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Water Quality R&D: Successful Bridging Between Theory and Applications

25 - 27 February 1986
New Orleans, LA

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A seminar on Water Quality R&D: Successful Bridging Between Theory and Applications was held on 25 - 27 February 1986 in New Orleans, Louisiana. The purpose of the seminar was to provide a forum for Corps of Engineers personnel who are routinely involved in water quality and water control work. Topics included application of water quality models, case studies on reservoir and river water quality, and case studies on coastal and estuarine water quality.

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Attendees:
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Sponsored By:
US Army Corps of Engineers
Committee on Water Quality
20 Massachusetts Avenue, NW
Washington, DC 20314-1000

Co-Sponsored By:
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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FOREWORD

A two-day seminar on "Water Quality R&D: Successful Bridging Between Theory and Applications" was held in New Orleans, Louisiana on 25-26 February 1986. The purpose of the seminar was to provide a forum for Corps of Engineers personnel who are routinely involved in water quality and water control work.

Topics addressed during the seminar and included in these proceedings include ten papers on Applications of R&D by various Corps R&D staff, nine papers on Reservoir and River Case Studies by Corps field office staff, and ten papers on Coastal and Estuarine Case Studies by both R&D and field office staff. An appendix is also included which contains abstract type presentations by those displaying materials during the poster session.

The seminar was co-sponsored by the Hydrologic Engineering Center and the Committee on Water Quality. This seminar proceedings, in addition to the general seminar coordination, was organized by Mr. R. G. Willey of the Hydrologic Engineering Center. Valuable assistance was graciously provided for coordination of the separate sessions by Mr. Earl Eiker, OCE; Dr. John Harrison, WES; Ms. Chris Correale, Wilmington District; Dr. Robert Engler, WES; Mr. John Grace, WES; and Dr. David Mathis, WRSC. The conference room, individual rooms and all local arrangements were organized by Mr. James Farrell, LMVD and Ms. Joan Fredricks, New Orleans District.

Two optional field trips were arranged by Ms. Fredricks for 27 February. The trips included either a trip on a Mississippi river boat through two Corps' locks or a visit through several local sewage treatment plants.

The views and conclusions expressed in these proceedings are those of the authors and are not intended to modify or replace official guidance or directives such as engineering regulations, manuals, circulars, or technical letters issued by the Office of the Chief of Engineers.

R. G. Willey
Editor

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Robert G. Willey	Hydrologic Engineering Center

SEMINAR ON
"WATER QUALITY R&D: SUCCESSFUL BRIDGING BETWEEN THEORY AND APPLICATIONS"
25-27 FEBRUARY 1986

Participants	Office	Phone	
Chandra Alloju	Fort Worth District	FTS	334-2880
Donald Anderson	Tennessee Valley Authority	FTS	858-7329
Dr. Mark Anthony	Ohio River Division	FTS	684-3070
Townsend Barker	New England Division	FTS	839-7631
Dennis Barnett	South Atlantic Division	FTS	242-4580
M. Pam Bedore	Detroit District	FTS	226-7855
Robert A. Biel	Louisville District	FTS	352-5640
Joseph O. Boda	Mobile District	FTS	537-3864
Robert H. Bosenberg	New Orleans District	(504)	862-2260
John Bruza	New Orleans District	(504)	862-1288
David P. Buelow	Ohio River Division	FTS	684-6252
Edmund B. Burkett	Mobile District	FTS	537-2737
Dr. John B. Bushman	Office of the Chief of Engineers	FTS	272-0132
Charles C. Calhoun, Jr.	Waterways Experiment Station	FTS	542-2001
Richard Cassidy	Portland District	FTS	423-6469
Dennis Chew	New Orleans District	(504)	862-2523
Carol A. Coch	New York District	FTS	264-5621
Glendon L. Coffee	Mobile District	FTS	537-2729
Chris Correale	Wilmington District	FTS	671-4749
David Cowgill	North Central Division	FTS	353-6354
Jim Crawford	New England Division	FTS	839-7211
Mark Dortch	Waterways Experiment Station	FTS	542-3517
Marvin A. Drake	New Orleans District	(504)	862-2532
Earl E. Eiker	Office of the Chief of Engineers	FTS	272-8509

Douglas Emanuel	Kansas City District	FTS	758-3773
Dr. Robert Engler	Waterways Experiment Station	FTS	542-3624
Arnoldo Escobar	Fort Worth District	FTS	334-3493
James Farrell	Lower Mississippi Valley Division	FTS	542-5890
Norman Francingues	Waterways Experiment Station	FTS	542-3703
Joan Fredricks	New Orleans District	(504)	862-2447
Thomas J. Furdek	St. Louis District	FTS	273-4008
James Gallagher	Savannah District	FTS	248-5515
James L. Gottesman	Office of the Chief of Engineers	FTS	272-0243
John Grace	Waterways Experiment Station	FTS	542-3346
John Harrison	Waterways Experiment Station	FTS	542-3227
Jim Helms	Seattle District	FTS	399-3544
Dennis Holme	St. Paul District	FTS	725-5951
Stacy Howington	Waterways Experiment Station	FTS	542-2939
David Johnson	Vicksburg District	FTS	542-7221
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Carl Keller	New Orleans District	(504)	862-2041
Dr. Robert Kennedy	Waterways Experiment Station	FTS	542-3659
Garland Kersh	Kansas City District	FTS	758-3773
Dr. William L. Klesch	Office of the Chief of Engineers	(202)	272-8529
Mike Koryak	Pittsburgh District	FTS	722-6831
James F. LaBounty	US Bureau of Reclamation, Denver	FTS	776-6002
Lynn M. Lamar	Office of the Chief of Engineers	FTS	272-8513
Mathew M. Laws	Mobile District	FTS	537-3829
Bob Lazor	Waterways Experiment Station	FTS	542-2935
Sandy Lemlich	Los Angeles District	FTS	798-0233
Joseph V. Letter	Waterways Experiment Station	FTS	542-2845

Jay Lincoln	Los Angeles District	FTS	798-6916
Walt Linder	Kansas City District	FTS	758-3854
David Lubianez	New England Division	(617)	928-4711
Dr. John Lunz	Waterways Experiment Station	FTS	542-3303
Rodney Mach	New Orleans District	(504)	862-2443
Dr. Jerry Mahloch	Waterways Experiment Station	FTS	542-3635
Morton Markowitz	South Pacific Division	FTS	556-6210
Dr. James Martin	Waterways Experiment Station	FTS	542-3283
Robert Martinson	New Orleans District	(504)	862-2258
David Mathis	Water Resources Support Center	FTS	385-3099
Victor McFarland	Waterways Experiment Station	FTS	542-3721
Dr. Ike McKim	Cold Regions Resrch and Engr Lab	FTS	836-4479
Dr. Clark McNair	Waterways Experiment Station	FTS	542-3674
Warren Mellema	Missouri River Division	FTS	864-7323
Jerry Miller	Vicksburg District	FTS	542-7130
Jan A. Miller	Chicago District	FTS	353-6518
Stephen J. Morrison	Charleston District	FTS	677-4614
Dr. Thomas Myers	Waterways Experiment Station	FTS	542-3939
Roger Myhre	St. Louis District	FTS	273-4008
Patrick L. Neichter	Louisville District	FTS	352-5878
Fred L. Nibling, Jr.	US Bureau of Reclamation, Denver	FTS	776-6017
George Nichol	Sacramento District	FTS	448-2510
William A. Otto	Omaha District	FTS	864-4622
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Andrew Petallides	North Atlantic Division	FTS	264-7459
Jesse Pfeiffer	Office of the Chief of Engineers	FTS	272-0257
Mary Lee Plumb-Mentjes	New Orleans District	(504)	862-2292

Theodore S. Postol	St. Louis District	FTS	273-5031
Dr. Richard E. Price	Vicksburg District	FTS	542-2644
Dr. Richard Punnett	Huntington District	FTS	924-5604
John Reddoch	New Orleans District	(504)	862-2277
Dr. Susan Ivester Rees	Mobile District	FTS	537-2724
Stanley T. Rikard	Savannah District	FTS	248-5816
John K. Robertson	New Orleans District	(504)	862-2318
Richard Roline	US Bureau of Reclamation, Denver	FTS	776-6005
Mark Rosenthal	New England Division	(802)	886-8111
Jim Ruane	Tennessee Valley Authority	FTS	858-7323
Bill Rushing	Waterways Experiment Station	FTS	542-3542
Harold T. Sansing	Nashville District	FTS	852-5675
Dr. Lloyd Saunders	Jacksonville District	FTS	946-2202
Mike Seckar	Baltimore District	FTS	922-4893
Steve Servay	New Orleans District	(504)	862-1816
Dennis Slate	New Orleans District	(504)	862-1287
James C. Staves	Tulsa District	FTS	745-7859
Ann Strong	Waterways Experiment Station	FTS	542-2726
Laura J. Swilley	New Orleans District	(504)	862-2272
Helene Takemoto	Pacific Ocean Division	(808)	438-2263
Dr. Bolyvong Tanovan	North Pacific Division	FTS	423-3764
Burnell J. Thibodeaux	New Orleans District	(504)	862-2445
Frank Urabeck	Seattle District	FTS	399-3708
LTC Kit Valentine	Office of the Chief of Engineers	FTS	272-0166
Memphis Vaughan, Jr.	Mobile District	FTS	537-2730
Dr. David Vigh	New Orleans District	(504)	862-2040
Dr. Thomas H. Wakeman	San Francisco District	(415)	332-5485

Oyster Creek

Charles Wener	New England Division	FTS	839-7686
Dr. Robert Whalin	Waterways Experiment Station	FTS	542-2664
Steve Wilhelms	Waterways Experiment Station	FTS	542-2475
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Frank Yelverton	Wilmington District	FTS	671-4640
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CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

REMOTE SENSING OF WATER QUALITY DATA

by

Harlan L. McKim *

INTRODUCTION

Remote sensing has come of age over the last five years and now has a great future in many water quality areas. Satellite data are available for the entire world. The resolution has gone from 80 m in the first Landsat series of satellites (1972) to 10 m in the French SPOT (Système Probatoire d'Observation de la Terre) satellite system launched in February 1986. The Thematic Mapper sensor system aboard Landsat-4 and -5 covers three spectral areas not previously obtained in the Landsat data series. The visible blue bands give a more detailed picture, with 30-m resolution, of the sediment plumes and other information on water habitats than do other spectral bands. The mid-infrared band is adding significantly to scientific knowledge of plant stress. The thermal band, at a resolution of 120 m, has much to offer, but not a great amount of research has been accomplished with thermal data.

Aircraft systems have long provided data on water quality in the projects we are responsible for. Color, infrared, and thermal sensors can provide information on plume structure and extent. Video cameras can be an effective way to identify and monitor potential trouble spots. Lidar and impulse radar systems will help define areas of deposition and measure ice cover thickness in the near future.

Advances in in-situ sensor technology continue to be impressive. It is now possible to obtain water quality data in near real time at any of our water project, navigational lock and dam, or estuarine environments while sitting at our desks. The quality of the data is assured as it passes from the sensor and data collection platform to GOES (Geostationary Operational Environmental Satellite) and down to the field offices, where it goes through stringent quality assurance and control procedures before it enters the data storage system (DSS). In the late 1980's, sensors and techniques for using the sensor data operationally will be available not only to the Corps water quality program, but to dredging, hydropower, environmental, water supply, and water management programs.

* U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755-1290

SATELLITE SYSTEMS

Landsat Multispectral Scanner (MSS) data

The first in a series of Landsat satellites was launched in July 1972. Presently two satellites are providing data -- Landsat-4 and Landsat-5; both satellites are in a near-polar orbit, at an altitude of 576 miles. The MSS is a line-scanning device that obtains data for an area 115 miles on a side, at a resolution of 80 m or 1.1 acres. The data are taken every 18 days over any given area on the Earth at the same local time. Data are obtained in four spectral regions -- two in the visible and two in the near infrared -- ranging from 0.5 μm to 1.1 μm.

Landsat Thematic mapper (TM) data

The Landsat-4 satellite which was launched in July 1982 had on board the next generation sensor after the MSS. The Thematic Mapper sensor is a high-resolution multispectral scanner. It is a mechanical line scanner device, similar to the MSS, but it scans and obtains data for six scan lines in both directions during the scanner sweep. (The MSS only scans and obtains data for six scan lines at a time in one direction.) The TM data are at a 30-m resolution for seven spectral bands ranging from the blue part of the spectrum into the thermal infrared region. The TM data constitute 8-bit information, as compared to the MSS sensor, which provides 6-bit information. This means there is a greater radiometric resolution with the TM sensor so we can map more subtle changes in the land and water. The additional blue band ranges from 0.45 to 0.52 μm. There are two additional bands in the near infrared portion of the spectrum, at 1.55 to 1.75 μm and 2.08 to 2.35 μm. Also, a thermal band located from 10.4 to 12.5 μm is obtained at a 120-m resolution.

French SPOT High Resolution Visible (HRV) sensor

The SPOT satellite was launched on 21 February 1986 by the French government. It is carrying two HRV instruments. The satellite is in a polar orbit, similar to the Landsat satellites. The orbital cycle is longer at 26 days and images later in the morning. This new generation sensor -- the HRV -- is a "push broom" scanner, which means it obtains the data instantaneously in one sweep. There are no mechanical moving parts, which characterized the MSS and TM sensors. The instrument is also pointable, imaging ±26° from nadir. The data are of high radiometric quality, similar to the TM, with 8-bit data for 256 radiometric levels. There are two modes of operation, the multispectral and panchromatic modes. The 20-m multispectral mode covers three spectral regions -- 2 in the visible and 1 in the near infrared. The 10-m panchromatic mode covers a wide band ranging from 0.52 to 0.73 μm.

When the satellite is pointed straight down at nadir, the two HRV's image a 60-km-wide swath. With a 3-km overlap in the center, the total image width for both HRV's is 117 km. The satellites can point off to either side of the orbital path at 0.1° increments from nadir to 26°. The satellite can thus image any area within a 950-km swath centered on the orbital path. This allows for stereo acquisition of imagery and for more revisit opportunities over an area of interest. At our latitude, the sensor could image an area 11 times during a 26-day orbital path. A maximum of six stereo-pairs can also be obtained during the 26-day cycle.

AIRCRAFT SYSTEMS

Systems available for obtaining data on water quality from aircraft include active and passive systems for determining bathymetry, airborne spectroradiometers and thermal imagery.

Bathymetry

An impulse radar system that has been mounted in a helicopter and is used in the ice engineering research program to determine the depth of water and thickness of ice in a river is under evaluation at CRREL. The beam is swept parallel to the river to determine a cross section of the channel bottom. Such sensors could be used in the dredging program to map the channel bottom and define areas of shoaling.

Airborne laser mapping systems have demonstrated considerable potential for providing bathymetric data to water depths of 10 m or more and topography of adjacent beach and shore features. Both profiling and scanning (areal coverage) systems are available.

Spectroradiometer

A 512-channel spectroradiometer was mounted and flown in a Cessna 180. An electron beam scans the diode array with a raster of 500 lines, each line being one "monochromatic" channel of a complete spectrum. The spectral range is 0.4 to 1.1 μm; the dispersion is 700 nm over 500 channels or 1.4 nm per channel. At the nominal operating altitude of 600 m over land or water, and a speed of 200 km/hr, the footprint of a ten-frame spectrum is approximately 18 m square. The size of the footprint can be controlled by the operating altitude and speed of the aircraft, the focal length of the objective lens, and the number of frames per spectrum.

The airborne spectroradiometer can detect suspended sediment concentrations of up to 168 ppm. The curve for each concentration level peaks in the visible part of the spectrum. Concentrations of less than 25 ppm can easily be differentiated from clear water conditions.

The spectroradiometer can also detect changes in algae concentration. As the concentration increases, the chlorophyll absorbs more of the radiation in two spectral regions, creating a peak in the visible.

Thermal imagery

Thermal imagery has long been used to define water temperature. The warm areas of the image are usually shown in white; the cooler areas are the darker tones. Temperatures of 1°C can be differentiated using thermal imagery.

IN SITU SENSORS

There are many water quality systems available to monitor pH, conductivity, dissolved oxygen, temperature and depth. Techniques are now being evaluated to obtain their data in near real time via the GOES system.

Various conductivity meters and temperature probes are being tested for use in the Rock Island District by interfacing the instrumentation to data collection platforms. The data, read through the GOES data collection system, can be used to graph conductivity and temperature for near real time conditions at the District.

APPLICATIONS

Bathymetric charts of coastal areas can be prepared from Landsat MSS data. Computer programs have been developed to map water depths, one for deep water and another for shallow water.

A suspended sediment map of Delaware Bay was prepared by the Oceanographic Group at the University of Delaware. The map was prepared using Landsat MSS data, the concentrations being verified with ground truth water quality sampling. Suspended sediment concentrations ranged from 5 to over 100 mg/L.

During July 1983, CRREL had the Hart/Miller Island flown with an aircraft scanner to obtain 20-m multispectral data and 10-m panchromatic data, similar to what we would expect from the SPOT High Resolution Visible sensor.

The image was preprocessed and filtered first so that the maximum amount of information could be extracted from the water pixels. The digital gray levels in the water were enhanced using sophisticated algorithms. The tonal patterns were somewhat indistinct, and a set of plumes were visible flowing from the north end of the island to the west. Applying an edge detection algorithm to the preprocessed data showed the strongest edges where plumes occur. Two distinctly different water types were adjacent to each other. Our research is working towards developing a way to determine the relational aspects of all the edges in order to have an automated system to detect and analyze plumes. In this way, in conjunction with selected water quality sampling, we can develop a nearly continuous monitoring system for large geographic areas using high-resolution satellite data.

CONCLUSION

A five-year cooperative demonstration program has begun at the Rock Island District to demonstrate remote sensing techniques in their Water Control Data Center activities. Specifically, remote sensing techniques in water quality are to be demonstrated in dredging, hydropower and reservoir regulation. The water quality parameters that we will be examining include temperature, pH, conductivity, dissolved oxygen, ammonium, nitrate/nitrite and water depth. A proposal has been submitted and is under review to examine all available sensors addressing these water quality measurements. Iowa State will test their prototype water quality measurement system and compare these measurements to field-collected water samples taken at Saylorville Lake. The water quality probes (conductivity, dissolved oxygen, temperature and pH) will be tested for reliability, accuracy and degree of maintenance. Each sensor will be interfaced to a data collection platform. This will allow for comparison of three independent measurements to check the quality control and assurance of the water quality data.

WATER QUALITY ASSESSMENT AND MANAGEMENT FOR RESERVOIRS

BY

Robert H. Kennedy[1]

INTRODUCTION

Historically, man has constructed dams for the purpose of controlling the movement of water. In areas in which water is present in excess, dams provide a means for reducing the impacts of flooding; in areas in which water is scarce, dams allow for increased utilization through storage and retention. Dams, and the reservoirs which they impound, also provide for hydroelectric power generation. To better accomplish these purposes and thereby meet the needs of a growing society, comprehenive methods for managing water quantity have been developed and implemented.

Recently, new emphasis has been placed on the environmental and water quality aspects of reservoirs. While these aspects have always received some degree of consideration, nationwide concern over the deterioration of the environment has focused public attention on the quality of water-based recreational resources. This attention has prompted implementation of local, state and Federal regulations, and efforts by public and private organizations to better understand aquatic ecosystems and their problems.

To better meet the challenge of maintaining and/or improving the environmental quality of Civil Works projects, the Corps has conducted several comprehensive, environmentally-oriented research programs. The Dredged Material Research Program (DMRP), initiated in 1973 and completed in 1978, resulted in the development of the technology required to remove and dispose of impacts. Efforts in this area continue under the sponsorship of the Dredging Operations Technical Support (DOTS) Program, the Long-term Effects of Dredging Operations (LEDO) Program, and the Field Verification Program (FVP). The Aquatic Plant Control Research Program (APCRP), initiated in 1963, continues to provide basic and applied research related to methodologies for the management of nuisance aquatic vegetation. The recently completed Environmental and Water Quality Operational Studies (EWQOS) Program, along with the newly established Water Quality Program, allowed delineation of relations between project design, contruction and operation, and water quality. This provided the

[1] Aquatic Processes and Effects Group, Ecosystem Research and Simulation Division, Environmental Laboratory, WES

basis for the development of assessment methodologies and techniques for improved management of reservoir water quality in ways consistent with other project purposes. EWQOS also paved the way for cooperative demonstrations of technology, such as those under way at Richard B. Russell Lake (Savannah District) and Eau Galle Lake (St. Paul District). The former demonstration, as well as the transfer of technology, is being supported by the Water Operations Technical Support (WOTS) Program; the latter is supported by the Algal Control Demonstration Program.

Together, these and other ongoing research efforts, as well as initiatives by District and Division offices, have resulted in a wealth of information and numerous tools for environmental and water quality management of reservoirs. Unfortunately, their utilization is hampered by the fact that those delegated the responsibility for reservoir management are confronted with a large and diverse body of information documented in a large number of technical documents distributed across several research programs. Lacking is the means for easy access to and use of this information. Also lacking is a comprehensive and universal plan or protocol for the development and implementation of holistic management initiatives.

PROBLEM SOLVING AND WATER QUALITY MANAGEMENT

Problem solving and the development of management strategies should involve five basic steps; (1) data collection and assessment, (2) problem identification, (3) development of management alternatives, (4) implementation, and (5) post-implementation evaluation. Methods used for the assessment and evaluation of environmental and water quality are diverse. Considering constraints on manpower and funding, future efforts to assess and evaluate environmental and water quality must be cost and manpower effective. Methods for designing and conducting data collection efforts, for storing, analyzing and evaluating data, and for incorporating this information into the decision making process must be streamlined. Attempts should also be made to establish uniform guidelines for field office efforts.

The assessment and evaluation process should lead to a defining of problems and possible priorities for their solution. This can be accomplished through comprehensive descriptions of environmental quality and through reviews of recorded user complaints and/or conflicts. Provisions should be made for the ranking of problems through the application of a graded evaluation scale. This should be a holistic approach which considers the entire range of factors influencing environmental, operational, and recreational value of the project. Since this process can occur on several levels (project, district, division, etc.), the ranking and prioritizing of problems or potential problems will aid in a more effective allocation of funds and manpower.

A variety of management tools and techniques have been developed and demonstrated during the course of the above mentioned research programs and through such efforts as the EPA-funded "Clean Lakes Program." Although technically diverse, they can be broadly grouped as in-lake or operational techniques. In-lake techniques are designed to address such problems as anoxia in bottom waters, internal nutrient loading, excessive algal or macrophyte abundance, turbidity and storage loss due to excessive sediment accumulation, and shoreline erosion. Many of these techniques can be implemented either on a whole-lake basis or targeted against localized problem conditions. Operational techniques may involve either design and structural considerations or modifications to current operational procedures. While many of these techniques were developed for the purpose of ensuring that acceptable conditions are maintained in tailwaters, many also offer additional means for managing environmental and water quality within the pool.

Evaluations of the relative merits (e.g., cost, effectiveness, benefits to be gained, possible secondary impacts, etc.) of each applicable technique should provide the basis upon which a particular technique is chosen for implementation. In many cases, a multi-technique approach will be appropriate. Considering the great size of many reservoir projects, decisions may also have to be made concerning the spatial or temporal limits of the management strategy.

Post-implementation evaluation is an important component of any management strategy. Only through such efforts can success, and therefore benefits, be quantified. Such assessments also provide necessary information for the refinement of management plans.

SUMMARY

The optimization of benefits of the reservoir ecosystem requires the development and application of a holistic approach to the management of these valuable resources. However, while the appropriate technologies are currently available, a framework within which to construct such a management approach is lacking. Such an approach will require careful integration of selected planning, operation, and construction activities by field offices. If successful, the development of these improved methods for environmental and water quality management will lead to longterm benefits to the Corps and to those who utilize the reservoir resource.

HEC-5Q: System Water Quality Modeling

R. G. Willey [1]

INTRODUCTION

Several state-of-the-art models [2,3,5] are available for analyzing water quality conditions in complex reservoir systems for a given set of operational conditions. Some of these models can even make operational decisions regarding proper gate regulations to obtain a desirable water quality condition at a dam site for a given set of flow conditions.

