EWQOS

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U. S. ARMY CORPS OF ENGINEERS
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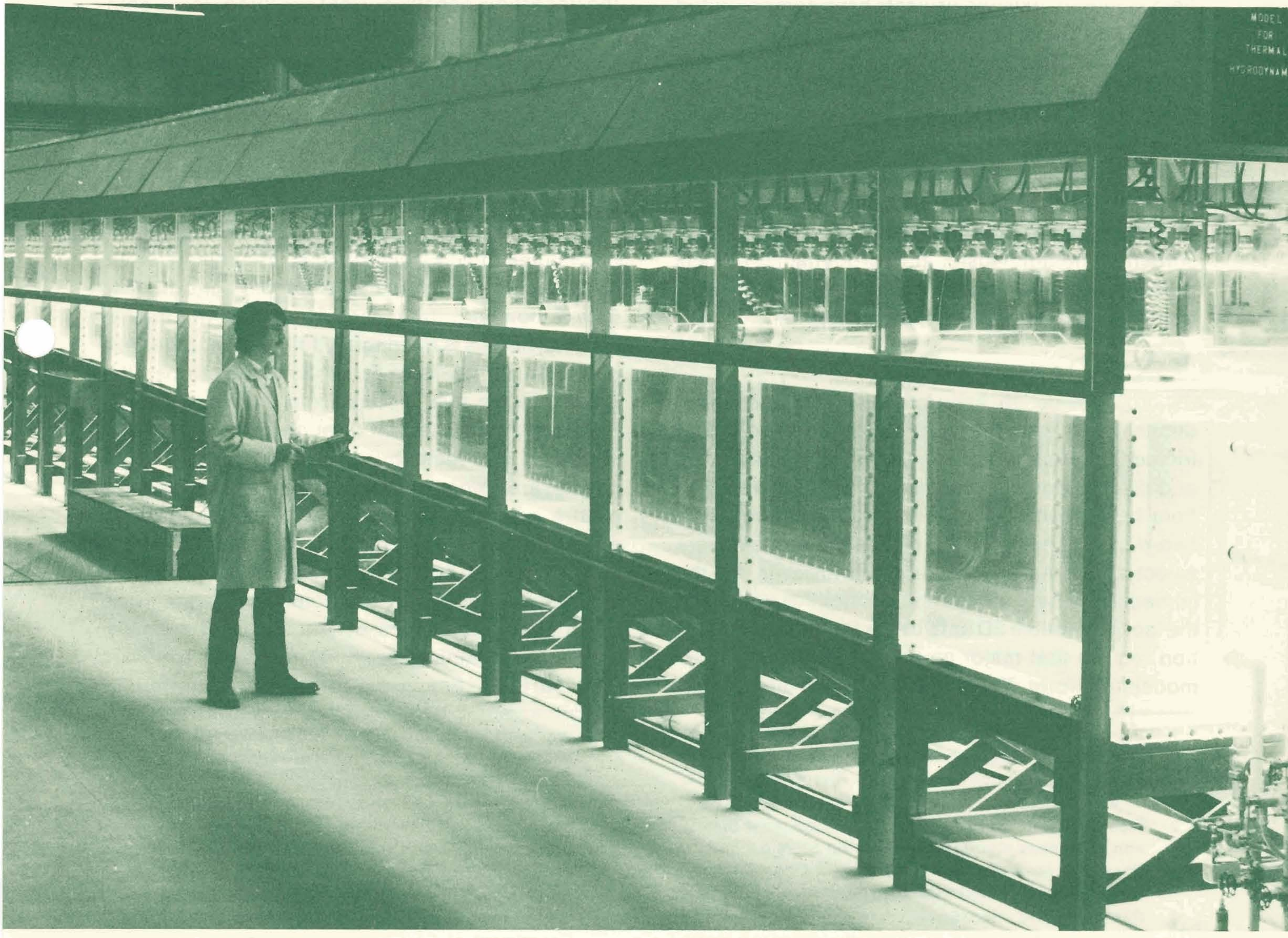

The Generalized Reservoir Hydrodynamics (GRH) flume shown above is being used by personnel of the Waterways Experiment Station's Hydraulics Laboratory to simulate the underflow density current resulting from a cold-water inflow into an initially homogeneous water body. The results are used to assess the performance of various multidimensional models that include thermal effects. The investigation, part of EWQOS Task 1A, is described in the following article.

