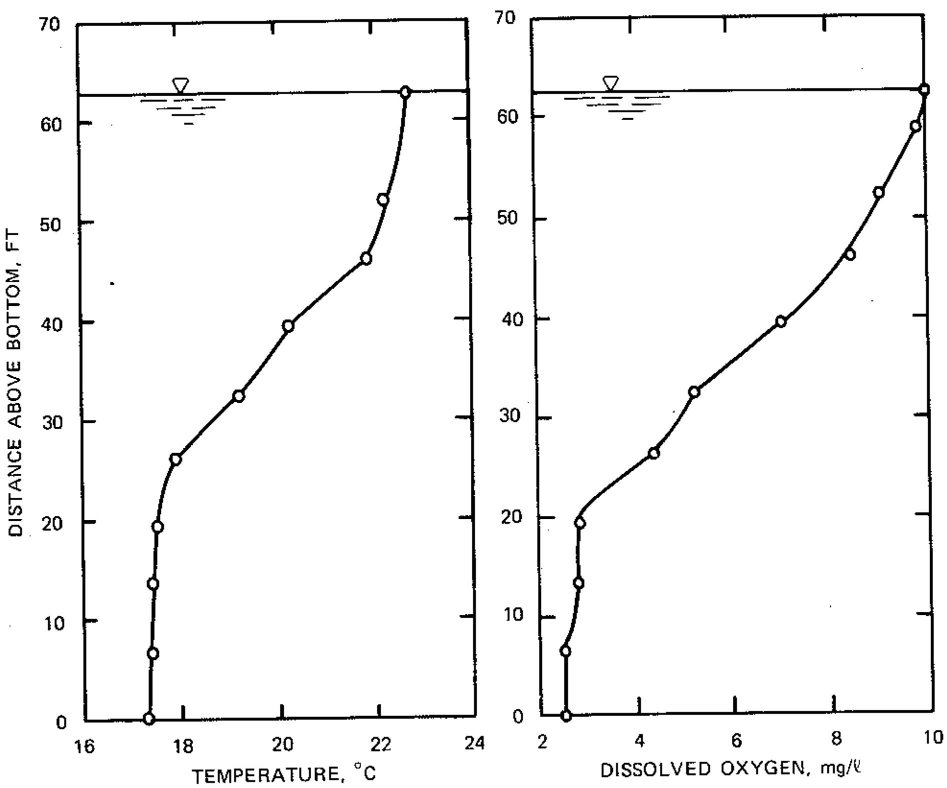


Figure 4. Detailed vertical temperature and dissolved oxygen distributions for example reservoir

As part of this EWQOS research effort, a design procedure has been developed that provides guidance for both conditions. The procedure provides both guidance on and a first approximation for the design of localized mixing systems. Certain site-specific effects (such as the effects of reservoir geometry on near-field mixing and withdrawal) have not been quantified in this example and may require specific physical/numerical modeling to complete the design.

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ENVIRONMENTAL AND WATER QUALITY OPERATIONAL STUDIES

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

The design of the cover of *Environmental and Water Quality Operational Studies* has been changed as part of an overall plan to standardize WES publications and to enhance their professional appearance.

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