HEC-5Q, Simulation of Flood Control and Conservation Systems (Including Water Quality Analysis) [4] computer model, has the unique capabilities to accept user-specified water quantity and quality needs system-wide and to decide how to regulate the network of reservoirs. The decision criteria are programmed to consider flood control, hydropower, instream flow (municipal, industrial, irrigation, water supply, fish habitat) and water quality requirements.

The HEC-5Q program was first applied to the Sacramento River system in California and a report was published in July 1985 [8]. Two other applications are in progress, the Kanawha and Monongahela River systems, and are expected to be completed by September 1986. A brief description of the HEC-5Q concepts and these three applications will be discussed below.

MATHEMATICAL MODEL CONCEPTS

HEC-5Q has been developed specifically for evaluating the type of problem shown in Figure 1. The model is capable of evaluating a reservoir system of up to ten reservoirs and up to thirty control points. The model will define a best system operation for water quantity and quality; evaluating operational concerns like flood control, hydropower, water supply, and irrigation diversions. Since the computer program users manual [4], and several technical papers [1,6,7] adequately document the details of the model concepts and the input description, only a brief overview is provided below.

[1] Hydraulic Engineer, U.S. Army Corps of Engineers, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616

Flow Simulation Module

The flow simulation module was developed to assist in planning studies for evaluating proposed reservoirs in a system and to assist in sizing the flood control and conservation storage requirements for each project recommended for the system. The program can be used to show the effects of existing and/or proposed reservoirs on flows and damages in a complex reservoir system. The program can also be used in selecting the proper reservoir releases throughout the system to minimize flooding as much as possible while maintaining a balance of flood control storage ("balanced pool") among the reservoirs.

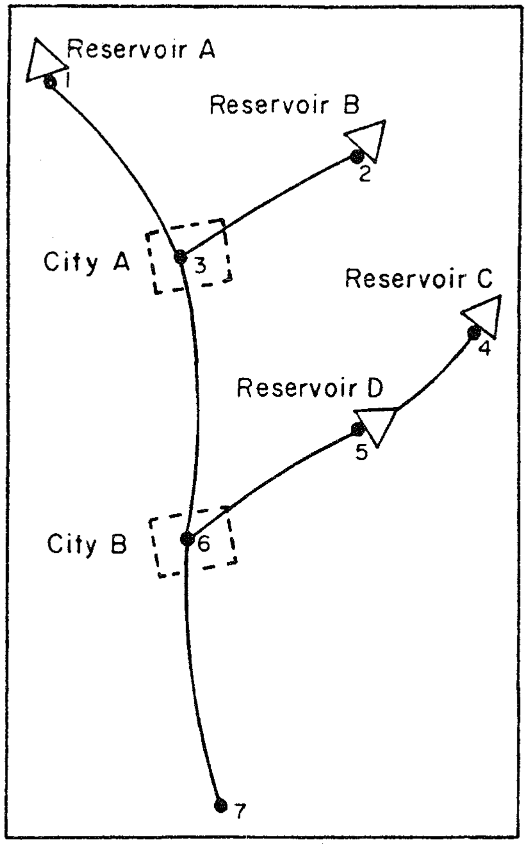

Figure I
TYPICAL RESERVOIR SYSTEM SCHEMATIC

Water Quality Simulation Module

The water quality simulation module is capable of analyzing water temperature and up to three conservative and three non-conservative constituents. If at least one of the nonconservative constituents is an oxygen demanding parameter, dissolved oxygen can also be analyzed.

The water quality simulation module accepts system flows generated by the flow simulation module and computes the distribution of all the water quality constituents in up to ten reservoirs and their associated downstream reaches. The ten reservoirs may be in any configuration.

Gate openings in reservoir multilevel withdrawal structures are selected to meet user-specified water quality objectives at downstream control points. If the objectives cannot be satisfied with the previously computed "balanced pool" flows, the model will compute a modified flow distribution necessary to better satisfy all downstream objectives. With these capabilities, the planner may evaluate the effects on water quality of proposed reservoir-stream system modifications and determine how a reservoir intake structure should be operated to achieve desired water quality objectives within the system.

SACRAMENTO RIVER SYSTEM APPLICATION

The Sacramento Valley reservoir system consists of four major reservoirs as shown in Figure 2. Shasta and Keswick Reservoirs are located on the Sacramento River in northern California about 240 miles north of Sacramento. Below Shasta and above Keswick, inter-basin water transfers enter the Sacramento River through Spring Creek. Along the Sacramento River, Cow Creek and Cottonwood Creek are major inflowing tributaries and the Anderson-Cottonwood (ACID), Tehama-Colusa (TC), Corning (C) and Glenn-Colusa (GCID) Irrigation District Canals are major irrigation diversions.

Oroville Reservoir is located on the Feather River in the Sierra foothills about 100 miles north of Sacramento. Major tributaries entering the Feather River include the Yuba and Bear Rivers. Major diversions are located immediately below Oroville Dam from the Thermalito Afterbay. The Feather River flows into the Sacramento River near Verona.

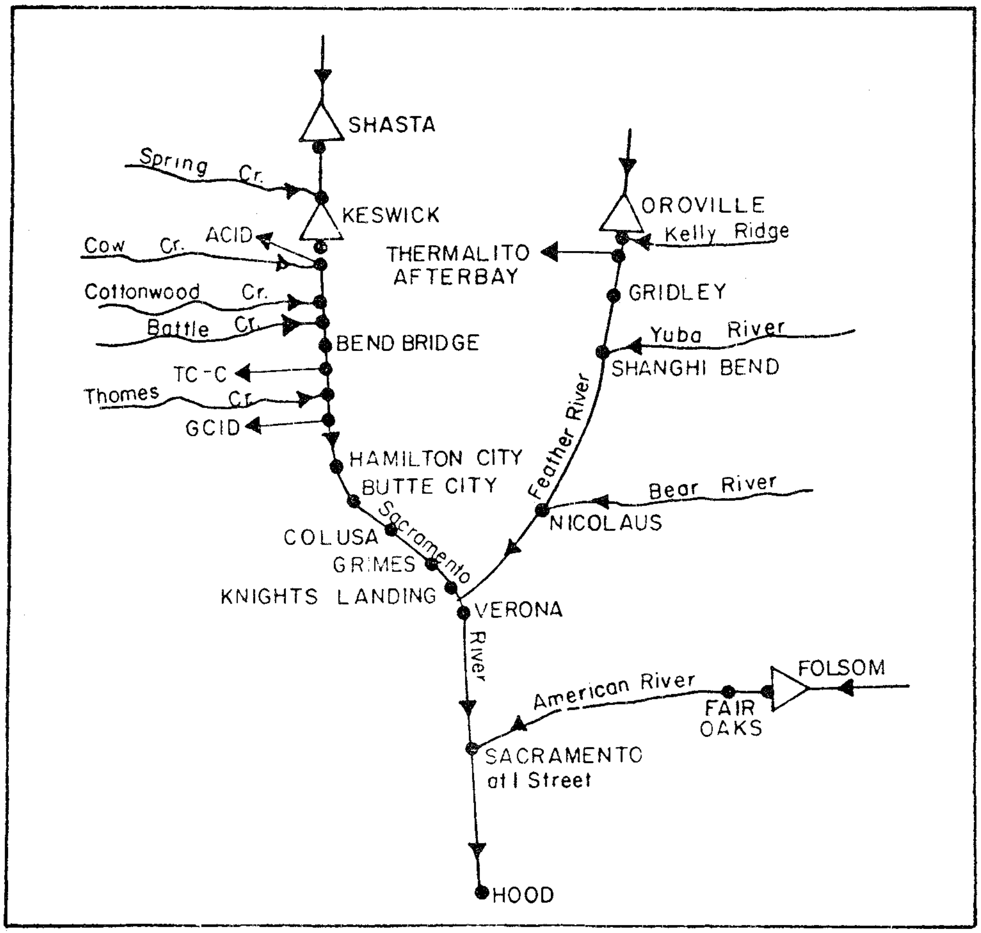

Figure 2
SACRAMENTO VALLEY RESERVOIR SYSTEM SCHEMATIC

Folsom Reservoir is located on the American River in the Sierra foothills about 30 miles east of Sacramento. The American River below Folsom Reservoir is leveed with no major tributaries entering before its confluence with the Sacramento River at Sacramento.

The Sacramento River continues to flow south towards the San Francisco Bay. This study's lower boundary is located near Hood about 20 miles south of Sacramento.

The application of the HEC-5Q model to the Sacramento Valley reservoir system, includes data assembly, model execution and interpretation of results as described below and elsewhere in more detail [8].

Data Assembly

The HEC-5Q model data requirements are similar to those of most comprehensive water quality models. The data to be assembled are categorized into three types: time independent, required time dependent and optional time dependent.

The time independent data include: physical description of the reservoir (i.e., elevation, volume, surface area, discharge capacity, and vertical reservoir segmentation), physical description of the river (i.e., cross sections, channel discharge capacity, and river reach segmentation), control point desired and required flows, model coefficients (i.e., flow routing; reservoir diffusion; physical, chemical and biological reaction rates) and initial conditions for the start of the simulation. The required time dependent data include: evaporation, meteorology, diversions, inflow quantity and quality for all reservoir and river tributaries, discharge quantity from reservoirs (only required to reproduce historical operation), and control point target flow and water quality conditions. The optional time dependent data include: reservoir storages; river flows at other than control points; and reservoir and river water quality profiles. These data are used as checks on the model output in contrast to the previously mentioned data which are required to make the model work.

Sources for the data categorized above are numerous. In general, they include all water-related agencies at the federal, state, local and private levels. Meteorological data are readily available from the U.S. Weather Service, local airports and universities. The primary data source is the NOAA's National Weather Service (NWS) office in Asheville, North Carolina.

Tributary inflows, diversions and reservoir discharges may be readily available from WATSTORE and STORET data systems. WATSTORE is managed by the USGS and contains streamflow data. STORET is managed by the EPA and contains water quality data. These computer data systems can often provide the necessary tributary inflow quantity and quality data.

Model Execution

The model simulation for the Sacramento Valley system used temperature, specific conductance (sometimes called electrical conductivity), alkalinity, carbonaceous biochemical oxygen demand (BOD), ammonia (NH_3) and dissolved oxygen (DO). These specific parameters were chosen based on the availability of at least limited data.

The model can be used for existing and/or proposed reservoirs. If an existing condition is being simulated, usually the objective is to reproduce historical events through model calibration. Selection of the calibration option can significantly decrease computer time by not using the time-consuming linear and non-linear programming algorithms in the model.

Once the model has been calibrated, the objective may be to modify an existing reservoir operation pattern or to evaluate the impact of proposed new reservoirs or channel modifications. This analysis requires the use of the linear and non-linear programming algorithms. These algorithms compute the water quality targets at the dam which will best meet all the user-specified downstream targets and decide on the best gate operations to meet these computed targets.

The simulation mode discussed above can be used either to evaluate the best water quality that can be provided throughout the system for given reservoir discharges (obtained either external to the simulation or determined by the HEC-5 flow simulation module) or to evaluate the best water quality operation without prespecified discharge quantities. The former operation is referred to as a balanced pool operation and the latter as a flow augmentation operation.

When using the balanced pool operation, the HEC-5Q program simply evaluates the best vertical level for withdrawal (assuming multiple level intakes are available) at each reservoir to meet all downstream water quality targets for the given reservoir discharge determined by the flow simulation module.

The flow augmentation operation allows the model to relax the balanced pool concept and to decide how much flow should come from which reservoir and at which vertical level in order to meet downstream water quality targets. Sometimes downstream water quality improvements require significantly increased discharge rates to obtain only small improvements in water quality. This flow augmentation operation is the most time consuming mode of execution.

For the Sacramento River application, the input data set was executed using the calibration option. Application of this option allows the user to define the exact level of the intake structure operated. This is the normal method of model application when calibrating the model to observed historical data.

Interpretation of Results

The HEC-5Q execution of the Sacramento Valley reservoir system produced results which were compared to observed water quantity and quality data in the four reservoirs and at all downstream control points. The data for comparison purposes consisted of discharge rates at most control points as well as water temperature at many of the same locations. Other water quality parameters are less available but were compared where they were available. Selected portions of the graphical display of these results are shown in Figures 3-6 for the reservoirs and at selected locations along the stream network.

These plots satisfactorily demonstrate the capability of HEC-5Q to reasonably reproduce observed reservoir and stream profiles on large systems. The legend on the reservoir temperature graph defines simulated and observed data for various dates. Shasta, Oroville and Folsom Reservoirs have sufficient observed temperature data to be useful for calibration purposes. Sufficient observed data for the other parameters were not available. (Only data for Shasta Reservoir are shown due to space limitations.) Considering the model limitation (at the time of application, but since corrected) of having only one weather station for the entire system, it is the authors' opinion that the reproduction is quite good. Perhaps some further refinement could be achieved with additional trials but the acceptability of the model can be demonstrated with these results.

The legend on the stream plots defines the various observed and simulated water quality parameters for the study period. Simulated constituents 1 and 2 are specific conductance (or EC) and alkalinity. Unlike the simulated data, the observed data points are often more than one day apart. Some caution should be applied to interpretation of the connecting line between observed data points further apart than one or two days.

In general, the calibration of the model is quite good along the Sacramento River for all the observed parameters down to Hamilton City, inclusive. (Only data for Hamilton City are shown due to space limitations.) Butte City and Colusa measured temperatures show that significant warming of this reach of the Sacramento River takes place, at least during the Spring (April and May 1956). This temperature increase, in addition to the lack of sufficient simulated quantity of flow at Butte City and Colusa (compared to accurate simulation of flow at Bend Bridge), suggests that the undefined return flows on the Sacramento River between Hamilton City and Knights Landing are significant and need to be evaluated.

The Feather River below Oroville and the American River below Folsom lack sufficient water quality data to provide adequate information for calibration purposes.

Since the Sacramento River below Sacramento is the combined product of all three river systems, the inaccuracies already discussed are also apparent at this location. Careful interpretation and

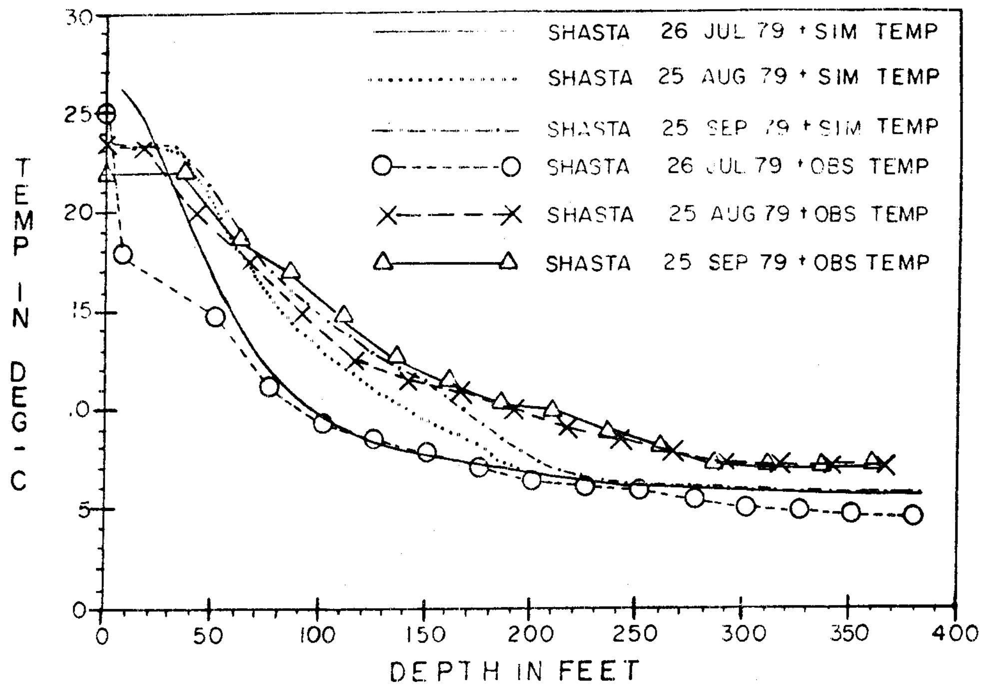

Figure 3

SHASTA RESERVOIR TEMPERATURE PROFILES

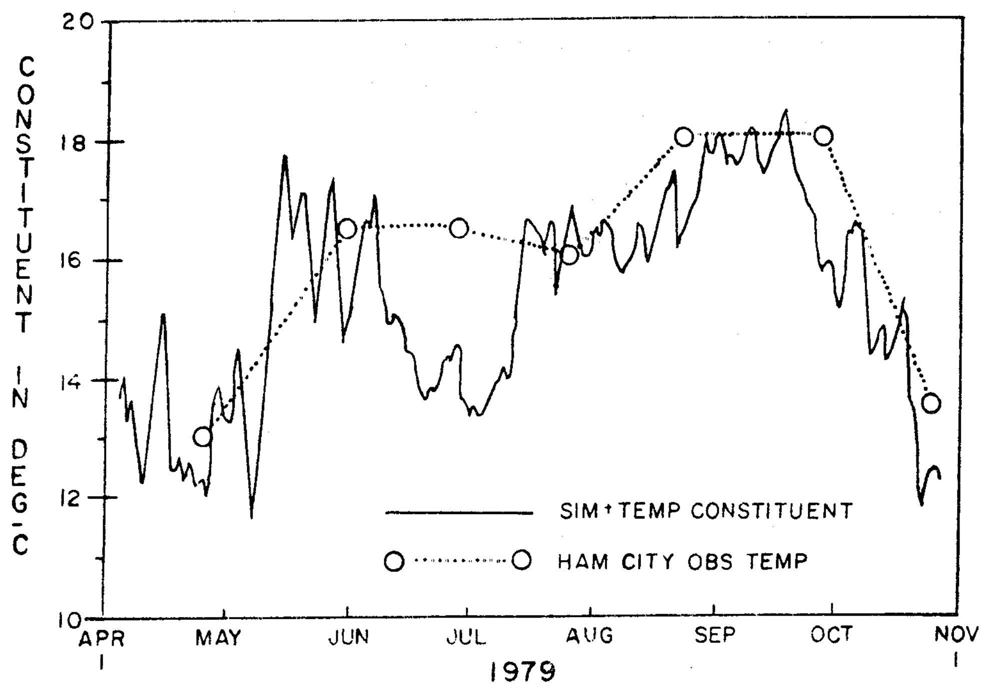

Figure 4

SACRAMENTO RIVER AT HAMILTON CITY – WATER TEMPERATURE

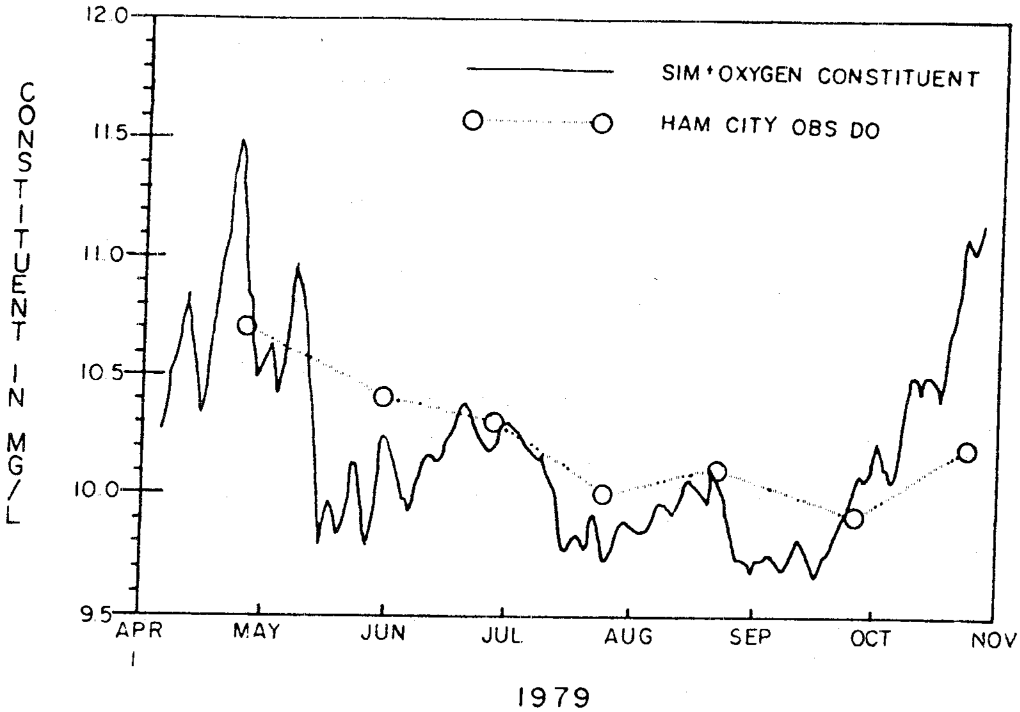

Figure 5

SACRAMENTO RIVER AT HAMILTON CITY-DISSOLVED OXYGEN

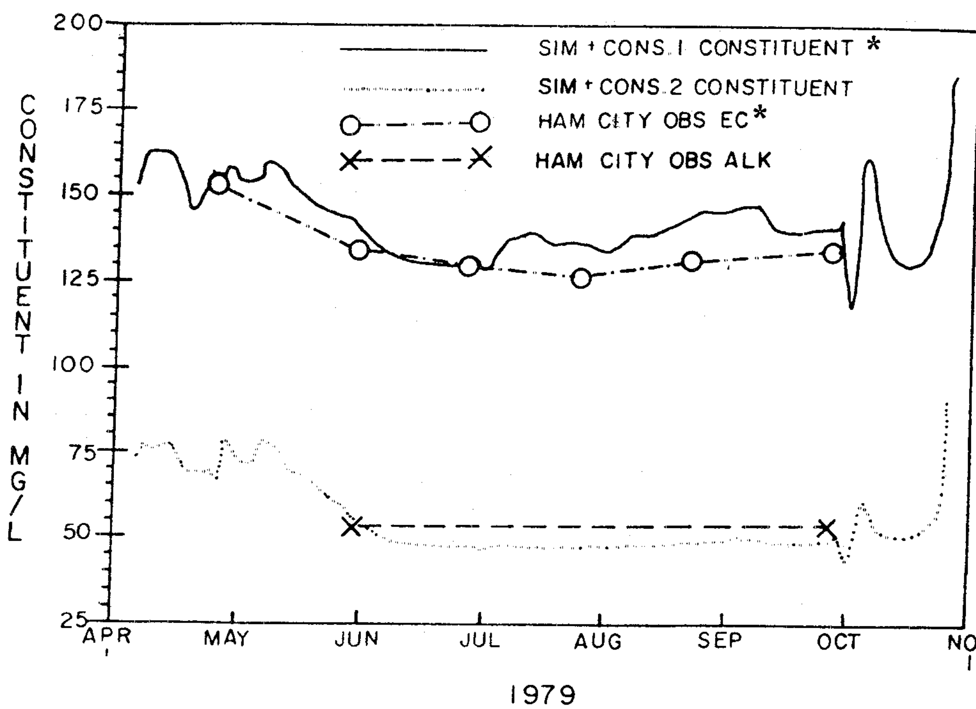

Figure 6

SACRAMENTO RIVER AT HAMILTON CITY - SPECIFIC CONDUCTANCE (EC) & ALKALINITY

*EC units are in micromhos

evaluation of all these results lead the authors to encourage the continued application of this model to help develop understanding of the workings and operation of any stream system.

KANAWHA RIVER SYSTEM APPLICATION

The Kanawha River system consists of three major reservoirs as shown in Figure 7. Bluestone Lake Dam on the New River is located about 107 miles south of Charleston, West Virginia. The Greenbrier River, a significant tributary, drains into the New River immediately below Bluestone Lake Dam and above Hinton, West Virginia; the site of significant gaged flow and water quality data. The Summersville Lake Dam on the Gauley River flows into the New River at Kanawha Falls, about 40 miles above Charleston. The Sutton Lake Dam on the Elk River flows into the Kanawha River at Charleston. The New River is renamed the Kanawha River at Kanawha Falls.

The Kanawha River system is being evaluated using HEC-5Q for temperature, specific conductance (or electrical conductance, EC) biochemical oxygen demand (BOD) and dissolved oxygen (DO). Since the necessary input data are available at Hinton (below Bluestone Lake) and analysis of Bluestone Lake is of no interest, only the two lakes, Summersville and Sutton, are being analyzed along with the three-river network.