MULTIDIMENSIONAL RESERVOIR HYDRODYNAMIC MODELING

PROBLEM IDENTIFICATION

An objective of the EWQOS Program Task IA is to develop numerical models that will predict water quality within reservoirs as well as in the reservoir releases. Economical techniques are required that realistically simulate the impact of reservoir hydrodynamics on water quality and ecology over extended periods of time.

Historically, one-dimensional (1D) models have been applied to yield information in the vertical but with no longitudinal or lateral resolution. However, field studies of existing projects have demonstrated the importance of predicting the longitudinal as well as the vertical exchanges in describing water quality changes in long, relatively narrow and deep impoundments. In some Corps reservoirs the lateral exchange is also important, which of course results in the need for a fully three-dimensional (3D) analysis. Since water movement in reservoirs plays a vital role in the prediction of the location of constituents, multidimensional hydrodynamic models that are time dependent are required to support multidimensional water quality modeling.

APPROACH

To provide an accurate and versatile multidimensional reservoir hydrodynamic model that includes thermal effects, a search of the literature and discussions with prominent researchers in the field have been ongoing over the past year. Both two-dimensional (2D) as well as 3D models were selected and have been studied; however, for the immediate future, computing economics as well as the lack of suitable 3D data bases for model verification require that major emphasis be placed on 2D modeling efforts. The models most consistent with CE requirements will be selected and subsequently improved.

RESULTS

The 2D hydrodynamic models for the computation of reservoir flows in the vertical-longitudinal directions that have been investigated include those of Edinger,[1] Waldrop,[2] Roberts and Street,[3] and Norton et al.;[4] 3D models include those of Lick,[5] Spraggs,[6] and Tatom.[7]* To aid in the initial assessment of the performance of the various models, the Edinger, Waldrop, and Norton 2D models and the 3D models of Spraggs and Tatom are in the process of being applied to the Hydraulics Laboratory's GRH flume (cover photo) to simulate the underflow density current resulting from a cold-water inflow into an initially homogeneous water body (Figure 1). Such a simulation is representative of the flow created by the plunging of a dense stream entering a reservoir. Dense inflows can result from low temperatures, a large quantity of dissolved minerals, suspensoids, or a combination of these variables.

Application of the mathematical models to the GRH flume must be classified as preliminary at the present time. Based upon the comparisons made to date, a common deficiency of most of the mathematical models is an inability to force an underflow density current (Figure 1) to follow steep slopes. It is believed that this results from the necessity of representing the bottom through a "stair-step" cell structure on a rectangular grid. Additional investigations are being conducted to delineate the source of the problem and to develop the necessary computational modifications.

Of the 2D and 3D models studied, only the Edinger model is not restricted in its numerical stability characteristics by the speed of a gravity wave while retaining the ability to allow for a moving free surface. For short-term applications, the

* 1. Edinger, J. E., and Buchak, E. M., "A Hydrodynamic Two-Dimensional Reservoir Model: Development and Test Application to Sutton Reservoir, Elk River, West Virginia," U. S. Army Engineer Division, Ohio River, June 1979.

2. Waldrop, W. R., and Farmer, R. C., "A Computer Simulation of Density Currents in a Flowing Stream," *International Symposium on Unsteady Flow in Open Channels,* University of Newcastle-Upon-Tyne, England, April 1976.

3. Roberts, B. R., and Street, R. L., "Two-Dimensional, Hydrostatic Simulation of Thermally-Influenced Hydrodynamic Flows," TR 194, Department of Civil Engineering, Stanford University, July 1975.