The study is still in progress. Only initial calibration efforts have been completed. This study will be the second test case of real prototype data and has already helped debug several parts of the code not previously tested. The case is similar to the Sacramento River case but involves only Corps reservoirs; therefore, it is a likely candidate for future model testing in the real-time water control and reservoir operation area.

MONONGAHELA RIVER SYSTEM APPLICATION

The Monongahela River system consists of three major reservoirs as shown in Figure 8. Stonewall Jackson Lake Dam (presently under construction) is located about 202 miles south of Pittsburgh, Pennsylvania, on the West Fork Monongahela River. Tygart Lake Dam about 152 miles north of Pittsburgh on the Tygart River drains into the Monongahela River at Fairmont, West Virginia (CP25 in Figure 8). Youghiogheny Lake Dam about 85 miles east of Pittsburgh on the Youghiogheny River drains into the Monongahela River at Braddock, West Virginia (CP65). Braddock is about 11 miles south of Pittsburgh.

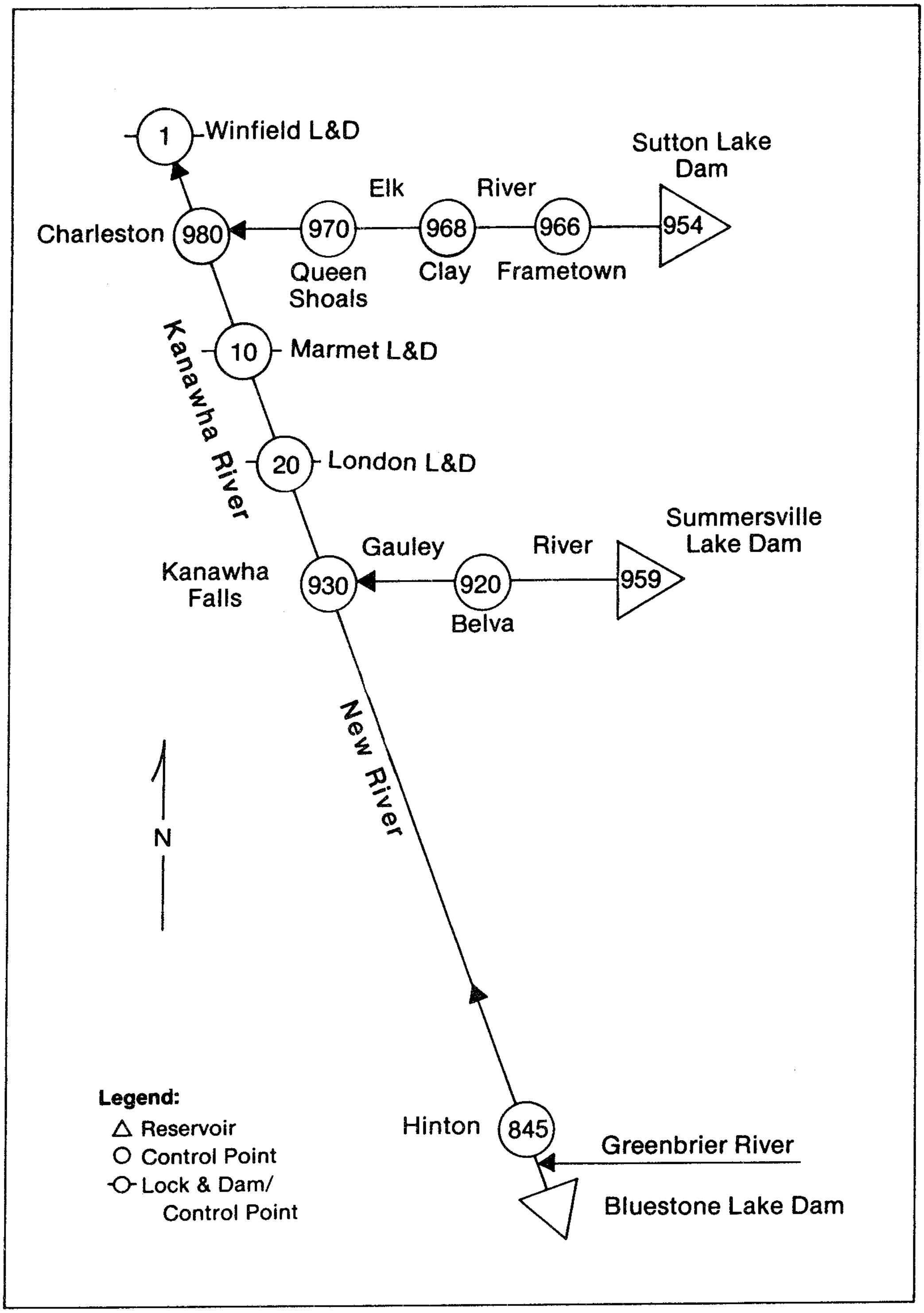

Figure 7

KANAWHA RIVER BASIN SCHEMATIC

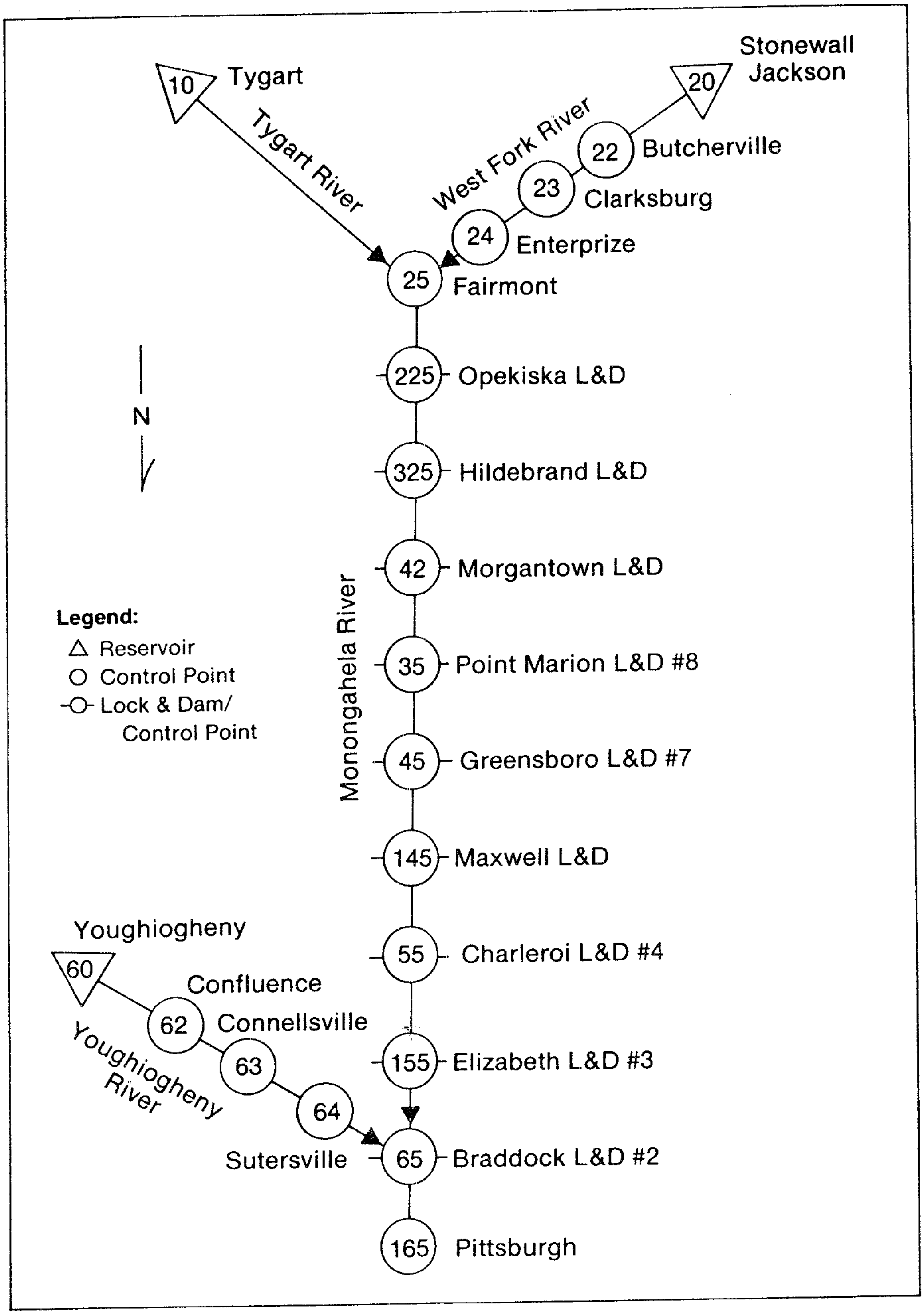

Figure 8

MONONGAHELA RIVER BASIN SCHEMATIC

The Monongahela River system is being evaluated using HEC-5Q for temperature, EC, BOD, and DO. The study is also still in progress with data files still being developed. This study will be the third test case and, similar to the Kanawha River system, it is a candidate for future testing of real-time operations capability. This data set could easily be modified to include evaluation of hydropower retrofit on the nine locks and dams along the lower Monongahela River up to Fairmont.

SUMMARY

In this paper, the author has provided a brief description of the HEC-5Q computer program for analysis of water quality impacts due to reservoir system operations and a discussion of three applications, one completed and two in progress. The model results are very encouraging and future applications are being considered.

The model has the capability to evaluate present operations on large integrated reservoir systems such as the Columbia/Snake/Williamette Rivers or similar large systems in other parts of the United States. Once calibrated to historical conditions, alternative regulation can be easily evaluated to "best" meet all project purposes at all points in the system and provide the water managers with input to their operation decisions either in a planning or "real-time" mode.

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APPLICATIONS OF WATER QUALITY MODELS,

AN OVERVIEW

by

Mark S. Dortch[1]

INTRODUCTION

The application of water quality simulation models for site specific studies provides an extremely important feedback mechanism for model development and evolution. Several water quality models were developed and/or modified during previous and on-going Corps of Engineers (CE) research programs, such as the Environmental and Water Quality Operational Studies, EWQOS (Waide and Dortch 1984, and Dortch 1985). During the past several years, the Waterways Experiment Station (WES) has applied these models to prototype systems. Some of these applications were research funded model confirmation studies while others were reimbursable investigations for CE district offices. Several of these applications are summarized in this paper.

Applications of water quality models for reservoir, riverine, and estuarine systems are addressed in this paper. However, because of the need for brevity, only the key features of these studies are presented. For additional details, the reader should refer to referenced material. This paper is intended to give the reader a greater understanding of model requirements, application procedures, performance, costs, benefits, problem areas, and needed improvements.

ASHTABULA RESERVOIR AND CE-QUAL-R1

The one-dimensional (1-D) reservoir water quality model, CE-QUAL-R1 (Environmental Laboratory 1985), was applied to Ashtabula Reservoir, ND, for a reimbursable study (Wlosinski 1986) funded by the St Paul District, CE. The purpose of the study was to calibrate the model for subsequent use by the St Paul District to develop eutrophication control strategies for the reservoir. Ashtabula Reservoir, which is on the Sheyenne River, provides flood control, water supply, and recreation benefits. The reservoir is long (52 km), narrow, and relatively shallow with a maximum depth of 13 m at normal summer pool. The volume of the reservoir is 84,000,000 cu m (68,000 acre feet) at normal summer pool. The reservoir is segmented into three pools by the earth embankments for two roads. The bridge openings for these roads are less than ten percent of the reservoir width; this inhibits circulation and results in water quality differences among the three segments.

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[1]Chief, Water Quality Modeling Group, Environmental Laboratory, WES

Because Ashtabula Reservoir exhibits longitudinal and vertical water quality gradients, the use of a laterally averaged, two-dimensional (2-D) reservoir model would have been more appropriate. However, the development of the 2-D water quality model, CE-QUAL-W2 (Environmental and Hydraulics Laboratories 1985), had not been completed at the time this study was initiated. Therefore, it was necessary to use the 1-D (vertical) model, CE-QUAL-R1. To deal with the pool segmentation problem, the model was applied individually to each pool segment. The application procedure was to simulate each pool sequentially starting with the most upstream pool (pool 1). This allowed the outflows through the bridges from one pool to be used as the inflows for the next pool. By knowing the reservoir inflow and outflow rates, pool elevation changes, and volume versus elevation characteristics, the flow between segments could be estimated. The flow distribution through the bridges was assumed to be uniform from the surface to the bottom and in the downstream direction only. With this modeling strategy, it was not possible to predict or allow for any reverse (upstream) flows through the bridge openings.

A brief description of input data requirements for CE-QUAL-R1 follows.

1) Site characteristics, such as site elevation, latitude, longitude, outlet configuration, surface area and volume versus elevation data, etc. Site information can be obtained from the district office.

2) Meteorological data (dry bulb and dew point temperatures, wind speeds, barometric pressures, and cloud cover), which can be obtained from NOAA.

3) Inflow quantity and quality data. Inflow quantity can be obtained from CE records and/or USGS gaging data. Some inflow water quality data may be available from USGS gaging stations, CE recordings or sampling, sampling by the state, or studies conducted by local universities. If sufficient data are not available, it may be necessary to collect the required data.

4) Reservoir operations data, which is available from the district office.

5) In-pool water quality data, which is used to calibrate/confirm the model. For preimpoundment studies, true calibration is not possible. It may be advisable to model a nearby reservoir that has similar characteristics prior to preimpoundment modeling.

6) Rate coefficients. Selection of values for rate coefficients are part of the calibration process; however, the range of values should be selected from literature sources, recommendations in the user manual, and a coefficient selection report (Collins and Wlosinski 1983). Additionally, site specific field studies may provide valuable insight for setting rate coefficients.

Data requirements for all water quality models are basicly similar in that they require site descriptions/geometry, initial conditions, boundary conditions and driving variables, calibration coefficients, and verification data (if available).

For the Ashtabula Reservoir application, much of the input data were available from CE and USGS records. The inflow and in-pool water quality data were not available; thus, the St Paul District contracted with a university to collect these data, which included temperature, total organic carbon, orthophosphate phosphorus, ammonia nitrogen, chlorophyll a, nitrite plus nitrate nitrogen, dissolved oxygen, pH, and total dissolved solids. Information on inflow suspended solids was available from USGS records. In-pool profiles were collected every two weeks for May through September of 1981.

The model was first calibrated for temperature and total dissolved solids for all three pools; the abbreviated version of CE-QUAL-R1, CE-THERM-R1, was used for this exercise. The model accurately simulated the slight, intermittent stratification of all three pools. Water quality rate coefficients were next calibrated for pool 1; pools 2 and 3 were tested using the pool 1 calibration values. At first there was difficulty in achieving satisfactory results for pools 2 and 3; the geometric input data of pool 2 was found to be in error. After this was corrected, satisfactory results were obtained for pools 2 and 3 using the coefficients developed for pool 1.

The labor requirements to develop the input data and calibrate the model for all three pools is estimated to have been approximately six man-months. This amount of time is greater than most applications because of the extra effort associated with modeling the three pools. The Ashtabula model required about 30 minutes of CPU time on a VAX 11/750 minicomputer to simulate one year on all three pools. This is comparable to about two minutes on a CDC Cyber mainframe computer.

The benefits of the Ashtabula model will be realized when the St Paul District begins to use the model to evaluate eutrophication control strategies; of course, the model could be used for other future studies should they arise. This application demonstrated that the model could be used to simulate water quality in linked pool segments.

DEGRAY RESERVOIR AND CE-QUAL-W2

The 2-D, laterally averaged water quality model, CE-QUAL-W2 (Environmental and Hydraulics Laboratories 1985), was applied to DeGray Reservoir, Arkansas, for model confirmation purposes (Martin 1986a). DeGray Reservoir has an extensive water quality data set (Thorton et al 1982 and Kennedy et al 1983) because it was one of the four primary reservoir field study sites during EWQOS. DeGray was also used as one of the confirmation data sets for CE-QUAL-R1 (Wlosinski and Collins 1985). This application of CE-QUAL-W2 to DeGray was the first test of the comprehensive water quality version of this model following its development.

DeGray is a deep tributary reservoir on the Caddo River. It provides flood control, hydropower, recreation, and water supply benefits. DeGray has a volume of 790,000,000 cu m (640,000 acre feet) and a maximum depth of 57 m at normal summer pool. The reservoir is about 32 km long. DeGray exhibits strong vertical and longitudinal gradients in water quality; thus it was an excellent test case for the 2-D model. The upstream portion of the reservoir is characterized as eutrophic, while the downstream portion is oligotrophic.

The model was calibrated and confirmed on DeGray using 1979 and 1980 data, respectively. Input data requirements are very similar to those for CE-QUAL-R1 except that the 2-D model requires more geometric input, which includes reservoir widthsfor each grid cell. This data must be carefully developed such that, not only is reservoir morphometry properly modeled, but the reservoir volume and surface area versus elevation must also be accurately reproduced.

The water quality algorithms of CE-QUAL-W2 are configured in four levels. Level 1 includes primarily physical constituents (temperature, inorganic suspended solids, total dissolved solids or salinity, conservative tracer, and coliform bacteria). Level 2 involves DO, organic matter, nutrients, sediments, and phytoplankton. Level 3 simulates carbonate equilibrium and pH. Level 4 simulates total iron, which can be important for properly simulating phosphorus. The user can select the level of water quality detail to model and can exclude constituents within a level. All model constituents were included in this application.

The procedure for applying the model consisted of selecting the spatial and temporal resolution, developing the input data, calibrating for temperature, calibrating for other water quality constituents, and model confirmation. The spatial resolution selected for the grid was two meters in the vertical dimension and one kilometer in the horizontal dimension. The selected model time steps varied between 6 and 25 minutes with the smaller time steps used during high inflow periods.

Development of the reservoir width data can be a labor intensive exercise. The best approach for determining the widths is to divide the surface area for the grid cell by the longitudinal length of the cell. This requires that the surface area versus elevation be known for each longitudinal segment. This information can be measured with a planimeter and surface contour maps, but the process is tedious and time consuming. It is possible that similar measurements may be available from reservoir design studies.

Satisfactory thermal simulations for DeGray were obtained after two problems were properly handled. It was determined that double precision is necessary when applying the model on a VAX 11/750 minicomputer. Without double precision, roundoff error resulted in artificial circulation that caused excessive vertical transport of temperature. Additionally, care must be excercised in setting the dispersion coefficients for temperature to assure that artificial circulation does not progress and result in distorted temperature distributions. For a more detailed discussion of this problem, the reader should refer to the study by Martin (1986a).

During the water quality calibration procedure using 1979 data, it was found that the model simulation results were reasonable and quite accurate except during the fall. The model had properly predicted high concentrations of orthophosphate phosphorus in the early fall, which were released from the upstream sediments when the upper reaches of the reservoir were encountering anoxic conditions. However, when the model predicted partial mixing later in the fall (which did actually occur), this phosphorus was made available to the epilimnion and resulted in an excessive algal bloom, which did not occur in nature. Additionally, high phosphorus concentrations were not found in the prototype epilimnion following the partial mixing. The best explanation for the prototype behavior is that the phosphorus adsorbed to and coprecipitated with particlate iron and rapidly settled out of the epilimnion. Reduced iron was also released from the sediments during anoxic conditions and rapidly oxidizes to particulate iron when mixed with the oxygenated epilimnion. Adopting this theory, iron was added to the model. With this modification, the fall predictions yielded much lower phosphorus concentrations in the epilimnion without the excessive algal bloom.

Following the calibration and modification discussed above, the model was confirmed on the 1980 data set. The results are quite impressive as the model properly predicted the conditions upstream and downstream as well as vertically in the lake. For example, the model predicted upstream anoxia with high nutrient levels that begin to form in early summer and progress toward the dam during the summer creating a metalimnetic DO minima with low nutrient levels near the dam. The simulation of this phenomena is demonstrated by the DO shading plots of Figure 1. Figures 2 and 3 further show that appropriate upstream and downstream DO distributions are predicted by the model. By calculating model fluxes for DO, it was concluded that the principle cause of the metalimnetic DO minima is the advection of upstream water that is low in DO and high in oxygen demanding materials. This water is advected by inflow density currents that travel along the metalimnion during most of the stratification season.

It was difficult to estimate the labor requirements for the DeGray study because portions of the work were interrupted. It is estimated that the study could be done within five man-months. A person with experience with this code could possibly do a similar study in less time. The simulation of 1980 for DeGray required about 15 hours VAX CPU time, which includes simulation of hydrodynamics and all levels of water quality for a complete year. This is equivalent to about one hour CPU time on a Cyber mainframe. Other applications could require more or less CPU time depending on grid size, flow rates, and other factors. These CPU requirements will soon be of little consequence with the strides being made in computer speed.

The major benefit of using CE-QUAL-W2 for reservoir water quality modeling is that it provides information in two spatial dimensions. Therefore, this model should be used if the issues required water quality definition along the vertical and longitudinal axes of the reservoir. If the issues only required definition of water quality at the dam and release water quality, then the 1-D model could be used with less cost. However, it does appear from the DeGray application that the 2-D model adds much more realism to water quality simulation due to the extra dimension and the inclusion of hydrodynamic simulation.

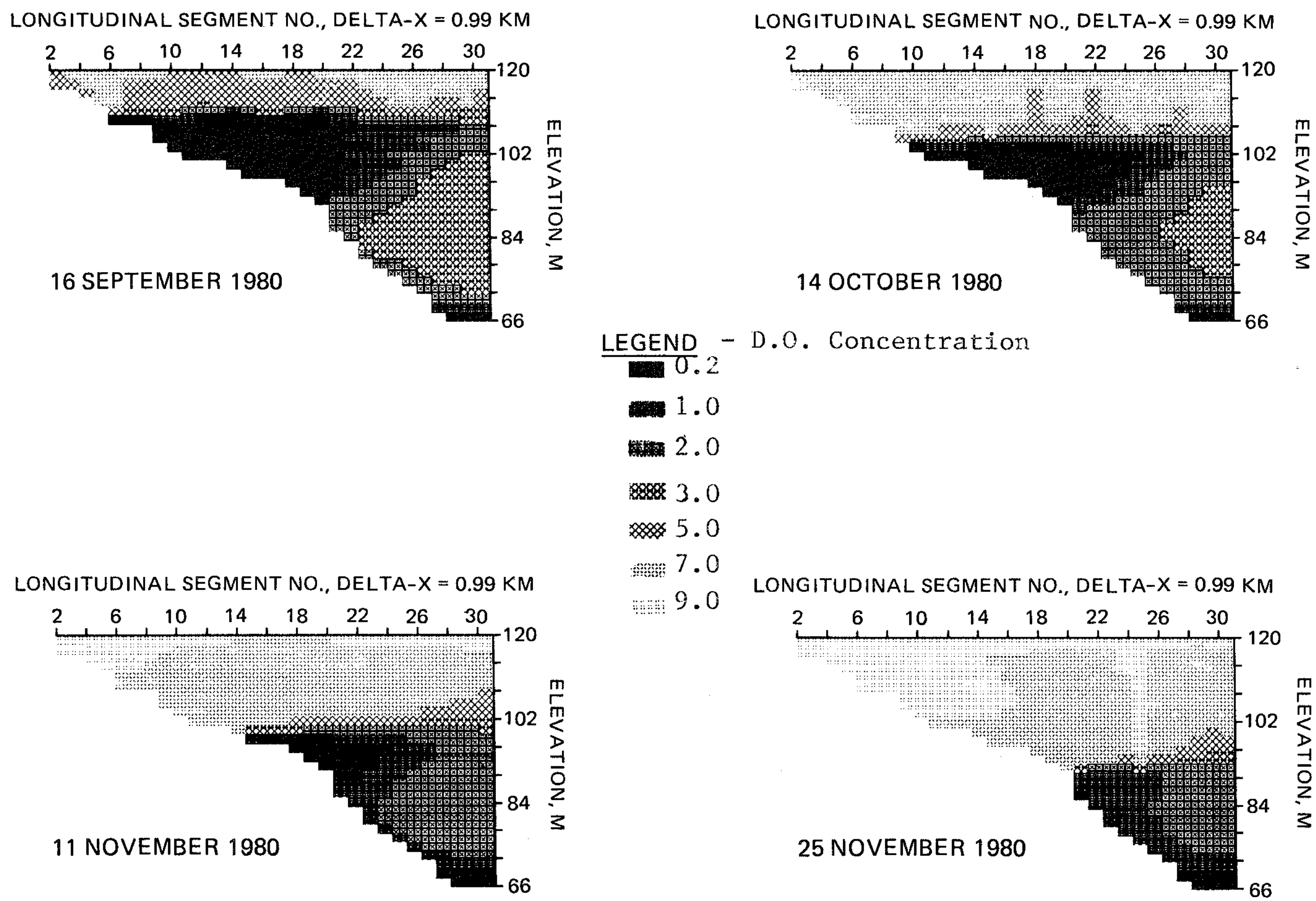

Figure 1. Simulated, two-dimensional dissolved oxygen concentrations for DeGray Reservoir, CE-QUAL-W2 application

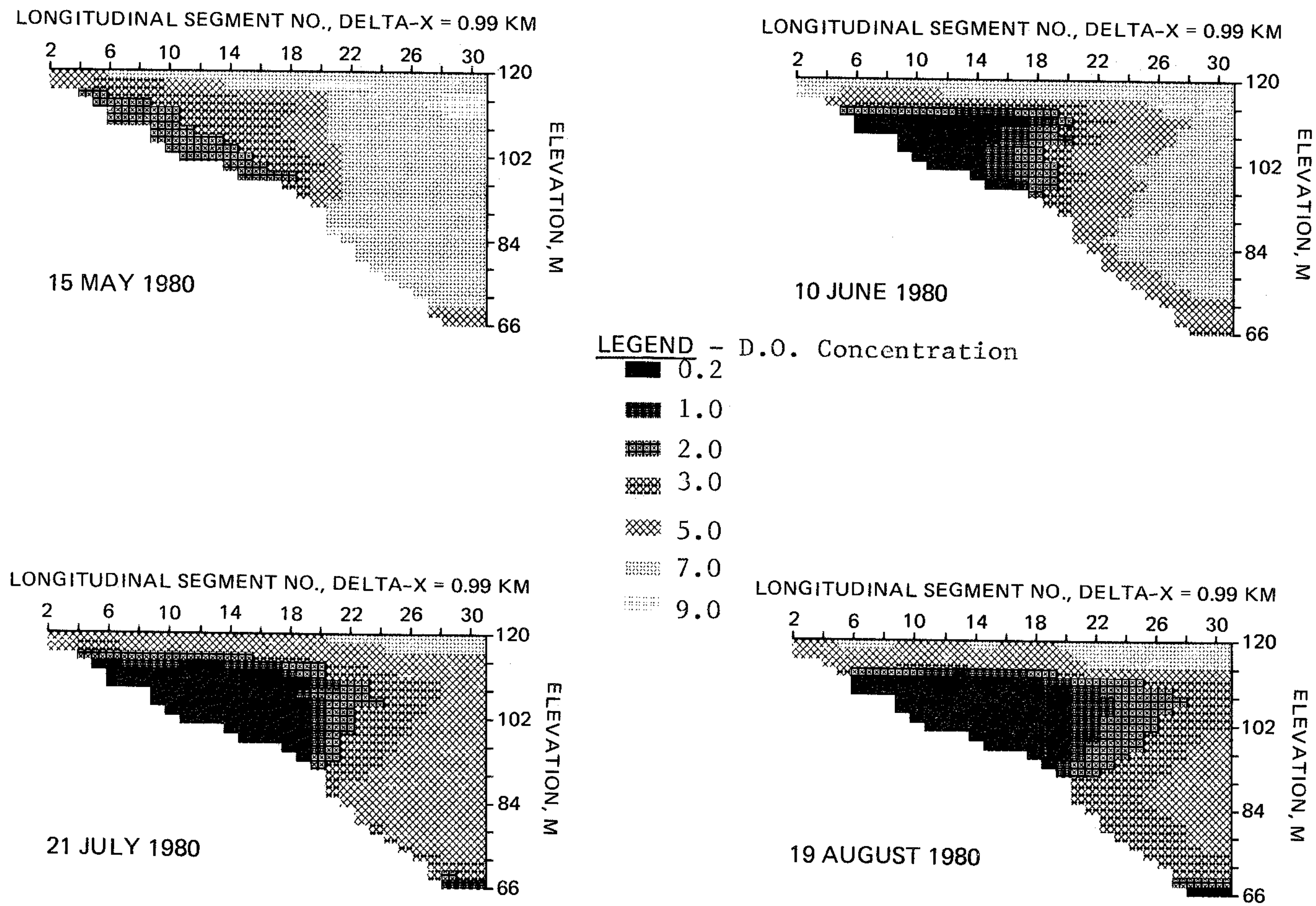

Figure 1. Simulated, two-dimensional dissolved oxygen concentrations for DeGray Reservoir, CE-QUAL-W2 application

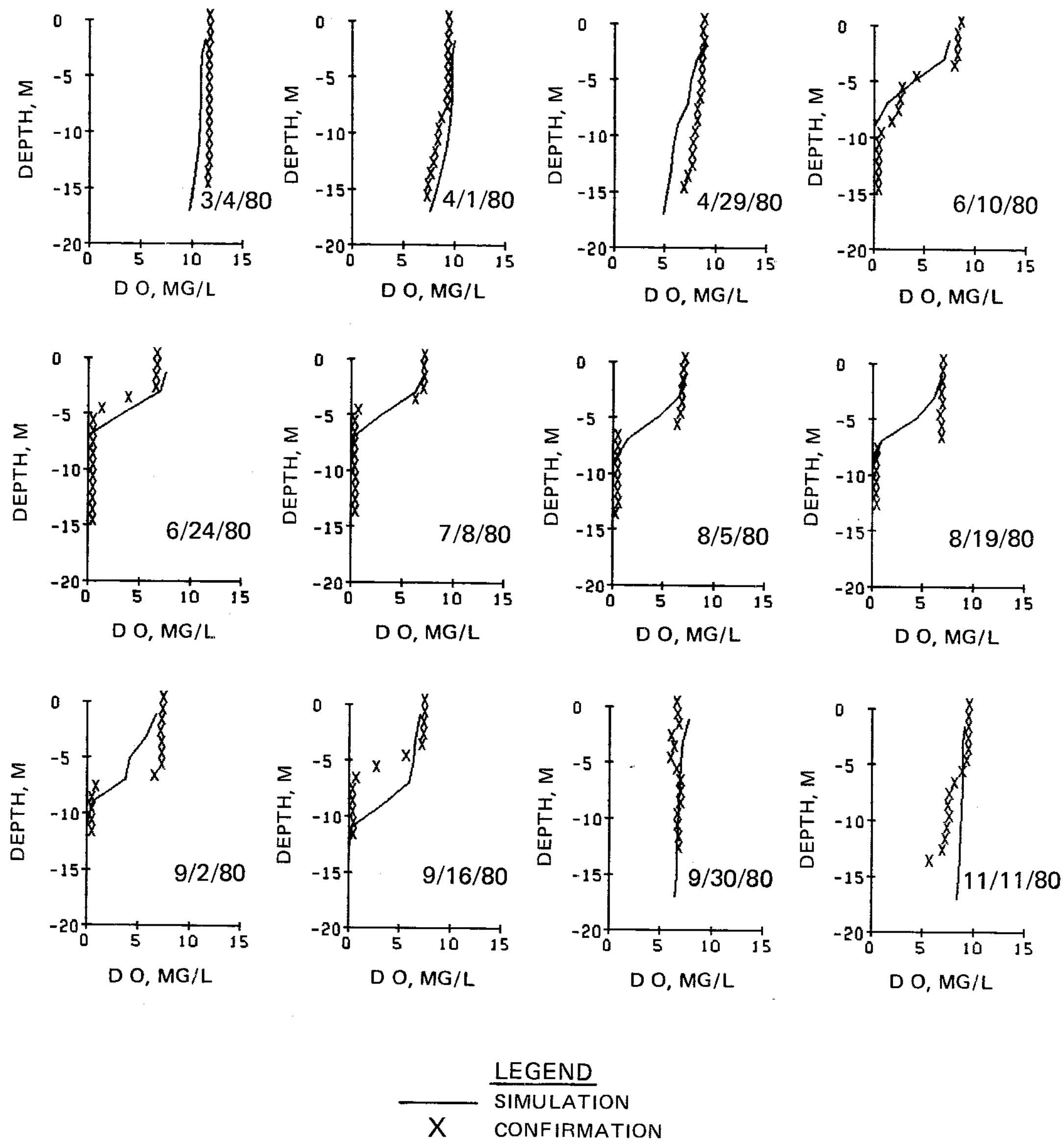

Figure 2. Comparison of predicted (CE-QUAL-W2 application) and observed dissolved oxygen profiles at an upstream station (station 12) of DeGray Reservoir

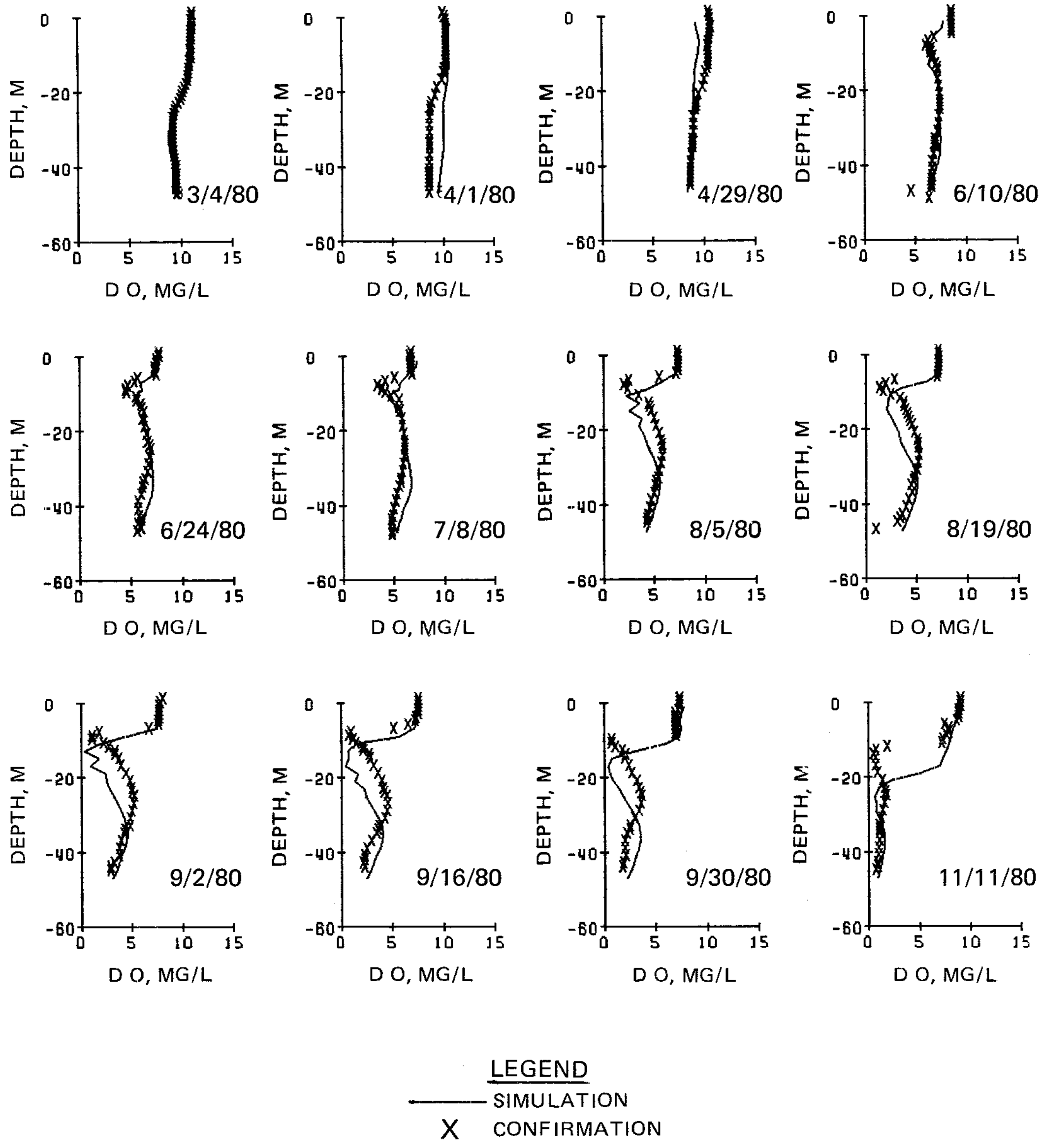

Figure 3. Comparison of predicted (CE-QUAL-W2 application) and observed dissolved oxygen profiles at an upstream station (station 4) of DeGray Reservoir

RIVERINE WATER QUALITY MODELING

Two 1-D riverine/stream water quality models are being used by WES. The EPA model, QUAL II (Roesner et al 1977), is being applied for the Portland District on the Rogue River system in Oregon. The purpose of the application is to develop a stream temperature model to assess the effect of project operations on the Rogue River fisheries. This study is addressed in another paper of this workshop. QUAL II is relatively easy to use, well documented, and widely used; however, it assumes steady flow for transport. This assumption may be satisfactory for some systems such as the Rogue. For highly dynamic streams, such as below peaking hydropower dams, this limitation may not allow adequate resolution. For these cases, an unsteady flow, dynamic stream model should be used.

The dynamic stream water quality model, CE-QUAL-RIV1 (Bedford et al 1983), can be used for dynamic flow cases. This model has been applied by WES to the Chattahoochee River, GA, for the Savannah District (Zimmerman and Dortch 1986) and the Cumberland River, TN, for the Nashville District (Martin 1986b). Both studies were conducted to evaulate the impacts of proposed reregulation dams below peaking hydropower dams. The Chattahoochee study is addressed in another paper presented at the workshop. Additionally, the model is being applied by the Louisville District on the lower 500 miles of the Ohio River, which includes multiple locks and dams, some of which have dynamic releases.

The CE-QUAL-RIV1 model has been found to be very versatile and accurate. Comparisons with dye studies and stage and temperature recordings for dynamic flow conditions on the Chattahoochee River showed that the model will closely track surface and particle wave speeds, phases, and amplitudes.

The Cumberland River application only required two man-months to conduct. Other studies could take longer depending on the scope. A one week simulation with 50 nodes requires about 20 minutes of CPU on a VAX (about 2 minutes on a Cyber). The CPU time depends on the size of the time step; time steps for applications thus far have varied from three minutes to one hour. Generally, the model is used to simulate time periods on the order of a week to several months. The model documentation is being upgraded and should be published within a year. The code is also undergoing some improvements, such as adding the capability to handle tidal boundaries and the accompanying flow/transport reversals.

ESTUARINE AND COASTAL EMBAYMENT WATER QUALITY MODELING

This section does not go into the details of an estuarine water quality model application, but generally discusses the modeling approaches being developed. Water quality modeling for estuaries and coastal embayments requires a wide assortment of modeling tools. A 1-D longitudinal model such as CE-QUAL-RIV1 may be sufficient for narrow, well mixed, river estuaries. A 2-D laterally averaged model, such as CE-QUAL-W2, should be used for narrow, stratified estuaries. A 2-D vertically averaged model could be used for wide, shallow, well mixed (vertically) estuaries or coastal embayments. Other cases may require a 3-D model or even mixed dimensions depending on the local morphometry. Some water quality applications may address short term water quality trends on the order of days or weeks, while others may need to address long term, seasonal variations on the order of months or years.

WES is developing a variety of tools to meet these needs. CE-QUAL-RIV1 will be modified to include tidal boundary conditions for head and constituent concentrations. CE-QUAL-W2 has already been developed for estuarine applications and tested on the Savannah River Estuary (Hall 1986). Several existing vertically averaged models, such as the TABS-2 system (Thomas and McAnally 1985) and WIFM-SAL (Schmalz 1985) can be used for wide, shallow estuaries and embayments. Two 3-D models, RMA-10 (King 1982) and CELC3D (Sheng 1984), are also available. These 2-D vertically averaged and 3-D models are presently used primarily for hydrodynamic and sediment transport studies; however, water quality transport and kinetics could be incorporated into these codes. This is referred to as a direct linking of hydrodynamics and water quality as the hydrodynamic and water quality computations would be done with the same temporal and spatial scales. Direct linking is convenient for the modeler, but the computational expense may not be acceptable for long term water quality modeling.

A method is being developed at WES to overcome the computational expense of long term water quality modeling in multiple dimensions. This method involves driving a finite segment, box type, water quality model with temporally and spatially averaged hydrodynamic output. Water quality kinetics may not require the temporal and spatial resolution required by hydrodynamic models. The coarser box model grid overlays the hydrodynamic grid. The box model segment sizes, time step, and dispersion coefficients are adjusted to assure that transport with the box model adequately reproduces that of the finer scale hydrodynamic/transport model. Applications of the box model to two estuarine/coastal systems have shown that the procedure works quite well and reduced computational costs by factors of 720 to 2200 can be achieved. This modeling development, plus the other models mentioned above, give the CE a broad and flexible capability in the area of estuarine/coastal water quality modeling.

CONCLUSIONS

The evolution and fate of water quality models will be guided by the applications that are made to prototype systems for the solution of real, practical issues and problems. Numerical water quality models are sophisticated tools that have substantial data requirements. Proper application can require several months of effort by a professional with modeling skills. The benefit of these costs is that numerical water quality models provide detailed, realistic, and accurate aid in predicting and resolving future or existing water quality issues/problems, as well as for evaluation of management and control alternatives prior to prototype implementation. In spite of the time, cost, and skill required to apply numerical water quality simulation models, more and more CE district/division offices are developing in-house capabilities to apply these models. Those that have applied models have found that the learning curve is steep; thus once a person has made one application with a particular type of model, the next application is much easier. WES is assisting several CE offices in the application of water quality models through the Water Operations Technical Support (WOTS) Program, which is free of cost to the CE field offices.

ACKNOWLEDGMENT

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LABORATORY INSPECTIONS FOR QUALITY ASSURANCE/QUALITY CONTROL

By

Ann B. Strong[1]

INTRODUCTION

The question arises as to how this topic applies to the title of the seminar--"Water Quality R&D: Successful Bridging Between Theory and Applications." Analytical data for nutrients, heavy metals, and organic contaminants are the basis for many decisions made with respect to water quality R&D. The theory is that if an R&D project is properly designed, if the scope of work is comprehensive and includes Quality Assurance/Quality Control (QA/QC), and if the contractor selection criteria are evaluated properly, then good reliable data will be forthcoming. Unfortunately, this doesn't always happen. In fact, it frequently doesn't.

CONTRACT PROCESS

Almost all water quality analyses performed for the Corps that are not generated by the Division Labs or by the R&D labs, such as the Waterways Experiment Station (WES), are accomplished by Invitation for Bid (IFB) or Request for Proposal (RFP) contracts. This contract process for obtaining analytical data is summmarized as follows:

a. Preparation of IFB or RFP

b. Contractor Evaluation and Award

c. Laboratory Inspection

d. Contract Oversight

e. Data Review

f. Contract Officer Representative - Contractor Interaction

Ideally, the RFP would be the method of choice because there is more latitude in selecting the best qualified bidder and specific items can be negotiated. The scope of work in the RFP contains the experimental design and can be as specific or as general as desired. With water quality work, it is usually best to be fairly specific to assure that data will be adequate for project needs. Also contained in the RFP are evaluation factors, a schedule of reports, data presentations, and other miscellaneous items. The award is a

[1]Chief, Analytical Laboratory Group, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station

two step process involving evaluation factors (technical qualifications) and costs. Unfortunately with the new contracting regulations, an RFP is required to have the cost factor weigh at least 30% in the evaluation. The remaining factors should be sufficient to reject a low bidder that obviously isn't qualified to perform the work. WES has used the following evaluation factors in selecting an overflow contractor to perform analysis exceeding our workload capacity:

a. Experience and expertise of contractor in environmental chemistry analysis

b. Methodology and quality control used in the analysis of specific constituents including mean detection limits under routine operating conditions and standard deviations observed by the contractor with proposed methods

c. Cost of analysis including internal quality control

d. Performance on audit samples

e. Schedule for completion of analysis and submission of data

The greatest emphasis is placed on experience and expertise followed by methodology and quality control. Cost is listed third only because of regulatory requirements.

The District contracting officers usually require the use of the IFB which is awarded to the lowest responsive and responsible bidder. Since cost is the overriding factor in this award, the contract must necessarily be very specific if one wants to obtain good quality data. The sampling protocol, analytical procedures, quality control measures, and reporting requirements must all be spelled out in great detail.

LABORATORY INSPECTIONS

After the contractor has been selected and prior to the initiation of sampling and analysis, an on-site laboratory inspection is performed. Guidelines for laboratory inspections for water and wastewater projects are provided in ETL 1110-2-268 dated 31 December 1981. These inspections are a requirement as stated in ER 1110-1-261 dated 28 September 1979. More recently, ER 1110-1-263 dated 30 December 1985 was issued regulating procedures for chemical quality management of toxic and hazardous wastes at Superfund and Defense Environmental Restoration Account (DERA) projects. WES has been involved with putting together the protocol to inspect and validate Corps Division Laboratories providing quality assurance for these projects and also the procedures that the Division Laboratories will use to inspect the contractor laboratories.

Basically, these laboratory inspections are a three phase operation consisting of a contract review, an on-site visit, and a report of findings. In the contract review, the following items are addressed:

a. Field Sampling and Analysis

(1) Methods of Collection and Preservation

(2) Field Analyses

(3) Sampling Schedules

b. Laboratory Analysis Requirements

(1) Quality Control Plan

(2) Personnel Qualifications

(3) Analytical Methods and Instrumentation

(4) Detection Limits

(5) Reporting Requirements and Laboratory Records

(6) Schedule for Completion of Analyses and Reporting of Results

After the contract is reviewed, an on-site inspection is coordinated with the Laboratory Director. An initial interview is held with the Director to discuss the contract, the laboratory's capabilities to perform, and his overall quality assurance philosophy. If the lab is responsible for any field sampling and analyses, these records are examined to check agreement with contract specifications and to assure that samples are being collected properly using appropriate containers and preservation techniques.

The in-house laboratory analyses are discussed and interviews are held with key personnel to assess their qualifications, experience, and knowledge of procedures to be performed. A check is made to be sure that a working QA/QC program is in effect. Records are examined for quality control data such as performance on duplicates, spikes, standard reference materials, and external QC samples. The methods of analysis are discussed with the analysts to assure conformance to standard methods and deviations or variations are checked to be sure that they do not affect the quality of the data. Record keeping and data management are examined.

An extensive inspection is made of the physical facilities with respect to general appearance, laboratory services, instrumentation, glassware and chemicals, storage facilities, and safety equipment. An exit interview is then held with the Lab Director to discuss merits and deficiencies noted during the inspection. This is followed by a written report of findings.

CASE HISTORIES

Some case histories of lab inspections performed by WES over the last several years illustrate problems encountered with the contracting process.

The first is one made for the New Orleans District several years ago for an IFB contract. When the contract was initially reviewed, problems were evident. The contract was awarded to a lab in Texas to sample a project on the Red River and perform subsequent field and laboratory water quality analyses. With the number of samples to be collected over a twelve month period and the amount of work involved with performing the analysis, it would have been impossible for them to perform the work for the contracted price even if they were only paying minimum wage. A visit to the laboratory only confirmed suspicions. It was dirty, instruments were only marginally satisfactory, and analysts were evaporating solvents for petroleum analysis in the open laboratory. Their only hoods were used as storage for acids and other reagents. They did not have a written quality control program. Copies of analytical procedures were not readily available for review and the list goes on and on. The laboratory inspection report was written recommending that audit samples be sent to evaluate their ability to perform routine water quality analyses. Twenty-three of twenty-eight parameters fell outside acceptable limits. After some delay, the contract was terminated. This was a case where low bid was low quality.