4. Norton, W. R., King, I. P. and Orlob, G. T., "Water Quality Report—Lower Granite Lock and Dam, Snake River, Washington-Idaho, Appendix F, Finite Element Hydrodynamic Model," May 1973, prepared for the U. S. Army District, Walla Walla, Washington.

5. Lick, W., "Numerical Models of Lake Currents," Environmental Research Laboratory, U. S. Environmental Protection Agency, Duluth, Minnesota, EPA-600/3-76-020, April 1976.

6. Spraggs, L. D., and Street, R. L., "Three-Dimensional Simulation of Thermally-Influenced Hydrodynamic Flows," Department of Civil Engineering, Stanford University, TR 190, August 1975.

7. Tatom, R. B., and Smith, S. R., "Near-Field Model for Brine Diffusion at West Hackberry," Engineering Analysis, Inc., Huntsville, Alabama, August 1978.

EWQOS STATUS SUMMARY, FY 79

Project Title/Work Unit/Task	Mode of Conduct*	Completion	Cost to Date	Status
I. Predictive Techniques for Determining Environmental Effects				
IA. Reservoir Hydrodynamics				
1. Develop and verify techniques for describing inflow mixing processes	EL, HL; WES	Sep 80	$ 96,000	Active
2. Develop and verify techniques for describing internal reservoir mixing processes	EL, WES	Sep 81	129,000	Active
3. Improve and verify physical hydrodynamic modeling techniques for reservoirs	HL, WES	Sep 83	151,000	Active, interim guidance on use of physical models provided during FY 79
4. Improve and verify multidimensional hydrodynamic mathematical models	HL, WES; HEC: Contract, J. E. Edinger Asso., Inc.	Sep 83	167,000	Active
5. Develop and verify techniques for describing pumpback mixing processes	HL, WES	Sep 81	50,000	Active, literature review and data evaluation being performed
6. Modification of HEC-6	HEC	Sep 78	25,000	Complete, Users Manual published
7. The behavior of fine sediments in reservoirs	HL, WES	Sep 82	60,000	Active
8. Forecasting the development of reservoir deltas	HL, WES	Sep 82	55,000	Active
IB. Improved Description of Ecological and Water Quality Processes				
1. Improve and verify understanding and descriptions for reservoir ecological processes	EL, WES FWS-National Reservoir Research Progam USEPA; Las Vegas	Sep 83	238,000	Active, fisheries algorithms complete, literature review for benthic, zooplankton, and phytoplankton ongoing
2. Develop and verify description for aerobic/anaerobic chemical processes	EL, WES	Sep 83	338,000	Active
3. Develop and evaluate improved descriptions for important ecological processes unique to rivers	EL, WES	Sep 83	--	Initiate in FY 80
4. Formation and breakup of reservoir ice cover and effects on thermal energy budget computations	CRREL	Sep 83	132,000	Active
IC. Mathematical Water Quality and Ecological Predictive Techniques				
1. Improve and verify existing one-dimensional reservoir water quality and ecological prediction techniques	EL, WES	Sep 83	315,000	Active, revised model documentation completed in FY 79
2. Develop and evaluate multidimensional reservoir water quality and ecological predictive techniques	EL, WES	Sep 83	--	Initiate in FY 80
3. Improve and verify riverine water quality and ecological predictive techniques	EL, WES	Sep 83	--	Initiate in FY 80
4. Field test of the WQRRS river water quality module	HEC	Sep 80	95,000	Active
ID. Determination of Loadings to Reservoirs				
1. Evaluation of existing techniques for predicting annual loadings to reservoirs	EL, WES	Sep 79	26,000	Complete, final report to be published in FY 80
IE. Simplified Techniques for Predicting Reservoir Water Quality and Eutrophication Potential	EL, WES	Sep 83	66,000	Active, Phase I data base compilation completed
II. Reservoir Operational and Management Techniques				
IIA. Management of Nuisance Algal Blooms in Reservoirs				
1. Define and evaluate major causes of nuisance algal blooms in CE reservoirs	EL, WES	Sep 79	100,000	Complete, results to be published in FY 80, input to IIA.2
2. Develop and evaluate reservoir operational and management methods for controlling algal blooms	EL, WES	Sep 83	--	Initiate in FY 80
3. Evaluation of plant-mediated phosphorus release from sediments and effects on algal growth	EL, WES	Sep 80	145,000	First phase experiments completed
IIB. Guidelines for Determining Releases to Meet Environmental Quality Objectives				
1-4. Guidelines for determining reservoir releases to meet environmental quality objectives	EL, WES; FWS-National Reservoir Research Program: Contract, Dr. James Duke, Consultant	Sep 83	535,000	Active, sites selected, data collection ongoing to establish baseline conditions
IIC. Operational and Management Strategies for Reservoir Contaminants				
1. Survey of the nature and magnitude of reservoir contaminant problems	EL, WES	Sep 79	20,000	Complete, input to IIC.2
2. Fate and effects of major chemical contaminants in reservoirs	EL, WES	Sep 80	30,000	Active