Another case involved the Memphis District. In early 1983, they issued a contract for water quality testing and sediment analysis using the RFP process. This was a professional indefinite quantity services contract with a $5,000 minimum and $200,000 maximum. Staff from WES and the water quality coordinator for LMVD reviewed the contract and all agreed that the contract was detailed and definitive with regard to analytical procedures, quality control, and reporting practices. The District received the bids and one laboratory in the small business category was the low bidder by at least a factor of two. One of the requirements of the contract was that the lab be inspected by WES prior to award. A representative from WES inspected the facility and concluded in his report that the lab would not be able to perform at the level required by the contract. The contract lab sent a letter to the District stating that the deficiencies noted by WES would be corrected. In the meantime, the contracting officer sent a letter to the Small Business Administration (SBA) stating that the lab was not capable of performing the procedures specified in the contract. The lab sent a letter to SBA refuting the lab inspection results. In fact, they said the report was untrue and libelous. SBA subsequently declared the lab competent and insisted that they be awarded the contract. After several months of negotiating over procedures and the QC plan, the laboratory was again inspected by WES. At that time it was noted that the lab was not using the procedures specified in the contract. Audit samples were issued and they failed to obtain satisfactory results. The District tried unsuccessfully to terminate the contract for the next 2 1/2 years. There were 117 documented actions taken on this contract during this time period including a third laboratory inspection and two additional sets of audit samples. The District finally agreed to submit nutrient samples amounting to $5,000 to fulfill their contract obligations to the laboratory. The lab later threatened to sue the Corps for breach of contract and numerous man-hours and dollars were spent by the District and WES personnel trying to obtain reliable data. The paperwork associated with this dilemma is at least two feet high. District personnel kept good records and gave the lab an "unsatisfactory" rating which should eliminate them from competition for the next several years. This case illustrates the need for support by the contracting officer in addition to having a good contract.

Another inspection was for a DERA cleanup operation at an Air Force Base. In this case the bid package was extremely well written and contained all the necessary details for an IFB. In these projects, engineering regulations require the contractor to have an approved quality management plan prior to initiation of cleanup. The plan was received for review and it contained many deficiencies--primarily in the QC and industrial hygiene procedures for on-site work. The contractor was allowed to mobilize prior to receiving approval from the Design Division. Subsequently, partial information was given via telephone to correct the deficiencies and the contractor was given a provisional notice to proceed. The contractor maintained that since all the QC and industrial hygiene requirements were spelled out in the bid package, that it was not necessary to provide detailed information in their quality management plan. WES was then requested to make an on-site inspection. The field laboratory facilties to perform initial reaction and compatibility tests consisted of a hot plate, two burettes, and a Sears' stove vent used as a fume hood. These certainly did not meet contract requirements. Two off-site commercial laboratories were subcontracted to perform specific chemical analysis of soil and drummed waste samples, and industrial hygiene samples. Both were good labs with good QA/QC practices--but the samples were not submitted to them in the proper manner from the on-site contractor. The subcontractor labs were not given adequate information as to the analyses to be performed, and in some cases did not have sufficient sample. A Corps industrial hygienist also inspected the site and wrote a nine page report of deficiencies. Later when the monitoring wells were installed, the samples were contaminated with the solvent used to clean the sampling equipment--although specific instructions were provided detailing procedures to follow. The wells then had to be resampled. This was a case of insufficient coordination, oversight, and cooperation by all the parties concerned.

CONCLUSION

Many problems are encountered when contracting for chemical analyses, and the need for maintaining good QA/QC practices throughout projects is evident. There are many excellent contractor labs being utilized by the Corps, but in order to obtain their services the Corps must remember that quality data requires quality contracts, quality inspections, and quality coordination.

ACKNOWLEDGEMENT

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METHODS TO IMPROVE DISSOLVED OXYGEN IN RESERVOIR RELEASES

by

Steven C. Wilhelms*

BACKGROUND

A frequently cited problem associated with a proposed or existing hydropower project is the release of water with a low dissolved oxygen (DO) concentration. This problem is typically the result of low-level releases from a density-stratified pool coupled with an in-lake oxygen demand. Due to the heating of surface waters, a reservoir stratifies such that a surface layer of warm water, called the epilimnion, resides above a layer of cooler water, called the hypolimnion. DO concentrations in the epilimnion are generally high due to the extensive transfer of oxygen at the air-water interface. The presence of density stratification acts to inhibit vertical mixing, thereby limiting the transfer of oxygen into the hypolimnion from above. When a hypolimnetic oxygen demand is coupled with this absence of oxygen replenishment, deterioration of hypolimnetic water quality occurs, often to the point of anoxia. Several problems may develop under anoxic conditions such as the dissolution of trace metals, release of nutrients, formation of hydrogen sulfide, and depression of pH. Hydropower intakes are often located in the hypolimnion resulting in poor water quality releases downstream during power generation. Depending upon the severity of the DO deficiency in the release, it may be necessary to employ one or more techniques to enhance DO concentration in hydropower releases.

The retrofit of an existing flood control or other nonpower project with hydropower has produced a number of water quality concerns. At many nonpower projects, significant reaeration (often to near saturation) occurs in the high-velocity regions of open-channel flow through the outlet works and stilling basin. The incorporation of a downstream turbine and pressurized conduit results in the loss of this reaeration. While the impacts of this loss of reaeration are often site-specific, a change in release quality from highly oxygenated water to near-anoxic water would severely impact the downstream environment.

POTENTIAL SOLUTIONS

A wide variety of techniques are available to improve the DO of water released from hydropower projects. The system most effective at a specific site will depend upon many factors that include the degree of enhancement required, rate of release, turbine type and operation, upstream and downstream water quality objectives, and availability of economic resources. Selection of the "best" system must involve weighing the costs and benefits of each technique with regard to site-specific concerns.

These techniques may be grouped into three general categories: forebay, tailwater, and in-structure systems. A summary of the strengths and weaknesses of each alternative is presented in Table 1. The following paragraphs briefly discuss these techniques.

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*Research Hydraulic Engineer, US Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180-0631.

Table 1

Summary of Benefits and Detriments of Techniques to Enhance the Dissolved Oxygen (DO) Concentrations of Reservoir Releases

Technique	Benefits	Problems	References
Artificial destratification	a. DO content in the entire hypolimnion is enhanced preventing the dissolution of metals and the formation of hydrogen sulfide. b. Prevention of the development of anoxic conditions and subsequent fish kills.	a. Loss of cold water resources in the reservoir prohibiting the development of a coldwater fishery b. Redistribution of heat, dissolved gases and nutrients will change chemical and biological properties of a reservoir. c. Low-level releases will be warme influencing the downstream environment. d. Costs of destratifying large reservoirs with significant thermal stratification may be very large.	a. Dortch (1979). b. Pastorok et al. (1982). c. Johnson (unpublished).
Localized mixing	a. Hydropower releases are composed of water from both hypolimnetic and epilimnetic layers. b. Coldwater resources are maintained in the reservoir. c. Artificial circulation is restricted to regions adjacent to the project outlet. d. The costs of implementing this technique can be significantly less than the costs of other forebay systems.	a. The potential exists for destratifying the entire reservoir. b. This technique is generally suited for smaller flow rates. c. For low level releases, local destratification will warm project releases.	a. Holland (1984). b. Dortch and Wilhelms (1978). c. Garton and Rice (1974).
Selective withdrawal	a. Operational flexibility to select a specific in-reservoir water quality for release. b. Coldwater resources are maintained in the reservoir. c. Maintenance of the natural pattern of stratification.	a. Selective withdrawal outlet works require additional investment relative to a single level outlet works. b. Enhancing DO releases from low-level hydropower intakes by selective withdrawal will result in warm releases temperatures. c. Selective withdrawal capabilities will probably not enhance in-reservoir water quality.	a. Wilhelms (1985). b. Bonan and Grace (1969). c. Fontane, Labadie, and Loftis (1982). d. Davis et al. (1985).
Hypolimnetic	a. Oxygenation of bottom waters increases pH and lowers concentrations of reduced substances. b. Prevention of winter or summer fish kills due to anoxic conditions.	a. Total lake destratification is possible if proper precautions are not instituted. b. Using compressed air at large depths may result in nitrogen supersaturation and subsequent fish kills.	a. Holland and Tate (1984). b. Pastorok et al. (1982). c. Fast and Lorenzen (1976).

(Continued)

Table 1 (Concluded)

Technique	Benefits	Problems	References
	c. Enhancement of coldwater fisheries in warmwater climates	c. Significant investment may be required to maintain the DO concentrations in large hydropower discharges.	
	d. Maintenance of the natural pattern of stratification that with the presence of selective withdrawal facilities, can be used to meet downstream water quality requirements.		
Turbine venting	a. Enhancement is limited only to hydropower releases from a project.	a. The turbine operating efficiency is reduced for most gate settings.	a. Bohac, Boyd, and Harshbarger (1983). b. Wilhelms, Schneider, and Howington, (1986). c. TVA (1982).
	b. Capital costs to implement turbine venting are generally minor.	b. A loss in power generating capacity is experienced when turbine venting occurs.	
	c. The natural pattern of stratification is maintained in the reservoir.	c. Modifications to the turbine may be required to effectively incorporate turbine venting.	
	d. Hydropower release temperatures are not effected by turbine venting.	d. The degree of DO enhancement is limited.	
		e. Aeration at large depths may result in nitrogen supersaturation and fish kills.	
Tailwater systems	a. In-reservoir and release water quality characteristics remain unaltered.	a. Most techniques are limited to lower flow rates.	a. Gameson (1957). b. Bohac, Boyd, and Harshbarger (1983).
	b. Reaeration benefits from the significant air-to-water contact that occurs in this region.	b. Navigation restrictions in the downstream channel may be required.	
		c. Many of these techniques are not aesthetically pleasing.	
		d. Methods involving raising the tailwater cause potential reductions in power output.	

Forebay Systems. This class of alternatives refers to systems that modify the DO content of water entering the penstock. Four different forebay systems have been identified: (a) hypolimnetic aeration/oxygenation, (b) artificial destratification, (c) localized mixing/local destratification, and (d) selective withdrawal.

Hypolimnetic aeration/oxygenation is the injection of air or oxygen into the hypolimnion to increase the DO concentration of the lower levels of the reservoir while maintaining the existing thermal stratification. A number of delivery systems have been utilized to inject air or oxygen into hypolimnetic regions. A technique currently in use at Lake Richard B. Russell on the Savannah River (Savannah District, CE) is oxygenating the hypolimnion with molecular oxygen from a free bubble column generated from a series of flathead diffusers.

A partial air-lift hypolimnetic aeration device could provide improvement in the DO in the lower levels of the lake while maintaining thermal stratification. Typically, this technique uses compressed air to aerate hypolimnion water within an artificial confinement placed in the lake. Once aerated (resulting in a DO improvement), the water is returned to the hypolimnion. Some of these types of devices are available commercially. However, few, if any of these, have been applied to large reservoirs. An unknown in this alternative is the potential for these techniques to cause nitrogen supersaturation because of the very long contact time of the air and water deep in the pool.

An untried alternative involving the partial air-lift concept that could mitigate or eliminate the potential for nitrogen supersaturation is the use of molecular oxygen instead of compressed air as the gas causing water flow and oxygen uptake. Compressed air that reaches the top of the confinement region for the air-lift systems is vented to the atmosphere to prevent any potential destratification. However, if molecular oxygen were used, the capture and recycling of the "off-gases" could be economically attractive. However, this technique has had no known application, and thus no guidance on operation, efficiency, or success is available.

Total lake destratification would prevent or limit the occurrence of low levels of oxygen since temperature stratification would not inhibit vertical mixing and surface reoxygenation. Destratification requires the addition of sufficient energy to an impoundment to overcome the buoyant forces associated with stratification. This energy is added to the system by mechanically pumping water (hydraulic) or bubbling air (pneumatic) from the hypolimnion to the epilimnion. Total lake destratification has the effect of increasing the total heat content in a lake and may increase the temperature of hypolimnetic releases. The elimination of natural stratification may also change the ecological characteristics of a reservoir. The costs of implementing a total lake destratification system may be large for larger reservoirs because of the huge volume of water that must be affected.

Localized mixing systems are designed to destratify the reservoir in the vicinity of the hydropower intake. This system attempts to maintain the warmwater and coldwater resources throughout a reservoir except for a small region adjacent to the project outlet. The mixing in this region can be accomplished through pumping of water or air. Care must be exercised during operation of a localized mixing system to assure that the entire lake is not destratified; hence design and operation of this type of system can be critical.

The addition of selective withdrawal capabilities to an existing project has great potential for enhancing the quality of releases from a hydropower project.

Selective withdrawal involves withdrawing water from either a singlelevel or multilevels in a stratified reservoir. This alternative can provide the capability to withdraw the desired quality directly or blend high DO epilimnetic water with colder hypolimnetic water. The addition of a retrofit selective withdrawal outlet works enables the release of water from one or a series of multilevel ports. The advantage of selective withdrawal facilities is operational flexibility. Operational changes can be made quickly in response to in-reservoir conditions and downstream water quality objectives. The installation of selective withdrawal facilities may have little impact on the natural stratification patterns in a reservoir and downstream release temperatures will usually increase when warmer, high DO water is blended with hypolimnetic water.

In-Structure Systems. Turbine venting through aspiration or forced-air injection is another alternative to enhance hydropower releases. Aspiration systems take advantage of the hydrodynamic properties of the turbine which create low-pressure regions downstream of the turbine blades. These subatmospheric pressures, when vented to the atmosphere, cause air to be drawn into the water flow and enhance the DO concentrations of the release flow. Most Francis turbines are fitted with a vacuum-breaker system that allows aspiration to prevent cavitation at low wicket-gate settings. In some cases, the vacuum-breaker system can be modified to allow aspiration to continue into the higher wicket-gate settings. If subatmospheric pressures do not occur naturally downstream of the turbine blades, additional measures such as deflector plates or compressed-air injection must be employed to induce turbine venting. The benefits of enhanced DO concentrations in hydropower releases through turbine venting can be substantial but at a cost. In addition to the capital costs for the compressor system or deflector system, turbines typically experience an efficiency loss when air is injected or aspirated into the flow. The amount of efficiency loss is dependent (as is the oxygen uptake) upon the amount of air being injected into the flow. If deflectors are employed, an additional efficiency loss due to the deflector plates is incurred.

Tailwater Systems. Measures are available to enhance project releases in the region just downstream of the project. Air can be injected into the flowing water via horizontal pipes, hoses, or mats in a manner similar to some hypolimnetic aeration systems. Weir or channel steps can be added to the tailrace area to promote oxygen transfer that occurs in zones of turbulent mixing. Surface aerators, which usually agitate surface water, can be used but have found only limited application in improving tailwater quality. Tailwater systems usually have limited applicability to hydropower projects because of the relatively large discharges involved.

WOTS CASE STUDY I: LAKE SIDNEY LANIER

As would be expected at most eutrophic lakes, thermal stratification at Lake Sidney Lanier (LSL) during the summer results in anoxic or near-anoxic conditions in the hypolimnion. Consequently, iron and manganese problems generally occur during this period. Since the hydropower intakes are located deep in the pool (well below the thermocline), the release water is made up of a significant amount of hypolimnetic water. This water is cold (supporting a trout fishery downstream) but low in DO. Thus an objective of any improvement technique would be to improve the release DO (with a goal of 6.0 mg/l) without substantially increasing the release temperature.

Releases from LSL occur during hydropower generation for peaking power and local station service operation. That is, the main turbines are operated during periods of peak power demand and a small "in-house" generator is operated at all times to provide power for the project. This results in very high flow rates during peaking operations and relatively low releases during off-peak hours. Thus the alternative(s) for enhancing the release DO must be applicable during both flow conditions.

Recommended Alternatives. The recommended approach for the solution of the low DO release problem at LSL is a combination of hypolimnetic aeration/oxygenation and turbine venting. The hypolimnetic system should be designed to maintain a minimum level of DO in the LSL pool to ensure the mitigation of iron and manganese problems. A diffuser system should be developed based on the design of the oxygenation system at Richard B. Russell. The location of the diffuser(s) should be based upon operation of the LSL hydropower project and the morphology of the LSL basin in the vicinity of the dam.

In addition to the hypolimnetic aeration system, forced air injection at the turbines into the release flow should be implemented to "top-off" the DO entering the hydropower penstocks. This system would only be used as necessary to raise the release DO. For the Francis turbines, an injection system could potentially improve power production. At other hydropower projects, injection of very small amounts of air (too small for DO enhancement) has resulted in slight efficiency improvements. Employing an injection system for oxygen enhancement when needed during late summer and for efficiency improvement in the remainder of the year could prove to be very cost-effective.

Some guidance on the design and implementation of these two systems is available. For example, the efficiency losses and capital costs of a turbine venting system and its technical design aspects are fairly well understood. The expected improvement in DO for such a system can be estimated. The design of the oxygenation system at Richard B. Russell can provide the basis for an aeration system design. Additionally, guidance on destratification systems is available from the Bureau of Reclamation and may have application to the hypolimnion aeration system.

WOTS CASE STUDY II: MARK TWAIN LAKE

The summer stratification at Mark Twain Lake (MTL) also results in anoxic conditions in the hypolimnion. Ordinarily this problem would be overcome at MTL with the temperature control weir (TCW) which is an earthen dike approximately 125 m (400 ft) upstream of Clarence Cannon Dam (CCD). The crest of the TCW would normally act as a skimming weir and allow withdrawal of higher quality epilimnetic water. However, during 1984 significant rainfall in the MTL drainage basin kept the pool at very high stages. This resulted in the formation of the thermocline (region between epilimnion and hypolimnion) at an elevation well above the crest of the TCW. The high thermocline (relative to TCW crest) caused hypolimnetic conditions to be established in the area between the TCW and CCD. When hydropower or low-level releases were made, the result was low DO downstream. However, observations during the turbine tests tended to confuse this simplistic scenario. The causes and potential solutions to this problem and explanations of the apparent anomalies in the observed data are discussed in the following paragraphs.

The Data and Processes. Dissolved oxygen and temperature data were collected at several locations at the project: (1) main lake, upstream of the TCW; (2) mini-lake, the region between the main dam and TCW, and (3) downstream of the powerhouse. The DO and temperature profiles shown in Figure 1 were taken on 19 August, 23 August, and 13 September 1984, respectively. On these dates, turbine operation tests were being conducted that had a significant impact on the profiles observed in the mini-lake.

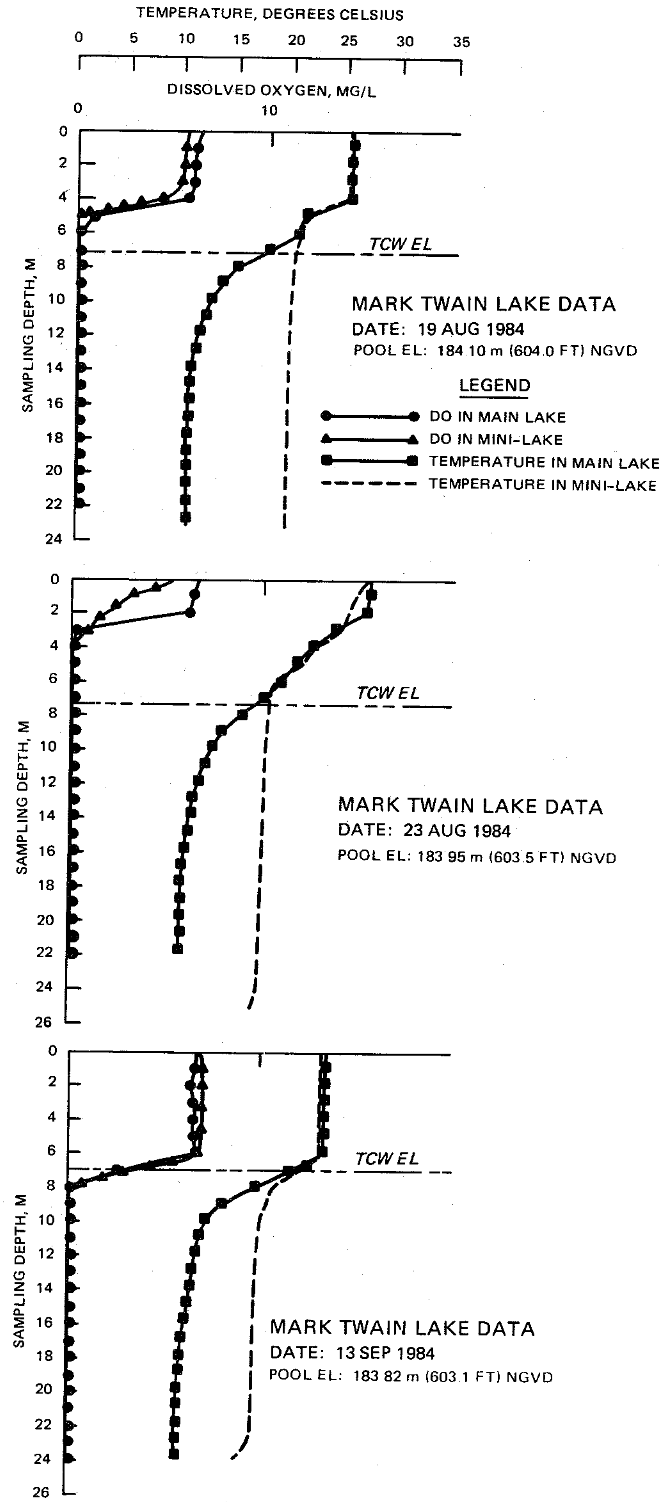

Figure 1: Mark Twain Lake Temperature and DO Profiles

Close examination of this figure will reveal that the mini-lake did not have the same temperature profile as the main lake. However, the mini-lake profiles were taken after turbine tests were run. It appears that the water in the mini-lake was withdrawn and replaced with water from the stratum near the TCW crest elevation. As a result, there was warmer water in the depths of the mini-lake than in the main lake but still anoxic conditions since the oxycline was above the TCW crest.

In the early part of the Francis turbine test, the "speed, no load" condition was tested. During this time the DO content of release water was very good, nearly as high as the DO content of the epilimnion. As the test progressed, and the discharge from the turbine increased, the DO decreased. However, after about 40 min of operation the DO began to increase accompanied by an increase in temperature.

During the speed, no load portion of the test, the extremely low discharge (about 28.3 cms (1,000 cfs)) through the Francis turbine would have caused the vacuum-breaker system to function. At this very low wicket-gate setting, large volumes of air would have been aspirated into the draft tube region just below the turbine wheel. As this air-water mixture traveled to the tailrace area, the DO uptake was quite significant. As the hydropower release increased, the amount of air aspiration decreased, resulting in lower DO uptakes and a decrease in the release DO. However, because of the small volume of water between the TCW and main dam, this was a short-lived phenomenon. Once the volume of the mini-lake had been withdrawn, the skimming characteristics of the TCW increased the release temperature and the DO improved.

The above conclusion was verified with data from the test of the second turbine at MTL: a reversible Kaplan turbine. The Kaplan unit does not have a vacuum-breaker system and during its start-up tests low or zero DO resulted in the releases. However, after approximately 40-50 min, the DO began to increase accompanied by a temperature increase. This illustrates the impacts of the mini-lake and the TCW.

It appears from comparison of the in-lake and mini-lake temperature and DO profiles and evaluation of the release DO and temperature values produced by operation of the MTL powerhouse that the major cause of low release DO is the chemical restratification of the mini-lake. This results in the low DO content in the releases until the TCW can influence the quality of the water being withdrawn.

Recommended Alternatives. The recommended approach for the solution of the low DO problem at CCD is a combination of local destratification and turbine venting. Hydraulic destratification of the mini-lake would prevent the occurrence of oxygen stratification without requiring the tremendous capital and energy outlay for a system to destratify the entire lake. Regardless of the operating procedures adopted for power production, or the level of the lake (which impacts the thermocline elevation), the DO content of the mini-lake could probably be maintained at an acceptable level. Further, the use of local hydraulic destratification would avoid the potential for nitrogen supersaturation that might be encountered with a pneumatic destratification system.

In addition to the local destratification system, forced air injection into the release flow should be implemented to "top-off" the DO entering the hydropower penstocks. This system would only be used as necessary to raise the release DO.

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RESERVOIR RELEASE WATER QUALITY MANAGEMENT THROUGH THE USE OF OPTIMUM INTAKE DESIGN AND BLENDING IN A SINGLE WET WELL

by

Stacy Howington[1]

INTRODUCTION

Water quality management is becoming a higher priority in reservoir regulation with existing project operations being geared more toward water quality maintenance than ever before. Water quality concerns are also a primary consideration in the design phase of new projects such that water quality objectives are met both in the reservoir and downstream . One method of meeting these is through the operation of a selective withdrawal structure.