(Continued)

* Abbreviations used in this column are defined as follows:

EL - Environmental Laboratory
HL - Hydraulics Laboratory
WES - Waterways Experiment Station
HEC - Hydraulics Engineering Center
FWS - Fish and Wildlife Service
USEPA - U. S. Environmental Protection Agency
CRREL - Cold Regions Research and Engineering Laboratory
USAE - U. S. Army Engineer
LSU - Louisiana State University

EWQOS STATUS SUMMARY, FY 79 (Concluded)

Project Title/Work Unit/Task	Mode of Conduct	Completion	Cost to Date	Status
IID. Reservoir Regulation Techniques for Water Quality Management				
1. Reservoir regulation constraints for water quality management	EL, WES	Sep 78	$ 68,000	Complete, internal working document, input to IID.2 and IID.3
2. Reservoir regulation techniques for water quality management	HL, WES	Sep 81	87,000	Active
3. Reservoir system regulation for water quality control	HEC	Sep 83	60,000	Active
IIE. Environmental Effects of Fluctuating Reservoir Water Levels				
1. Vegetation for reducing effects of fluctuating pool levels	EL, WES	Sep 83	389,000	Site selected and planted, literature review complete, flood trials initiated
IIF. Reservoir Site Preparation				
1. Develop procedures for reservoir site preparation and filling	EL, WES	Sep 83	25,000	Active
III. Engineering Techniques for Meeting Reservoir Water Quality Objectives				
IIIA. Techniques to Meet Environmental Quality Objectives for Reservoir Releases				
1. Evaluate field reaeration data at existing structures	HL, WES	Sep 82	165,000	Active, report being reviewed
2. Develop techniques to determine the reaeration potential of structural modifications	HL, WES	Sep 81	141,000	Active, Miscellaneous Paper - Gas Tracer Measurements of Reaeration; Application to Hydraulic Models
4. Describe the selective withdrawal characteristics of various outlet configurations	HL, WES	Sep 82	280,000	Active, revised design guidance available
IIIB. In-Reservoir Techniques for Improvement of Environmental Quality				
1. Evaluate the effectiveness of reservoir mixing/destratification techniques	HL, WES	Sep 81	150,000	Active, first phase evaluation published (TR E-79-1)
2. Environmental effects associated with reservoir mixing/destratification aeration/oxygenation techniques	EL, WES	Sep 82	--	Initiate in FY 80
4. Evaluate the effectiveness of reservoir aeration/oxygenation techniques	HL, WES	Sep 83	110,000	Active
IV. Environmental Assessment Techniques for Project Planning and Operationl Requirements				
IVA. Alternative Techniques for Environmental Analysis	EL, WES	Sep 83	486,000	Active, EC published, review of applicable methods being conducted
IVB. Data Management and Indices for Environmental Assessment				
1. Review and evaluate data management techniques applicable to environmental assessment	EL, WES	Sep 80	49,000	Complete, survey report to be published in FY 80
2. Evaluate selected biological indices that have potential application to impact assessment	EL, WES	Sep 83	90,000	Active
V. Environmental Impacts of Waterway Activities				
VA. Environmental Impact of Selected Channel Alignment and Bank Revetment Alternatives on Waterways	EL, WES	Sep 83	145,000	Active
VB. Impacts of Navigation Activities on Waterways	EL, WES	Sep 83	115,000	Active
VI. Waterway Project Design and Operation for Meeting Environmental Objectives				
VIA. Operational Procedures for Waterway Projects to Attain Environmental Quality Objectives				
1. Identify, document, and evaluate the effects of waterway operational procedures on environmental quality	EL, WES	Sep 80	60,000	Survey complete
VIB. Design and Construction Techniques for Waterway Projects to Attain Environmental Water Quality Objectives				
1. Identify, evaluate, document factors in design and construction of waterway projects affecting environmental objectives	EL, WES	Sep 80	95,000	Survey completed
VII. Long-Term Comprehensive Field Studies				
VIIA. Reservoir Field Studies; Field Studies for Environmental and Water Quality Aspects of Reservoirs 1. DeGray Reservoir 2. Red Rock Reservoir 3. Eau Galle 4. West Point Reservoir	EL, WES: USAE District, Rock Island; Arkansas Water Resources Research Center	Sep 83	1,500,000	Final selection complete, pilot surveys and initial data base complete, full-scale data collection under way
VIIB. Waterway Field Studies; Long-Term Field Studies Associated with the Environmental Quality of Waterway Projects 1. Tennessee-Tombigbee 2. Mississippi River	EL, WES; Contract, FWS Co-op Unit at LSU	Sep 83	1,440,000	Final selection complete, pilot surveys and initial data base complete, full-scale data collection under way