Selective withdrawal through multilevel reservoir outlet works has long been used as a tool for release water quality maintenance from stratified reservoirs (Bohan and Grace 1973). Methods have now been developed that build on the selective withdrawal concept in order to improve techniques for the design and operation of selective withdrawal structures. Two of these methods are optimum location of selective withdrawal intakes and blending of selectively withdrawn waters in a single wet well. The two techniques will be discussed separately.

OPTIMUM LOCATION OF INTAKES

Optimum intake location technology was developed to provide design and modification guidance for selective withdrawal structures in order that they might more closely and efficiently meet downstream water quality and quantity constraints. Numerical modeling is used in conjunction with mathematical optimization to arrive at the best combination of port number and location.

OPTIMIZATION

Traditionally, selective withdrawal structures have been operated to meet a downstream temperature objective. For this reason, the following discussion will be limited to temperature modeling and optimization. However, with a different model, this procedure could be applied to other release water quality parameters such as dissolved oxygen or a combination of parameters.

The numerical model, WESTEX, is adjusted for the specific project. This process requires hydrologic, meteorologic, and operational input data in order to represent the thermal processes in the lake. The coefficients of thermal exchange and wind mixing are adjusted until the in-lake temperature profiles are closely approximated by the numerical model. Selective withdrawal technology is built into the numerical model to predict in-reservoir flow distributions and release quality. DECIDE is a routine within WESTEX that, while taking into account the physical constraints of the intake structure,

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[1] Research Hydraulic Engineer, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180-0631.

determines which port openings and individual port flows will provide a release temperature closest to the downstream objective temperature.

A performance index called an objective function is then developed. It assigns a numeric value to a given port configuration that is an evaluation of its capability to meet the downstream target temperature for the given input conditions. This provides a means for comparing the various port arrangements. This objective function, usually a measure of the difference between the released temperature and the objective temperature, is then minimized to reveal the configuration with the optimum number and location of ports, i.e., the configuration that will yield the lowest deviation between the desired and the released temperatures for the input data provided.

CASE STUDY

The optimum intake location procedure was applied to Beltzville Dam on Pohopoco Creek in northeastern Pennsylvania. The selection of this reservoir was not based on any problems at this site, but on the availability of data needed to run the model. The Beltzville intake structure houses 2- by 4-ft water quality intakes at a total of seven elevations.

The case study was designed to demonstrate the utility of this procedure and is not an evaluation of the intake structure design at Beltzville. The hydraulic and meteorologic conditions under which these tests were conducted (one year) represent only a minor section in the range of possibilities.

First, the thermal exchange and wind mixing coefficients in the WESTEX model were adjusted using 1972 data until the model temperature profiles closely resembled the observed profiles. The following was used as an objective function:

$$F = \Sigma (TR_i - TO_i)^2$$

where

TR = release temperature predicted by the numerical model

TO = downstream objective temperature

i = time increment (days in this application)

The optimization process was completed for 1, 2, 3, 4, and 6 ports. Each of these combinations of ports was optimally located for the desired release temperatures prescribed. The existing structure was also modeled and an objective function value determined, but the port locations were not optimized.

RESULTS

The results from this evaluation are given in Figure 1. The objective function is shown for a varying number of optimally located intakes. The objective function appears to become approximately equal when four or more ports are optimally located. The "as built" objective function value

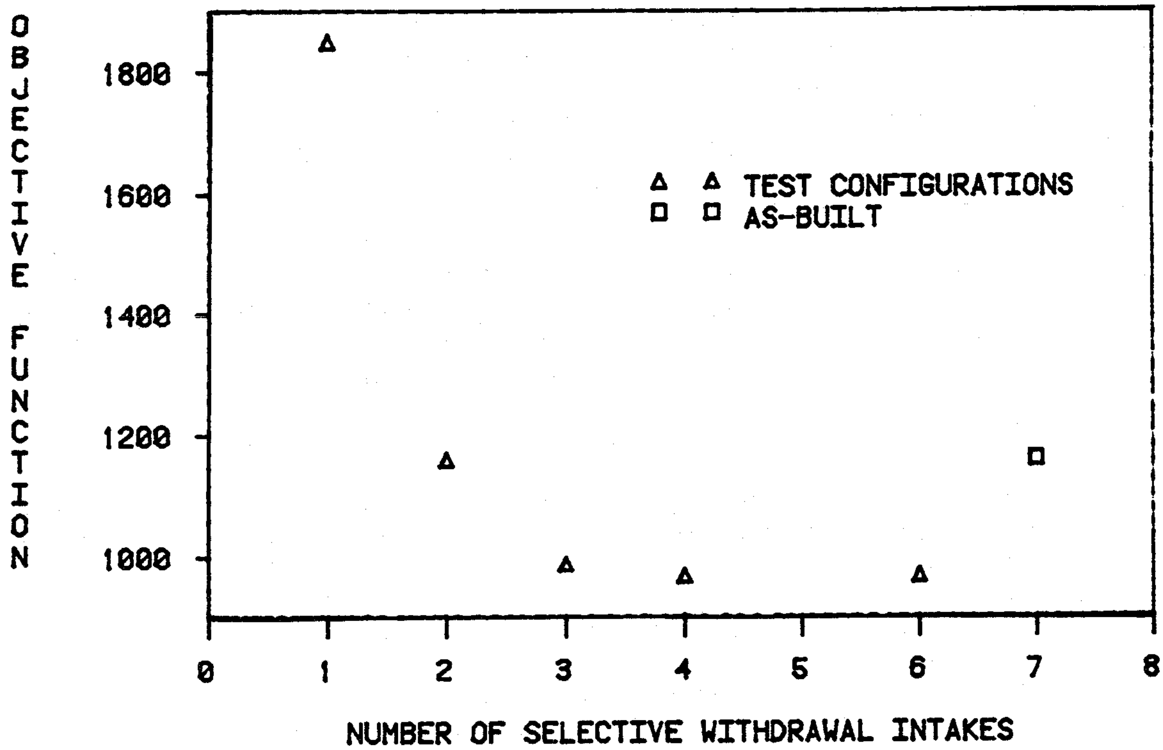

Figure 1. Comparison of alternatives

shows that for the given input data, three or more optimally located intakes could do a better job of meeting the prescribed downstream temperature objective than the existing structure with seven levels.

A detailed description of the optimum intake location technology as well as the application of the technology to the Beltzville intake structure is provided by Dortch and Holland (1984). This discussion includes the search techniques and the development of the objective temperature curves.

This technology has also been applied to the Cowanesque Reservoir. In this case, the District began investigating the reallocation of a portion of the flood-control storage for water supply. This would result in a substantial increase (30 to 40 ft) in the normal pool elevation that would alter the thermal structure of the lake considerably. It was discovered that the existing intake structure would not provide the flexibility necessary to meet the downstream temperature objective. Additional ports were needed to provide this flexibility. The optimum intake location procedure was used to determine the number and location of additional ports needed (Holland 1982).

BLENDING IN A SINGLE WET WELL

Another technique that may be used in water quality management is blending in a single wet well. Simultaneous multilevel withdrawal from a stratified pool is often needed to meet downstream water quality and quantity requirements. This has traditionally been accomplished through the use of a dual wet well system. Water is withdrawn from the desired levels in the pool (one level of withdrawal per wet well) and mixed downstream of the separate flow controls on each wet well.

The development of blending capability without separate flow control for each level of withdrawal would provide additional flexibility in the design and operation of multiport towers. Single wet well structures could regularly be considered as a design option and dual wet well structures with multiple ports in a single well might be operated differently to provide additional water quality control. In some cases, the addition of a single downstream point of flow control such as a hydroturbine to a dual wet well, dual flow control system would not necessarily mean a total loss of simultaneous, multilevel, selective withdrawal capability.

THEORY

Consider the simplified, idealized case in Figure 2. The stratification is perfectly two layered and one port resides in each of the homogeneous layers.

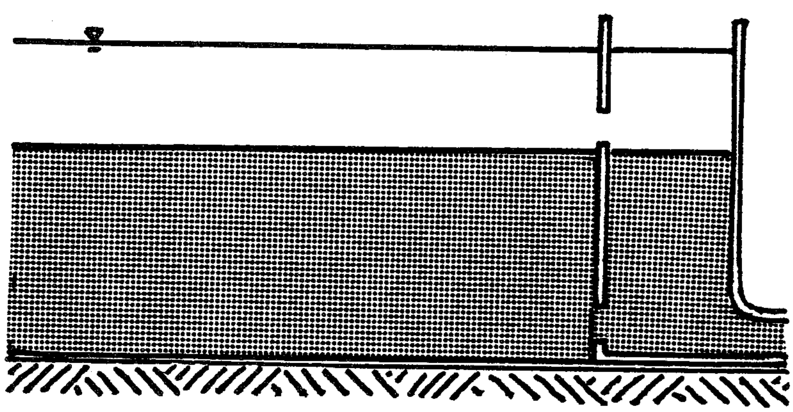

Figure 2. No flow condition

When the total discharge from the structure is zero, we assume that the same stratification exists in the wet well as does in the pool. As the service gate is slightly opened, flow will begin through the lower port, and the discharge from the structure will come entirely from below the thermocline. No discharge comes from the upper port due to the buoyancy of the lighter water on the surface.

As the flow enters the lower port, a head loss is experienced. This head loss is reflected by a lowering of the thermocline in the wet well. No water-surface differential exists between the wet well and the pool. Water enters the top port only fast enough to fill the void created by the receding thermocline in the wet well.

Once the thermocline is depressed to the top of the lower port, a theoretical critical equilibrium has been reached. If the flow is increased, the thermocline is lowered, the buoyancy is overcome and flow begins through the upper port. Therefore the discharge just below this point is called the critical discharge (Figure 3) and is referred to as "incipient" blending. This can be theoretically determined from Bernoulli's equation.

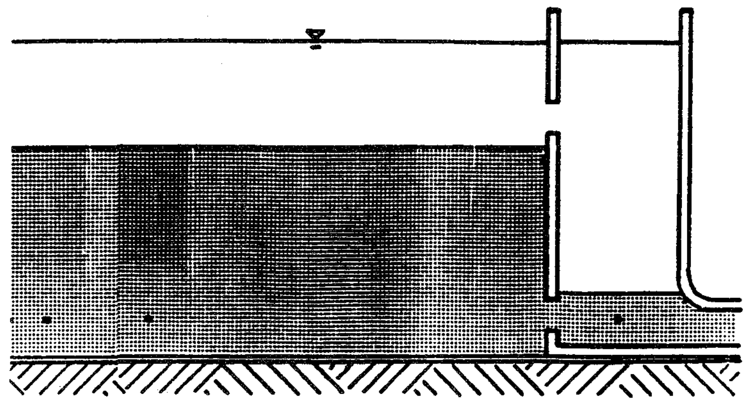

Figure 3. Critical discharge

For total discharges greater than that needed to overcome density blockage (post critical), flow will pass through each of the ports, but not necessarily in the same ratio as would be expected in unstratified conditions. This flow ratio can be determined analytically based on the theory. A more extensive description of the theory is provided by Howington (1985).

LIMITATIONS ON THE THEORY

Several assumptions that must be made are not truly representative of the physical situation. These differences include:

a. The velocity of the flow entering the lower port is negligible once it enters the wet well.

b. The thermocline inside the wet well remains completely intact until it reaches the elevation of the lower port. This neglects the mixing caused by the lower port velocity jet as it impinges on the backwall of the intake structure.

c. The stratification used in the derivation is perfectly two layered and the ports withdraw only the water from the layer in which they reside.

This theory does, however, provide a basis for further investigation.

APPLICATION

Lost Creek Lake is located in southwest Oregon on the Rogue River. It is a single wet well structure with 12 intakes that span five elevations. Release temperature management is crucial at this project due to the important downstream fishery. Downstream temperature targets are currently met by blending from multiport elevations based on operator experience.

The Lost Creek intake structure is currently under physical model study at the Waterways Experiment Station. This is an operational study that includes the development of descriptions for selective withdrawal, blending in the single wet well structure, and alternate operational schemes for cool water resource management.

The downstream minimum release for this project, 700 cfs, is greater than the critical discharge necessary to overcome blockage in the wet well for the stratification patterns observed. Therefore only the flow distribution between the levels of ports open needed to be established. Port coefficients similar to head loss coefficients were developed for each port. The theoretical description for blending in the postcritical range of discharges was applied to the results. The agreement was very good between the theoretical predictions of discharge ratios between the ports and the values observed in the physical model. These results will be published upon completion of the study.

This technology is new and little data exist for comparison. A research work unit is currently under way that should reveal a more accurate description of the blending phenomenon and more details about its general application.

ACKNOWLEDGMENT

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LONG-TERM MANAGEMENT STRATEGY FOR DREDGED MATERIAL DISPOSAL

Technical Management Strategy

By

Norman R. Francingues, Jr.[1]

INTRODUCTION

The National Dredging Program includes the maintenance and development of approximately 25,000 miles of Federal waterways that flow through 42 states and serve 130 of the Nation's largest cities. Most of the navigation channels in the waterways require periodic dredging to maintain safe and efficient operating conditions for maritime traffic. Only one estuary, Puget Sound in the State of Washington, has sufficient natural depth to accommodate large ships engaged in commercial international maritime activities. Thus, due to the significant economic and defense importance of this extensive navigation system, it is usually not a question of whether or not to dredge, but rather a question of how to effectively dredge and dispose of the dredged material in an environmentally acceptable yet economic and efficient way.

Obviously, there is a critical need to develop a logical, technically valid, and systematic approach to evaluate disposal alternatives for dredged material. Since the nature and level of contamination in sediment vary greatly on a project-to-project basis, the appropriate method of disposal may involve any of several disposal alternatives. Control measures to manage specific problems associated with the presence or mobility of contaminants may be required as a part of any given disposal alternative. Further, many states, in an effort to fully manage their natural resources, expect Corps of Engineers' (CE) assistance via a long-term approach to operating and managing dredged material disposal areas and providing additional storage capacity.

An overall long-term management strategy for disposal of dredged material is required. Such a framework for decisionmaking must include a technical management strategy with appropriate testing protocols and design procedures to aid in selecting the best possible disposal alternatives and to identify appropriate control measures to offset any problems associated with the presence of contaminants.

[1] Chief, Water Supply and Waste Treatment Group, Environmental Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

POLICY GUIDANCE

In a recent letter to the field, General Patrick J. Kelly, the CE's Deputy Director of Civil Works, transmitted policy guidance regarding management and disposal of contaminated dredged material. The guidance included a technical management strategy for disposal of dredged material with emphasis on contaminant testing and control. The basis of the strategy was the extensive database developed in CE R&D programs and the experience gained in managing dredged material disposal over the last decade.

Where appropriate, it is now CE policy to use the management strategy to supplement the review procedures and requirements outlined in the 404 (b)(1) Guidelines (40 CFR 230) and the Ocean Dumping Criteria (40 CFR 220), when these regulatory requirements are applicable. This paper presents an overview of the technical framework of the management strategy and recent experiences with the application of the strategy to various Corps projects.

TECHNICAL MANAGEMENT STRATEGY

The long-term dredged material disposal management strategy developed for the Corps' dredging program must be broad enough to handle a wide range of dredged material characteristics, dredging techniques, and disposal alternatives. The long-term management strategy must consider the nature of the sediment to be dredged, potential environmental impacts of dredged material disposal, nature and degree of contamination, dredging equipment, project size, site-specific conditions, technical feasibility of disposal options, economics, and other socioeconomic factors. This section presents the technical management strategy that considers most of these factors (Figure 1) (Francingues et al. 1985).

The two major features of the technical management strategy are consideration of disposal alternatives and steps required for selection and implementation of appropriate disposal management practices. The required steps are as follows:

- Conduct an initial evaluation to assess contamination potential.
- Select a disposal alternative.
- Identify potential problems associated with that alternative.
- Apply appropriate testing protocols.
- Assess the need for disposal restrictions.

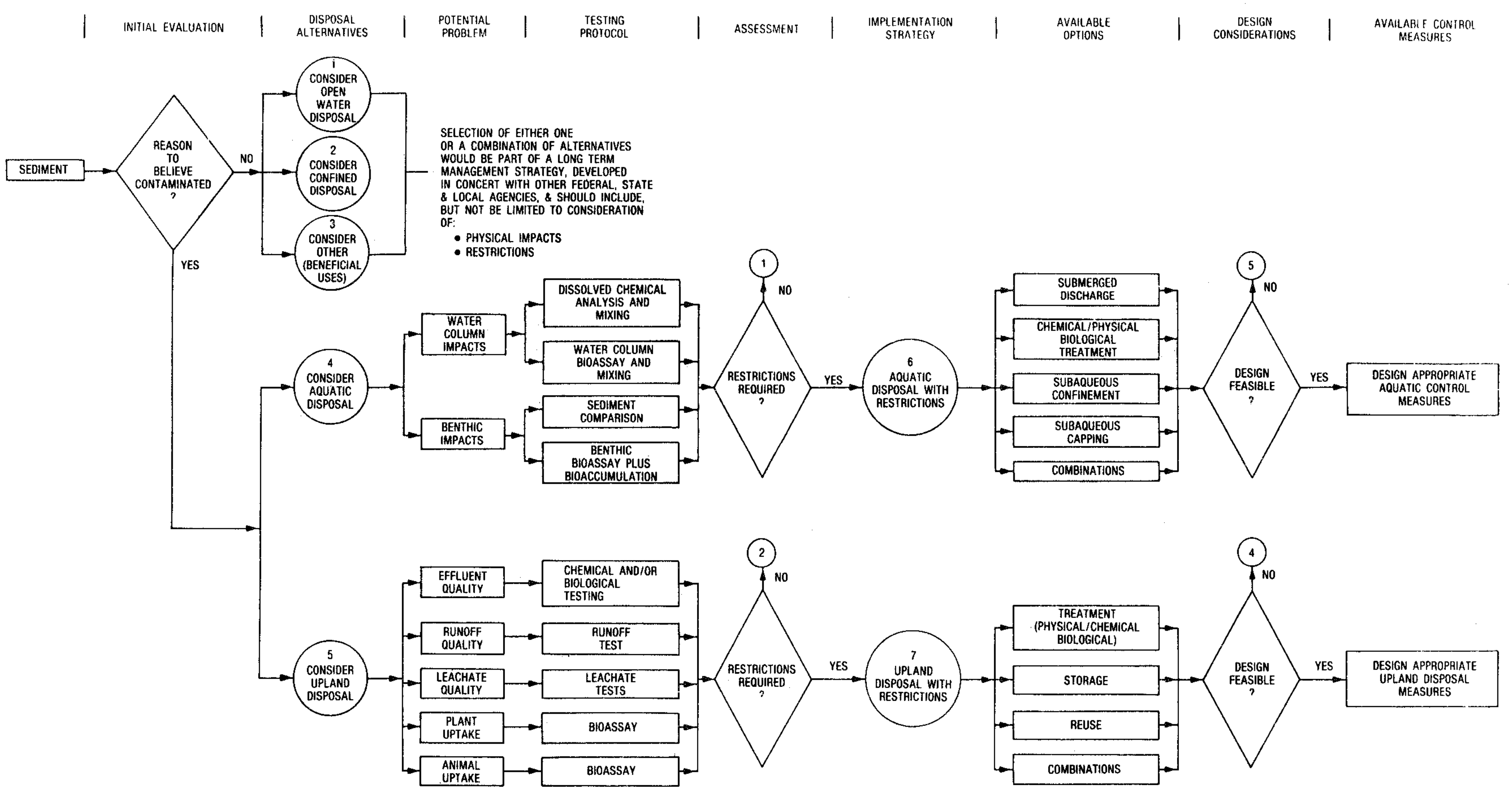

Figure 1. Management strategy flowchart

- Select an implementation strategy.
- Identify available control options.
- Evaluate design considerations for technical and economic feasibility.
- Select appropriate control measures.

Conduct an initial evaluation

The initial screening for contamination is the initial evaluation outlined in the testing requirements for Section 404 of the Clean Water Act (USEPA 1980). The evaluation is designed to determine if there is reason to believe that the sediment contains any contaminant at a significant concentration (above background levels). Considerations include but are not limited to:

a. Potential routes by which contaminants could reasonably have been introduced to the sediments.

b. Data from previous bulk sediment analysis and other tests of the material or other similar material in the vicinity, provided the comparisons are still appropriate.

c. Probability of contamination from agricultural and urban surface runoff.

d. Spills of contaminants in the area to be dredged.

e. Industrial and municipal waste discharges.

Select a disposal alternative

If there is available information indicating contaminants are not present above background levels, restrictions are not required. In this case any disposal alternative may be selected although the possibility of other environmental impacts such as effects of turbidity, salinity, suspended solids, temperature changes, and low dissolved oxygen concentrations must be considered in the final selection. Three disposal alternatives are shown in the flowchart (Figure 1) for acceptable materials or so-called "clean" sediments: [1]* open water (aquatic), [2] confined (intertidal, nearshore, and upland), [3] others, which include marsh or wetland development and other beneficial uses.

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* Numbers in brackets refer to the respective disposal alternative as numbered in Figure 1. Also, open-water disposal is used to describe only aquatic environments, whereas confined disposal operations can be classified for intertidal, nearshore, and upland environments.

If there is reason to believe that contaminants are present, the sediment must be evaluated in relation to the physicochemical conditions that would be present at the disposal site to examine the potential for environmental impacts. Either open-water [4] or confined [5] disposal could be initially considered and appropriately evaluated or both alternatives could be evaluated concurrently.

Identify potential problems

Each disposal alternative may pose potential problems for managing contaminated dredged material. Potential contaminant problems can be identified after the initial evaluation and consideration of site-specific conditions, dredging methods, and anticipated site use. For open-water disposal, contaminant problems may be either water quality related (water column) or sediment related (benthic environment). For confined disposal, potential contaminant problems may be either water quality related (effluent, surface runoff, or leachate) or contaminant uptake related (plants or animals).

Apply appropriate testing protocols

The magnitude and potential impacts of specific contaminant problems must be evaluated using appropriate testing protocols. Such protocols, designed for evaluation of dredged material, consider the unique nature of dredged material and the physicochemical conditions of each disposal alternative under consideration. The type of testing of the sediment to be dredged depends on which of the two questions in Figure 2 is being addressed.

Testing intended to answer the question, "Where should sediment be placed to minimize contaminant mobility?", is site selection testing and addresses the situation where there are no limitations on available disposal sites, i.e., open-water disposal sites are available as well as upland or nearshore confined sites. The emphasis is on selecting the most appropriate disposal environment for the dredged material.

Testing intended to answer the second question, "Is the available disposal site acceptable for dredged material?", is acceptability testing and addresses the situation where there are limitations on available disposal sites. Therefore, the sediment is tested to determine the acceptability of a given disposal site for the disposal of the sediment. For example, if the only disposal sites available are confined sites, then testing should focus on confined disposal and not on open-water disposal. Ultimately, the testing should be tailored to the available disposal site.

Assess need for disposal restrictions

The results of all testing are compiled and evaluated to determine the potential for environmental harm from contamination, to examine the interrelationships of the problems and potential solutions, and to determine

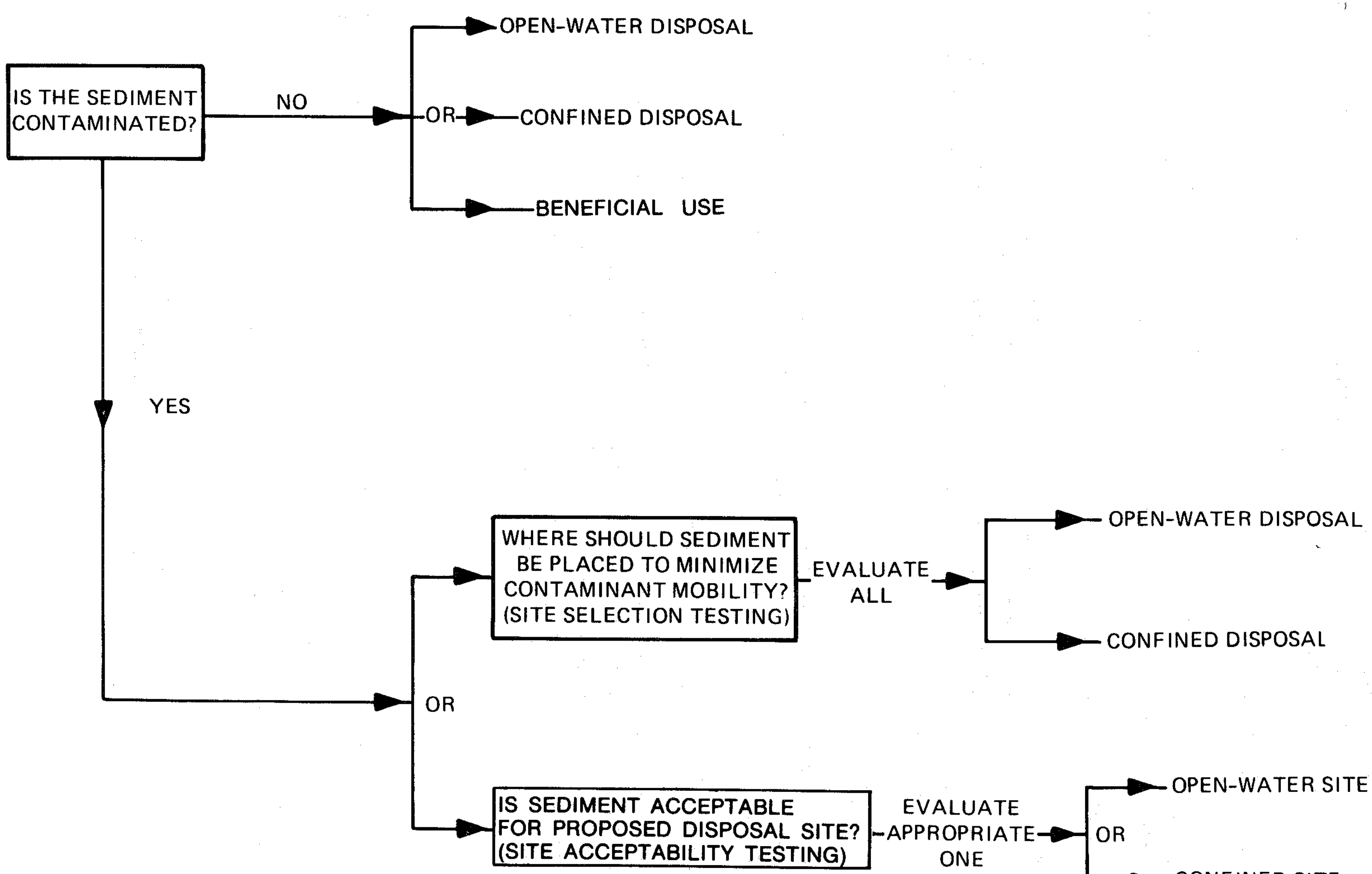

Figure 2. Initial questions to be addressed for testing of contaminated sediments

what restrictions on open-water (aquatic) disposal or confined disposal (intertidal, nearshore, upland) are appropriate. If impacts as evaluated by the testing protocols are acceptable, conventional open-water or confined disposal may again be considered.

Select an implementation strategy

Specific environmental problems identified by the testing protocols must be considered in the development of an implementation plan appropriate for dredged material and appropriate for the level of potential contamination.

Identify available control options

Several options may be available for the selected implementation strategy. Options for controlling water column and benthic impacts include bottom discharge via submerged diffusers, treatment, confined aquatic disposal, and subaqueous capping using cleaner sediment. Options for controlling confined disposal impacts include treatment, storage, and reuse.

Evaluate design considerations

Design considerations should be based on environmental and human health protection, technical feasibility, economics, proven reliability and performance considerations, and other engineering and operational factors.

Select appropriate control measures

The degree of contaminant control finally selected may range from disposal in open water with no special restrictions to a completely controlled confinement. Many of the technologies identified are either commonly used in CE dredging activities or are presently being evaluated as part of the CE's ongoing research and operations programs.

FIELD VERIFICATION AND APPLICATION

Several examples can be cited where the CE has applied the technical management strategy to assist in the evaluation of dredged material disposal alternatives. For example, applications for Puget Sound, in the State of Washington, include the Commencement Bay Superfund project, the Puget Sound Dredged Disposal Analysis (PSDDA) study, and the US Navy Homeport facility at Everett, Washington.

To improve interpretation of test data on dredged material and to assist decisions associated with the high cost of remedial action, a decisionmaking framework was developed for proposed dredging in Commencement Bay (Lee et al. 1985). The framework focuses on procedures for answering the question of how should dredged material be tested and the results be interpreted to evaluate the degree of potential contaminant mobility and the disposal considerations under which the dredged material would have the least adverse impact on the overall environment.

Because the Commencement Bay study identified a number of important issues and options for disposal of dredged material, the PSDDA study was developed to resolve the major issues associated with dredging. As part of PSDDA, evaluation procedures for dredged material disposal alternatives will be defined for the Puget Sound cleanup initiative. A major input to the testing and selection of appropriate controls is the technical management strategy. Further refinement of the strategy is underway at the Waterways Experiment Station (WES). The WES is developing a logic and technology substitution flow chart for identification and selection of control measures for disposal of contaminated dredged material.

Initial field application of the technical management strategy in Puget Sound is to dredging for the Navy Homeport facility at Everett, Washington. In June 1984, the Navy contracted with the CE to provide technical assistance for dredging and disposal of the dredged material. The CE applied the suite of tests specified in the strategy to assess the requirements for dredged material disposal. Results of the tests will be key to permit decisionmaking and final design of the Navy's dredging and disposal plans.

In addition to the Puget Sound application, the CE has applied appropriate portions of the strategy to several key projects. These projects include the Indiana Harbor Canal in the Chicago District, the Corps/EPA Field Verification Program at Bridgeport, Connecticut, and the New Bedford Superfund study at New Bedford, Massachusetts. Results of these efforts will be used to further refine the technical aspects of the overall management approach.

SUMMARY

The CE has taken a major step in developing a technically sound management strategy for disposal of dredged material. This strategy is intended to be applicable to the wide range of sediments that are dredged in Federal waterways, to provide guidance on appropriate testing and evaluation procedures for sediment contamination potential within all available disposal options, and to incorporate the state of knowledge on appropriate long-term disposal management strategies for a wide range of sediments. The CE is refining the technical management strategy and will perform selected field demonstrations projects in several regions of the country in the very near future.

ACKNOWLEDGMENT

The tests and the resulting data presented herein (unless otherwise noted) were obtained from research conducted under the Dredging Operations Technical Support (DOTS) Program. The DOTS Program is sponsored by the Dredging Division of the Water Resources Support Center, US Army Corps of Engineers, and is conducted by the Waterways Experiment Station. Permission was granted by the Office, Chief of Engineers, to publish this information.

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Long-Term Management Strategy for the Disposal of Dredged Material: Application of the Environmental Effects of Dredging Program

by

William L. Klesch[1]

BACKGROUND

On an annual basis the Corps of Engineers (CE) generates approximately 280 MCY (million cubic yards) of dredged material from its O&M program , another 40 MCY from new work and nearly 100 MCY under its regulatory programs. These quantities are generated in response to the CE navigation responsibility, as authorized by the Congress of the United States, to maintain nearly 25,000 miles of federally authorized navigation channels. By way of comparison, the twin towers of the New York Trade Center have been estimated to hold nearly 4 MCY, thus the CE would need nearly 80,000,000 Trade Centers to hold the 320 MCY of dredged material generated from the O&M and new work programs each year.

These figures serve to point out the enormity of the disposal problem facing the CE as it seeks to meet its navigation responsibilities in a timely, cost effective and environmentally acceptable manner. Combined with this obvious disposal need is the fact that, today, many states are becoming more responsible for the "health" of the lands and waters within their jurisdiction. There are several reasons, in my opinion, for this increased responsiveness on the part of the states:

- The voting public has become more vocal and influential with regard to natural resources, in particular, their protection and conservation.

- An increased public and institutional recognition that our natural resources, plentiful as they may be today; are finite and, as our population increases, more stress will be placed upon these desirable natural resources.

- Finally, there has been a change in the way natural resources, themselves, are viewed, namely, more of an understanding as to the "link" between the quality of life we wish to experience and a "healthy" environment.

1 OCE, Directorate of Civil Works, Planning Division, Review and Analysis Branch

Several examples of recent state activities along these lines include the Puget Sound and Chesapeake Bay Initiatives. I expect similar activities to be developed by other states in the future. In both of these examples the EPA, collectively with the responsible states, have approached the CE to aid in the development of management plans for these large, regional, aquatic ecosystems. Specifically, the CE was requested to initiate and conduct long-term dredging management studies in cooperation with the affected states and EPA. These requests serve to highlight the recognition that the CE is given as a center of dredging technology and expertise. Thus, it is in our own best interest to continue to maintain this technical position, particularly in view of our navigation responsibilities. In fact, the CE is the only government and private sector entity that has a comprehensive R&D program involving dredging and dredging technology within the United States. Nevertheless, an interesting paradox emerges. Despite this recognition of our dredging expertise, new disposal areas are becoming increasingly difficult to identify and use because of conflicting natural resource and developmental interests that are often associated with these aquatic systems.

The Environmental Effects of Dredging Program (EEDP) is a multi-facetted research program which deals with various aspects of the CE dredging program, including:

o the regulatory aspects of dredging, specifically, Sections 404 and 103 of the Clean Water Act and the Ocean Dumping Act, respectively;

o contaminant testing and control;

o aquatic and upland plant and animal bioassays;

o the evaluation and interpretation of sediment, engineering and ecological test results;

o sediment resuspension and modeling activities;

o innovative techniques for disposal management, including capping, CDF design, predictive methods and computer aided methods for consolidating engineering and design procedures, and

o beneficial use of dredged material, including habitat development, aquaculture, land improvement and beach nourishment.

CONCEPT

The marriage of the technical areas of EEDP and the technical experience of CE District offices into a meaningful compendium, i.e., a long-term management strategy for the disposal of dredged material, could provide a mechanism whereby the CE could view its navigational responsibilities in a more comprehensive manner, both from an operational (field activities) and a research and development perspective. This would allow the CE to simultaneously meet its navigation responsibilities and address the natural resource concerns of the states in which these navigation activities are conducted.

The EEDP Program Office together with the support of the Dredging Division of the Water Resources Support Center (WRSC-D) requested that the author be detailed to the Waterways Experiment Station to organize and conduct a national workshop. The purpose of the workshop was to discuss, within the CE family, the need for and implementation of a long-term management strategy (LTMS) for the disposal of dredged material.

Initially, we attempted to answer three basic questions regarding the concept of a long-term management strategy.

1. Is there a legitimate need for such an approach?

2. What would be the anticipated accomplishments of such a long-term management strategy?

3. How would such a long-term management strategy be implemented?

From our initial, limited perspective we developed a suite of answers to each of these basic questions for further refinement at an anticipated national workshop as follows:

Need

o Such a strategy would provide a systematic, logical approach to a complex natural resource and operational problem.

o Dredged material management is consistently being identified as a priority issue by concerned states.

o The development of a long-term management strategy meets, head-on, the problem of disposal and natural resource conservation.

o The CE is a leader in dredging and dredging technology, thus it is in our own best interests to proceed to define and implement the concept of a LTMS.

o Athough it will require more up-front costs, it is anticipated that future benefits will more than offset these costs.

Anticipated Accomplishments

o Will provide a comprehensive framework within which technical information can be used to evaluate alternatives.

o Will provide for the comprehensive consideration of all resources, natural and man-made, into the evaluation.

o Will provide for the early and continued input from other responsible state, federal and local agencies, recognizing the authorities under which both we and they operate.

o Should encourage the use of dredged material in environmentally acceptable ways, including, e.g., the setting of seasonal restrictions based upon scientific evidence, the consideration of beneficial uses as appropriate and an examination of traditional design practices for channels, harbors, ports and dredging and disposal practices.

o Will provide for adequate lead times to accomplish necessary testing, yet remain flexible enough to accommodate regulatory change.

o Will provide for both the consideration of contaminated and non-contaminated materials; however, the strategy must also include socio-economic considerations and testing based upon resources of significance within the regional area under investigation.

o There must be a commitment from all levels of the CE to endorse and mutually support the concept of a long-term management strategy including the cooperative efforts of the Planning, Operations, and Regulatory elements in the establishment and implementation of any LTMS.

o Funding and appropriate authorities must be investigated to remove any institutional constraints.

Implementation

o Conduct a national workshop to further discuss and refine the issues generated under Need and Anticipated Accomplishments as outlined above.

o Workshop recommendations should be forwarded to Headquarters, Office of the Chief of Engineers (OCE), specifically the Director of Civil Works, through WRSC-D for subsequent endorsement and implementation of the concept of a LTMS for the disposal of dredged material.

Based upon this preliminary assessment of need, anticipated accomplishments and implementation, the national workshop was designed to further refine these issues through the infusion of field experience. This infusion was accomplished in two ways; (1), formal presentations from Districts involved in major dredged material disposal activities, similar to those envisioned under a long-term management strategy and (2), through discussions and recommendations of smaller working groups designed to specifically address certain topic areas.

The workshop was held in Jackson, Mississippi, 20 thru 22 August 1985. Nearly 100 CE field personnel were in attendance, representing 21 Districts, 8 Divisions, and 2 Laboratories. The Office of the Chief of Engineers (OCE), the Dredging Division of the Water Resources Support Center (WRSC-D), and the Institute for Water Resources (IWR) were also represented. The entire group was about equally composed of planners, regulators and operations types, thus we had a good mix of organizational elements in addition to the broad District and Division representation. After the formal presentations on the first morning, the workshop participants were divided into six smaller working groups. A deliberate attempt was made to have an equal mix of planners, regulators and operational types in each group. After one and a half days of deliberation, the facilitators from each working group reported on their individual working sessions to a reconvened general session. Thus all workshop participants were knowledgeable of the discussions that took place in each of the working groups.

WORKSHOP RESULTS

A summary of each working group follows; however, when a similar recommendation was developed by several working groups that recommendation will only be summarized for the first working group in which it appreared.

WORKING GROUP 1. Feasibility Planning for Long-Term Management Strategies.

o The CE is a recognized leader in dredging and dredging technology. It would be in our own best interest to develop and implement LTMS's for the disposal of dredged material and to assume a leadership role.

o The concept of the LTMS is viable and should be pursued at the District level subject to the following conditions; LTMS's should be actively encouraged and supported by higher authority; the authority to undertake LTMS's should be clarified; LTMS's should be flexible enough to accommodate legislative change; short term operational problems need to be addressed first and all LTMS's should be naturally resource based.

o The CE planning process and experience in its implementation should be heavily relied upon in developing any LTMS; however, there are specific aspects that need to be addressed; including, the concept of beneficial-uses; the critical examination of traditional navigation design practices; the examination of system-wide navigation programs as well as individual projects; the incorporation of risk assessment techniques and the institutionalization of procedures for the evaluation of planning techniques (post-construction).

o Coordination, both internal CE and interagency, should be considered the critical element, with every effort being given to develop as complete a program as possible including comprehensive public involvement activities.

WORKING GROUP 2. Dredging and Engineering Needs.

o Regarding channel design, the configuration should reflect the capabilities of the dredges available and consideration of authorized channel locations and depths should be more flexible to allow for cost savings.

o There is a need to improve our ability to predict shoaling and scouring, both as to location and volumes (in particular fine grained materials), in open water sites and provide better geotechnical guidance for the characterization of new work material.

o We need to manage disposal sites for the long-term, considering the future use of the site and should continue to maintain a leadership role in their design for both contaminated and non-contaminated materials.

o Districts should make conscious efforts to coordinate construction schedules, thereby staging construction, lessening the competition for dredges and reducing equipment shortages within the same regional area.

o More emphasis should be placed upon dredging and dredging management as a professional discipline via the encouragement of cross-training of military and civilian personnel in the form of multi-disciplinary teams.

o Need to examine our contracting procedures to encourage innovation and/or recognize those innovations currently in place that allow work to be conducted in a timely, economical and environmentally sensitive manner by fostering inter-District communication, e.g., exchange of cost information and the blending of dredging experience with cost estimating procedures.

o Environmental information should continue to play a part in the selection of disposal areas; however, a more effective mechanism should be developed to transfer R&D results to the field and to the attention of the resource agencies with which we coordinate.

o Need to improve the mechanisms (workshops, briefings, videos and other media) whereby information is distributed among the professions involved in dredging and its evaluation both within and outside the CE.

<u>WORKING GROUP 3. Sediment Characterization</u>.

o Need to have a comprehensive listing of the requirements of the various environmental laws that affect navigation projects, specifically, a definition of information sufficiency.

o The CE must retain financial responsibility for testing and sediment characterization, in general, and seek to identify ways to reduce costs while assuring environmental protection, including streamlined procurement procedures and laboratory certification.

o Contaminated sediment evalulation should use a tiered approach considering in order, whether or not there is a reason to believe the sediments are contaminated (historic records); contaminant evaluation should be "effects" based using similar species and finally, the analytical sensitivity should be based upon the effects concentrations on the same species.

o Need to improve the procedures for sediment characterization, including recognition of data variability, guidance on hazard and risk assessment, the hydrodynamic conditions at the dredging and disposal site and the formulation of clear monitoring objectives.

o Seek to improve the transfer of sediment characterization data among Districts and Laboratories via computer information retrieval systems.

o Increased use of Section 115 of the Clean Water Act (as amended) for appropriately categorized sediments.

WORKING SESSION 4. Significant Resource Characterization

o There is little need to develop new study methodologies for the inventory of resources and the selection of significant resources.

o Recognizing that the development of a LTMS will be a multi-agency task, the CE should promote greater input and cooperation from project sponsors, resource agencies and other appropriate groups.

o Any LTMS must be reviewed periodically to allow for administrative and legislative changes in the region and for the problems and needs of the respective projects within the region.

o Beneficial uses and resource management of dredged material should be incorporated into all LTMS's to gain wider acceptance of the LTMS and to make disposal operations more cost efficient.

o Those policies, regulations, etc. relative to natural resources need to be completely reviewed prior to the development of any LTMS and reaffirmed or modified as appropriate, periodically.

o Promote the timely technology transfer of LTMS resource information among the Districts, Divisions, Headquarters, Laboratories and the appropriate resource agencies with which we coordinate.

o LTMS for the disposal of dredged material should be established as an agency goal, with appropriate, regional LTMS's developed by the Districts consistent with agency funding and authorization guidance.

WORKING GROUP 5. Navigation Needs.

o There is an abundance of management tools and approaches being used in the field; however, the general concept of a LTMS should be recognized and encouraged at the Headquarters level and any field initiatives in this area given due credit and considered in the development of any national guidance.

o Recognition must be given to new cost sharing proposals that are now being discussed and/or implemented and how they will affect the development of any LTMS.

o Encouragement of innovative practices and procedures or the innovative use of long-established practices, e.g., advanced maintenance dredging, use of newly developed or applied technology to dredging and disposal problems and strategic relocation of disposal areas; the critical evaluation of navigation design practices; the incorporation of engineering solutions to limit the amount of sediment reaching navigation channels and the consideration of regulatory strategies to lessen and/or eliminate adverse impacts associated with private sector dredging activities.

o Regarding the projection of navigation needs and benefits, it was felt that flexibility needs to be incorporated into the process through the periodic assessment of original forecasts. This could be improved by increased communication among Districts and the establishment of an improved data collection and management system.

WORKING GROUP 6. Legislative Compliance and Management Options

o The CE policy on mitigation needs to be reconsidered, whereby the concept is fully incorporated into the planning process rather then relegating it to the end.

o The planning process envisioned by a LTMS should consider the benefits generated by the productive use of dredged material and appropriate consideration made with respect to lessening the degree of mitigation required. Along these same lines a national workshop on beneficial/productive uses of dredged material should be conducted.

o Environmental documents need to be flexible enough to incorporate environmentally compatible operational changes without reopening the administrative (NEPA) record.

o The coordination envisioned with the development of a LTMS should consider processes to facilitate the long-term certification of water quality, coastal zone requirements and other state and/or local authority requirements.

o The management options considered by any LTMS should be comprehensive enough to include disposal activities equally within all media, i.e., aquatic, wetland and terrrestial. Full consideration of the "no action" alternative should be embraced along with the concept of "beneficial-uses" of dredged material.

o Each alternative will be a collection of management options developed at the same level of detail to facilitate comparison among alternatives leading to a recommended solution via the CE's planning process.

DISCUSSION

As can be seen from a comparison of our initial appraisal and the recommendations of the six working groups, we (the lab and headquarters) and the field were in relatively close agreement as to the need, anticipated accomplishments and implementation of the concept of a LTMS for the disposal of dredged material. Approximately

35 recommendations were developed by the workshop participants; however, there were four topic areas that were either constantly referenced during discussions or were emphasized in the recommendations that I would like to discuss further:

- o comprehensive coordination and public involvement;

- o use of the CE planning process;

- o beneficial-use of dredged material and

- o cost sharing and its implications upon the development of any LTMS.

Every working session recommended and stressed the importance of a comprehensive coordination and public involvement program and that without such a program the concept of a LTMS would fail miserably. The thrust of any coordination and public involvement program is to involve and educate those interests outside the CE. Thus, in keeping with the tone of this years seminar, these public involvement programs could be used to display appropriate R&D results and serve as a conduit to infuse any potential LTMS with current research information regarding dredging and dredging technology.

The emphasis placed upon using the CE's existing planning process focuses upon the fact that the planning process represents a proven and time tested method of addressing water resources problems. Fundamentally, it provides a systematic framework within which problems can be identified and appropriate solutions developed. However, its use in the development of any LTMS would necessitate the close cooperation of planning, operations and regulatory personnel. District planners, using their expertise and experience with the planning process and public involvement programs, working together with the operational elements of the District, relying upon their extensive knowledge of navigation and disposal problems, would cooperatively develop LTMS's for the disposal of dredged material. Given the magnitude of the topic areas to be covered in such a cooperative planning effort, it's easily seen how the products of our R&D programs, such as the EEDP, could and should be folded into the development of any LTMS.

The concept of beneficial-uses was discussed at length in many of the sessions with the concensus being that it should be made part of any LTMS that is subsequently developed. A chronic problem with the concept however, was the fact that many of the natural resource agencies with which we coordinate view the concept as a "shell game", i.e., one in which the CE is simply looking for a slick way of disposing dredged material. The CE needs to establish more credibility regarding the research it accomplishes in the natural resource arena. This can be partially accomplished through the publication of our research and District demonstration results in independent, scientifically recognized journals. Additionally, the use of recognized experts in the development of research proposals and the interpretation of results, along with cooperative, interagency research programs should be encouraged. Concurrent with these efforts, the popular press should be utilized to present, to the layman, the approach and anticipated results of any beneficial-use research and/or demonstration currently underway.

Certainly the issue of cost sharing was an item that raised a great deal of concern with workshop participants, particularly as it relates to the concept of LTMS. At this time, we are uncertain as to how cost sharing will impact the concept of LTMS. However, if the development of LTMS is to be a viable program within the CE, local sponsors for navigation projects must be made to see the benefits derived from the concept and cost share appropriately as they will ultimately be the beneficiaries.

Presently the Proceeding and Recommendations of the workshop are being prepared for transmittal to Headquarters and subsequent briefings for the Director of Civil Works and, if determined necessary, the Assistant Secretary of the Army for Civil Works. Once the Proceeding and Recommendations are edited and published they will be given CE-wide distribution. Subsequent approval and official implementation of the concept of a LTMS for the disposal of dredged material awaits the outcome of these briefings.

APPLICATION OF THE CE-QUAL-W2 NUMERICAL MODEL TO CORDELL HULL RESERVOIR

by

Stacy Howington[1]

DESCRIPTION OF THE PROJECT

Cordell Hull Reservoir, located about 75 miles east of Nashville in northeastern Tennessee, is the most upstream navigation project on the Cumberland River. The primary inflows to the project are the releases from the Wolf Creek and Dale Hollow storage reservoirs. Wolf Creek is at river mile (RM) 461 on the Cumberland River and Dale Hollow Dam is at mile 7.3 on the Obey River which has its confluence with the Cumberland at about mile 381. Both of these are Corps of Engineer projects and are operated out of the US Army Engineer District, Nashville (ORN), as is Cordell Hull. The releases from the Cordell Hull Reservoir feed the Old Hickory Reservoir which is immediately downstream on the Cumberland River.

Cordell Hull Dam, located at RM 313.5, is a run-of-the-river hydropower project with three hydropower units. Each unit is capable of producing 33.3 Mw at a maximum discharge of about 12,000 cfs.