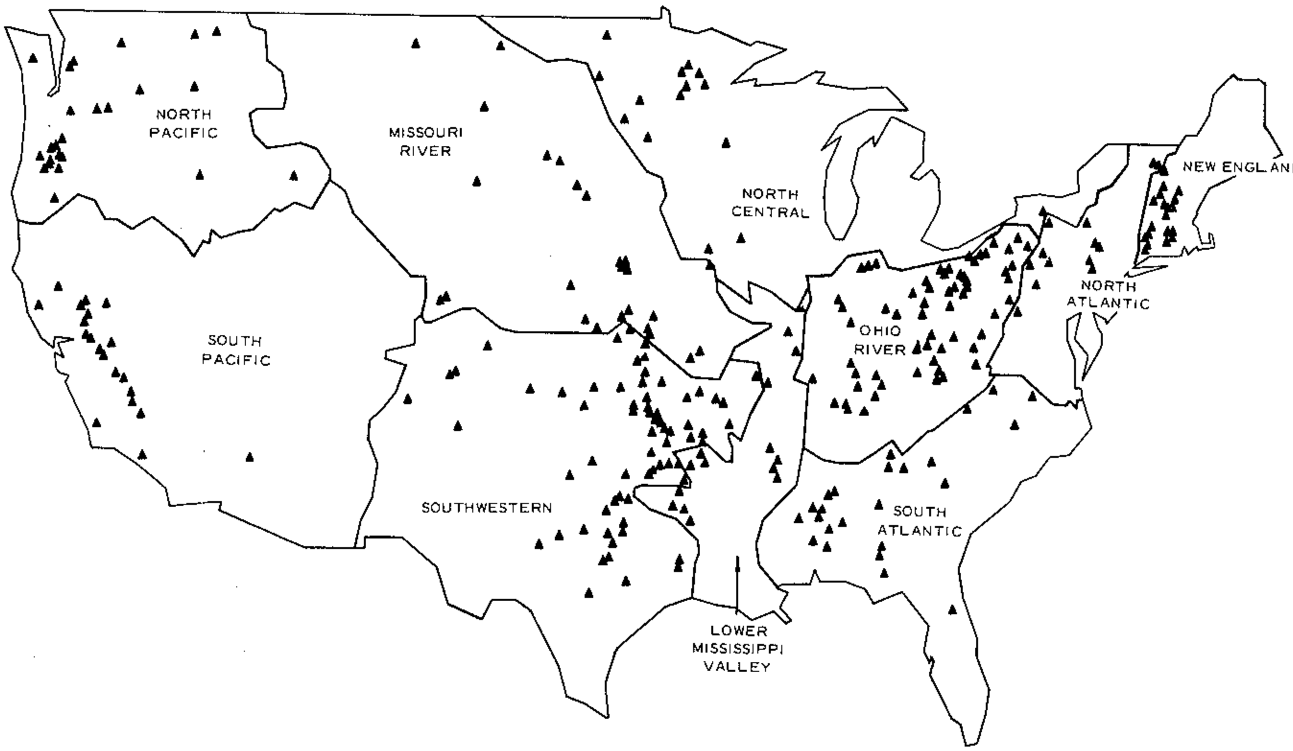

Figure 1. Regional Distribution by CE Divisions of Reservoirs Contained in the Data Base

locations, delineated by CE Divisions, are indicated in Figure 1 above.

The question of possible differences between natural and man-made lakes will play an important role in the evaluation and construction of simplified predictive techniques. Since these models relate system response variables to one or more causal factors, significant differences in the relative importance of various causal factors can seriously limit the use of empirical models developed for natural lakes to predict system responses for reservoirs.

Preliminary analyses of information contained in the NES data base have, in fact, identified several differences between natural lakes and reservoirs with respect to morphology, hydrology, and water quality (Table 1). CE reservoirs are, on the average, larger and deeper and have larger watersheds than do natural lakes. A threefold difference in the drainage area to surface area ratio results in a significantly greater inflow to reservoirs. Nutrient loading rates are also higher for reservoirs. Several differences in water quality variables of importance in evaluating eutrophication are also apparent. Total phosphorus and chlorophyll a concentrations are greater for natural lakes, while inorganic nitrogen concentrations are higher in CE reservoirs. Secchi disc depth is less for reservoirs despite lower chlorophyll a concentration, which suggests the possible importance of nonalgal turbidity in affecting light availability in reservoirs.

TABLE 1. COMPARISONS OF NATURAL LAKES AND CE RESERVOIRS

	Location Mean Variable Value	
Variable	**Natural Lakes**	**CE Reservoirs**
Watershed Size and Morphology:		
Drainage area, km^2	222	3228
Surface area, km^2	5.6	34.5
Drainage area/surface area	33	93
Lake volume, $km^2 \cdot m$	27.3	239.0
Mean lake depth, m	4.5	6.9
Hydrology:		
Water residence time, yr	0.74	0.37
Areal hydraulic load, m/yr	6.5	19.0
Loading Characteristics:		
Phosphorus loading, $g/m^2 \cdot yr$	0.87	1.7
Nitrogen loading, $g/m^2 \cdot yr$	18	28
Water Quality:		
Total phosphorus, mg/*l*	0.054	0.039
Inorganic nitrogen, mg/*l*	0.2	0.3
Secchi depth, m	1.4	1.1
Chlorophyll a, mg/m^3	14.0	8.9

Future efforts in Task IE will include further comparisons of natural lakes and reservoirs, evaluation of existing models using the CE data base, and the possible development of new, simplified predictive methods. When completed, this task will provide valuable information to CE offices on the use of simplified techniques, their assumptions and limitations, and guidance on how they might be used in conjunction with other techniques to evaluate planning and management alternatives.

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, 636-3111, Ext. 3635.

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