PROBLEMS

Cordell Hull reservoir can be divided into three regions according to flow characteristics. The upper reach acts much as a large river with no development of stratification and good reaeration characteristics. The most downstream reach stratifies during the warmer months causing dissolved oxygen (DO) depletion in the lower layers. In between is a zone that transitions from the unstratified section to the stratified section. It has been discovered that the location of these zones is largely dependent on the operation of the two upstream projects and Cordell Hull Reservoir.

Prior to the construction of the Cordell Hull Dam, this reach of the Cumberland River was free flowing and had good reaeration characteristics with the DO in this reach often at or near saturation. However, the impoundment of this reservoir has significantly decreased the DO concentrations in this area, making this reach a sink rather than a source for DO. Now oxygen-depleted water has replaced the nearly saturated, preimpoundment water as the primary inflow to the Old Hickory Reservoir. Consequently, the DO concentrations in the releases from Old Hickory have been significantly degraded.

Prior to impoundment of the reservoir, a substantial coldwater fishery was anticipated. However, these preimpoundment estimates of the fish population have not materialized. This may be attributed to the unstable stratification conditions that exist in the reservoir. In order to develop techniques for improving the fishery, an understanding of the hydrodynamic and thermal characteristics of the reservoir is necessary.

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[1] Research Hydraulic Engineer, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180-0631.

A potential method for improvement of the fishery is the use of submerged weirs at the entrances to some of the tributary embayments, specifically, Martin and Dillard Creeks which are very near a recreation site. The submerged weirs would potentially decrease the exchange between the lower layers of the embayments and the main body of the reservoir allowing the embayments to retain more thermal energy. This would improve the possibility of maintaining a warmwater fishery in these embayments.

Other forms of recreation such as swimming and skiing on the reservoir have not been as prevalent as expected. The water is cold due to the hypolimnetic releases from Wolf Creek and Dale Hollow Reservoirs as well as the instability of the stratification. Some recreation sites have even been closed due to lack of use. The submerged weirs might warm the embayments adequately to encourage contact recreation in these areas.

The main objective for the model study of the reservoir is to develop a better understanding of the effects of project operations (Wolf Creek, Dale Hollow, and Cordell Hull) on the hydrodynamics and the resulting thermal and DO patterns in the Cordell Hull Reservoir. Eventually, the model may be applied to several of the reservoirs in this system to evaluate the effects of a local operational or physical change on the entire system. Because of hydrodynamic and water quality concerns in this study, both the Waterways Experiment Station (WES) Hydraulics Laboratory and Environmental Laboratory are involved in the effort.

MODEL SELECTION

Since the primary interest was in stratification-related hydrodynamics, a two-dimensional laterally averaged model was proposed. The two dimensionality was needed because of longitudinal variations in the stratification patterns which were of importance in the study. Lateral averaging should not pose significant problems as the reservoir to be modeled is narrow and relatively deep. The primary interests in this study are temperature stratification and DO. However, ORN would like to have the capability to, at a later date, more extensively evaluate water quality if it is needed.

The CE-QUAL-W2 model was chosen because it is two-dimensional, laterally averaged, and relatively inexpensive to run. Up to 19 water quality constituents can be modeled and it has the capability to represent branches, tributary inflows, lateral inflow, withdrawals, and outlets.

Branches refer to discretized arms of the reservoir. Tributaries are simply represented by point inflows with specified temperatures and constituent concentrations. Withdrawals are point releases from any location in the reservoir (water supply intakes, etc.). Outlets refer to withdrawal from the downstream end of the reservoir such as hydropower and flood-control releases.

DATA COLLECTION

Having selected a model, the data required for model input and adjustment were collected. This included:

a. Hydrologic information such as inflows, outflows, water-surface data, inflow temperatures, and DO concentrations.

b. Meteorologic information including equilibrium temperatures, derived coefficients of surface heat exchange, wind velocities, and solar radiation.

c. Cross-sectional data for reservoir geometry and a description of the outlet devices.

d. Observed values of temperature and DO for model adjustment and verification.

For this study, the wind speeds were obtained through a meteorological support group at Scott Air Force Base. The remaining information was provided by ORN (personal communication with Mr. Jack Brown). The meteorologic and hydrologic data were provided on a daily averaged basis. The Wolf Creek and Dale Hollow release quantity and quality were routed by ORN using a one-dimensional riverine model and provided for input to the reservoir model at the upstream boundary.

GRID DEVELOPMENT

Based on the observed data from the reservoir, only minor stratification was expected toward the upper end of the reservoir. Therefore the higher concentration of computational divisions, or cells, was placed at the lower end near the dam. In order to accomplish this, the reservoir had to be broken into two branches. The lower branch extended from the dam (RM 313.5) to a large bend in the reservoir at RM 340.5. The large bend was chosen because of the assumption inherent in the model that all momentum in the secondary branch is lost at the juncture of the branches. The resolution in this first branch is good with each cell being 3.28 ft vertically and 1 mile longitudinally.

The second branch extends from RM 340.5 to RM 380.5 which is the upstream boundary of the model. The resolution in this branch is 3.28 ft by 5 miles. The branching was necessary in order to vary the longitudinal discretization. Only one cell length can be specified for each branch.

The resulting grid is 27 cells vertically by 39 cells horizontally for a total of 1053 cells. The 1st and 27th rows are inactive as well as the 1st, 10th, 11th and 39th columns. The code requires that all boundary cells be inactive.

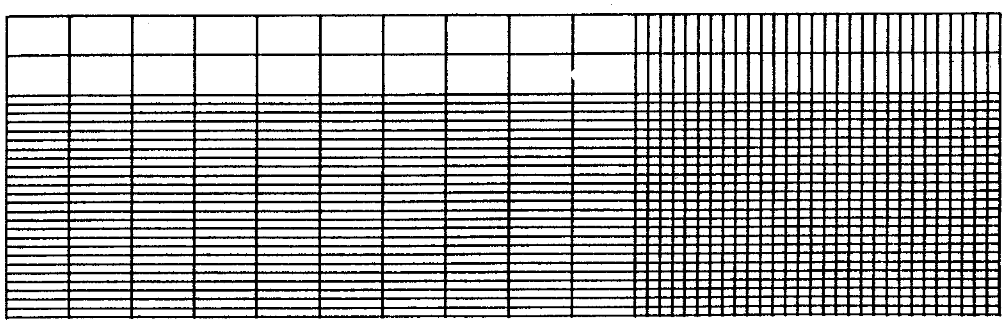

Figure 1. Cordell Hull Reservoir Computational Grid

A minor model modification to the code (Berger 1985) was made to permit variable layer thickness which is shown in Figure 1. This was necessary to maintain good resolution in the lower layers while preventing the water surface from spanning several layers.

APPLICATION

The input data were reorganized into the proper formats and the necessary conversions were made from English to SI (Standard International) units. The reservoir geometry was entered into a program that provides interpolated widths at specified elevations. This is also needed for input to the model.

The inflows had to be specified, so along with the river flow rate at the upstream boundary, five tributaries were assigned. They were:

a. Roaring River

b. Jennings Creek

c. Martin Creek

d. Dillard Creek

e. Defeated Creek

Inflow for each of these tributaries was based on a drainage area ratio to the gaged discharge at a point on the Roaring River. Lateral inflow was used to account for the discrepancy between the total inflow and the releases.

The water-surface slope was evaluated in order to establish a representative resistance coefficient for the reservoir. This was done by selecting a fairly stable period of inflow, comparing the model water-surface values with those observed at the reservoir and adjusting the coefficient until the values agreed.

The outlet configuration at the downstream boundary must be specified. If the outlet spans more than one layer (3.28 ft in this application) an individual discharge must be specified for each layer in the outlet. The layers are effectively considered to be individual outlets. The numerical model SELECT was used to obtain a representative withdrawal profile but the dimensions of the outlets decreased the reliability of the results.

A two-dimensional, laterally averaged model will inherently assume a line sink across the entire width of the reservoir at the outlet. Since the outlets at Cordell Hull do not span the entire dam laterally, an adjustment was made to the momentum equation to allow it to more accurately advect momentum horizontally at the outlet. In the equation, the actual port width is used in place of the reservoir width at that level.

Once the necessary input files had been developed, a representative resistance coefficient had been determined, and an acceptable estimate of the outlet configuration had been devised, adjustment of the model's thermal coefficients began. These coefficients consist of a surface absorption coefficient and an attenuation coefficient. Reasonable first estimates for these thermal coefficients can be determined using the Secchi disk depth. The wind shading coefficient also must be adjusted until the proper amount of mixing is achieved.

For this study, the years 1975, 1979, and 1981 were chosen to be modeled. This represents one "wet" year, one "dry" year, and one "average" year. The year 1979 was chosen for model adjustment. The model was run and the temperature profiles were compared with observed profiles in the reservoir. The model coefficients were then adjusted in an effort to improve the correlation between the model results and the observed values. After several modifications to the thermal and wind shading coefficients, it was noted that the profiles in the field were agreeing very well, but the profiles at the structure were not. The withdrawal configuration has since been modified in order to improve the correlation at the dam and more tests have been run.

SUBMERGED WEIR EVALUATION

The grid used in the modeling of the entire reservoir was not detailed enough to provide information about the exchange rates between the Martin and Dillard Creeks and the main stem of the reservoir. Therefore a separate grid was developed in the region of the embayments to be modeled. This grid had the same vertical resolution as the previous grid but the horizontal resolution was improved to 0.25 miles. Only a 5-mile section of the main stem of the reservoir is included in this grid.

The geometric data in the embayments were derived from topographic maps of the area with 5-ft contour intervals. In order to provide the necessary boundary conditions to model this smaller area, data must be output from the main stem modeling for input into the embayment simulation.

In order to represent a submerged weir, the horizontal velocity and momentum advection terms in the numerical model are set to zero for the layers below the weir crest elevation (Gordon 1981). This is done at the interfaces between the embayments and the main reservoir. For this application, the weir elevation is 4 ft below the minimum water-surface elevation at the mouth of the embayments.

HYDROPOWER OPERATIONS

Since the hydropower units are not actually operated at a constant level over the period of a day as is assumed with averaged daily release values, an evaluation of the impacts of short-term hydropower operations on the reservoir was requested. A two-week period was selected and the corresponding short-time interval data were collected for input. This modeling should also reveal the effects of cooling the water surface during the night.

CONCLUSION

The study is ongoing and model adjustment is continuing. The DO modeling is being performed in conjunction with the Environmental Laboratory, WES. Once completed, this model will be able to predict in-lake temperature, DO, and velocity profiles for Cordell Hull Reservoir for given input data.

ACKNOWLEDGMENT

The investigation is being sponsored by the US Army Engineer District, Nashville (ORN). Technical contact at ORN has been Mr. Jack Brown, under the supervision of Mr. Harold Sansing. The investigation is being conducted by Messrs. S. E. Howington and R. C. Berger, Jr., of the Hydraulics Laboratory, and Dr. J. L. Martin, of the Environmental Laboratory, WES.

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WATER QUALITY CONTROL OF LAKE CHICOT, ARKANSAS

By

Richard E. Price*

INTRODUCTION

Most projects within the Vicksburg District are authorized as flood-control or navigation projects with water supply, environmental, and other needs receiving lesser attention. However, the Lake Chicot project, located in southeastern Arkansas (Figure 1), is unique in that it is primarily authorized for water quality improvement to the lake (USAED, Vicksburg, 1966) with flood control as a secondary benefit. In 1963 when Congress authorized the investigation of the water quality problems in the lake, very few tools were available for assessment and control of water quality. The District then commissioned the US Department of Interior Fish and Wildlife Service (FWS) to provide some guidance on the problems and their solution.

The investigation began with field analysis of existing conditions. The FWS found that the lake, which is an old oxbow of the Mississippi River, is somewhat unique in that the northern third is divided by a dam effectively creating two separate and distinct lakes. This was caused by excessive flooding of the Connerly Bayou watershed in 1927 that deposited sand in the lake. This deposition was enlarged by locals and in 1948 was made into a road which crosses the lake. The Arkansas Game and Fish Commission installed gates in the roadway to provide water-level control and prevent erosion during high stages. Thus two separate lakes were created from the largest natural oxbow lake in Arkansas.

The northern third or upper lake, as it's called, has a relatively small watershed while the southern lake or lower lake fed by Connerly Bayou has an effective watershed of 350 square miles. Concurrent with these developments were agricultural developments in the Connerly Bayou watershed. As land was cleared, increased runoff and its associated suspended constituents increased, thereby degrading the water quality; however the upper lake remained relatively unpolluted. In the FWS report comparing the upper and lower lakes, the obvious "muddy" lower lake was a result of turbid inflow from Connerly Bayou indicating that the solution was to divert inflow away from the lake. With the assistance of a simple water quality model the volume of water to be diverted could be determined. In analysis, a clear lake was defined as 25 ppm turbidity, which was the same level turbidity as the upper lake, while a muddy lake was one of 100 ppm or more. Intuitively, an intermediate level was between 25 and 100 ppm. By plotting volume of inflow to achieve a turbidity of 100 ppm, a line was drawn from origin through that point yielding the basic model (Figure 2).

Lake Chicot reportedly maintained a renowned fishery prior to 1927. In order to restore that fishery, the FWS report recommended that the lake needed to remain clear 5 out of 6 years. To effectively do this, hydrologic analysis

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*Chief, Water Quality Section, US Army Engineer District, Vicksburg, Vicksburg, Miss.

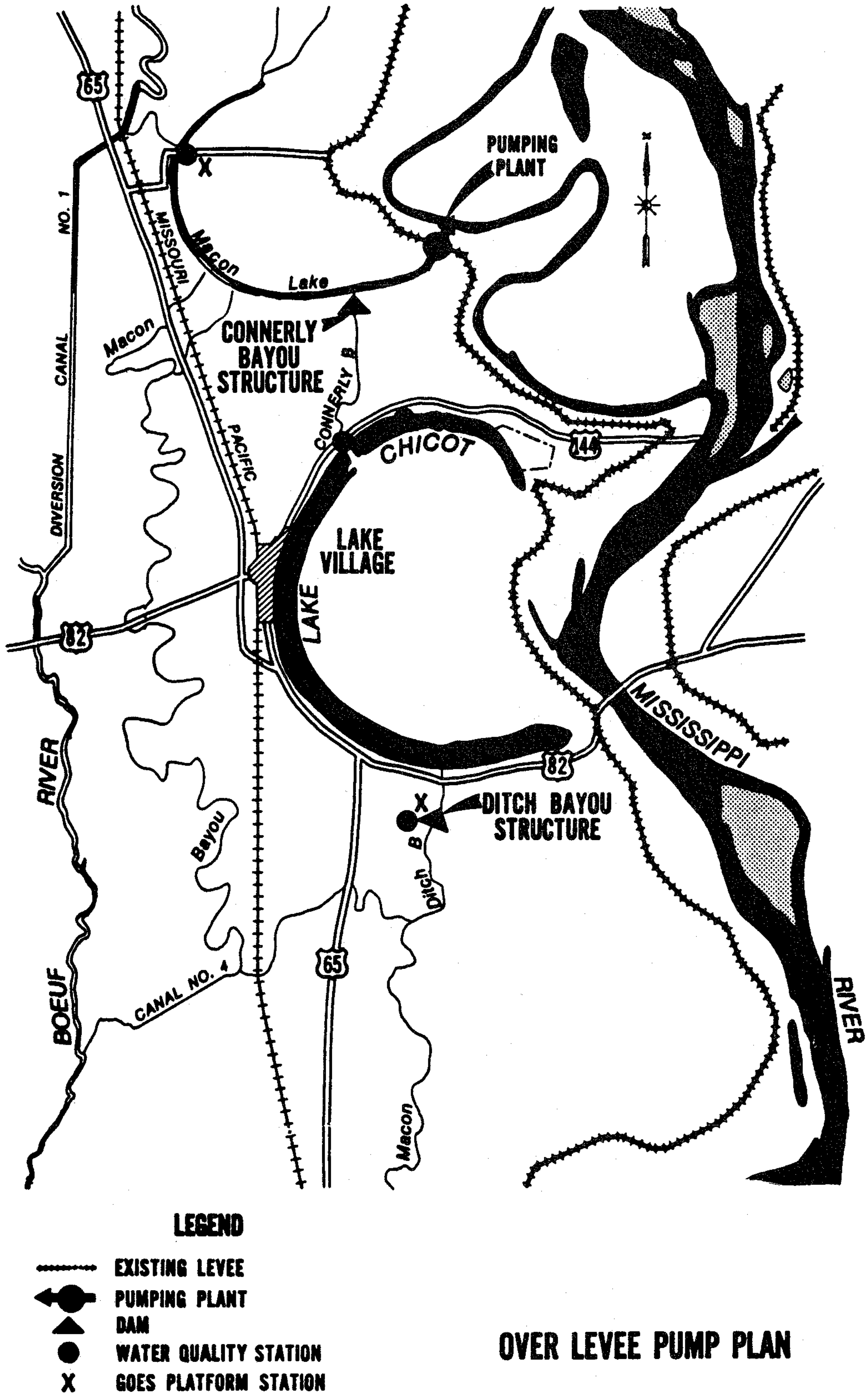


Figure 1. Lake Chicot project area

indicated that a diversion capacity of 6,500 cfs was necessary. Since diversion of all flow would deprive the lake of needed water to replace evaporation and outflow losses, a control structure should allow for some inflow into the lake. The need for water-level control in the lake to allow for management of the fishery was also expressed.

PROJECT DESCRIPTION

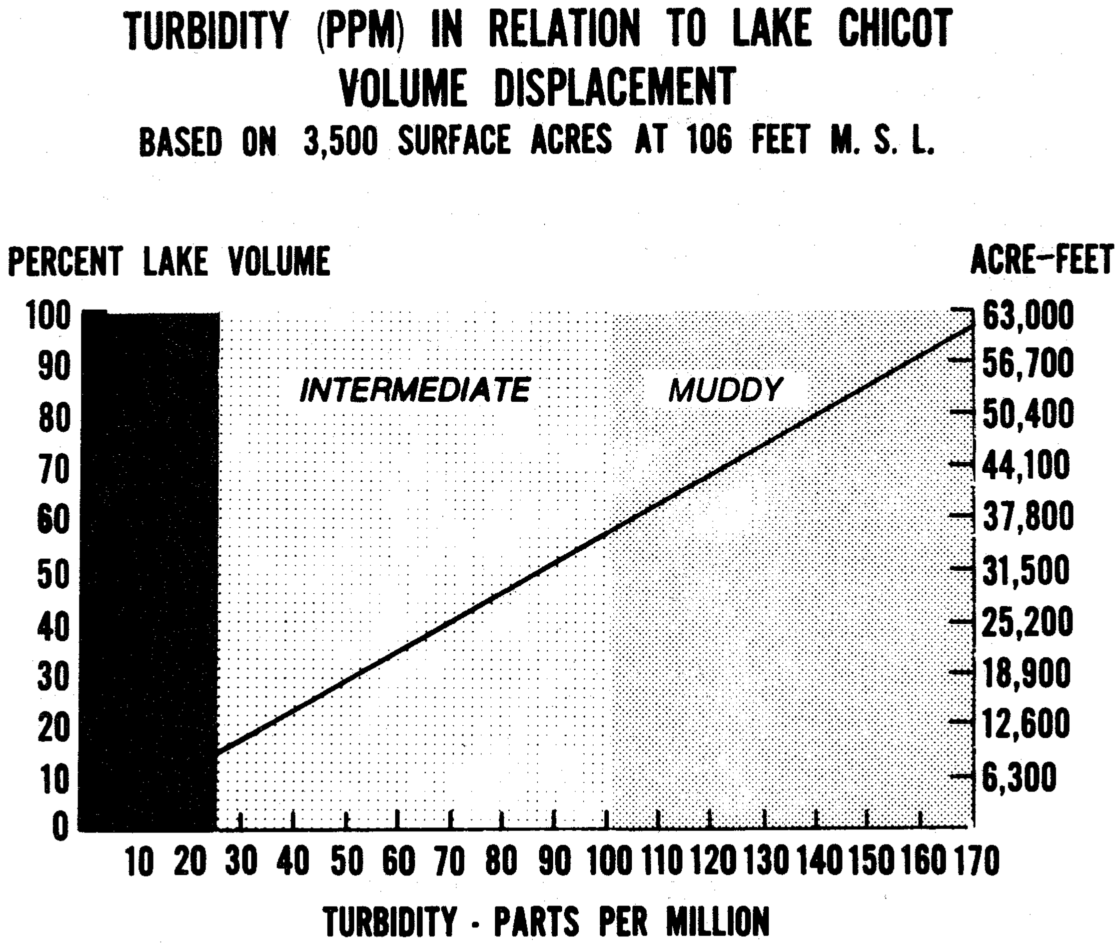
The FWS report served as a basis for project design. The need for diversion capability as well as control of lake levels resulted in the design of three structures. The Connerly Bayou structure that diverts flow away from the lake and to the pump plant was designed to pass up to 600 cfs into the lake through sluice gates. In the event flow exceeds the diversion capacity of the pump plant an overtopping weir in the Connerly Bayou structure allows the high flows to be routed the traditional path through the lake. This muddies the lake but should occur only once in every 6 years. The pump plant with a design pumping capacity of 6,500 cfs allows flow to be diverted to the Mississippi River. A gravity bay in the center of the plant allows up to 12,500-cfs discharge to the river but can be used only when the Mississippi River is at low stages. The third structure is located on the outflow of Lake Chicot. The Ditch Bayou structure is similar to the Connerly Bayou structure in that two sluice gates allow flow out of the lake with excessive flow passing over a fixed weir. Because of previous water-rights issues, a minimum flow out of the lake had to be maintained.

LIMNOLOGICAL INVESTIGATIONS

In 1976, funds were authorized for construction of the three structures with Ditch and Connerly Bayou Structures being constructed first. Concurrent with this action was the recognition of operational concerns for the project. The FWS report had given criteria for improvements but no means of developing operating procedures. The District then initiated limnological investigations in cooperation with the USDA Agricultural Research Service to define existing physical, chemical, and biological conditions and assist in developing an operating plan. The USDA had a primary interest because of the extensive agricultural watershed and its relation to the turbidity problem.

The first task involved description of current conditions by initiation of routine monitoring of inflow, outflow, and in-lake conditions for physical, chemical, and biological parameters. Physical and chemical concerns were limited to suspended sediment, nutrients, and pesticides while biological parameters involved bacterial concentrations. Routine monitoring indicated that pesticide levels in the inflow were no higher than other areas of the southeast and were dropped from the program. Nutrients and suspended solids, however, were of concern and were monitored for 3 years to develop material budgets. Results indicate that approximately 60 percent of the suspended sediment entering Lake Chicot is trapped while 46 percent of the available phosphorous is retained (Schiebe et al. 1984).

The computation of material budgets along with morphometric and meteorologic data allowed for development of a water quality model. Since there were no models available from the Corps at that time, RESQUAL II was adapted to Lake Chicot. This version simulates in daily increments lake stages, surface mixed layer depth, water temperature, suspended solids,



REPRINTED FROM: U. S. DEPARTMENT OF INTERIOR LETTER REPORT, SEPTEMBER 22, 1965

Figure 2. Basic water quality model as developed from early investigations

phytoplankton, available dissolved orthophosphorous, nonavailable particulate phosphorous, light attenuation coefficient, and Seechi depth. Inflow and outflow are basically from the surface. Specific details of the model and its development are published elsewhere (Stefan et al. 1984).

Other studies that were necessary involved assessment of microbiological conditions, specifically fecal coliforms. In general, concentrations of coliforms followed discharge patterns with increased levels during high discharges. Sources of the bacteria, as indicated by fecal coliform/fecal streptococci ratio, were warm blooded animals, excluding man (Cooper et al. 1984). There was a similar trend with regard to chlorophyll level but in reverse; higher discharges were accompanied by very low chlorophyll levels. Only when suspended solids dropped below 20 to 30 mg/l were algae growth rates not limited.

The problem detected with suspended sediments was further investigated by analysis of deposited sediments. Analysis of fallout Cesuim-137 content from selected cross sections in the lake revealed average deposition rates of 1 to 4 cm/year. Rates were two to three times greater in the lower lake when compared with the upper lake. At these rates the lower lake would be filled in another 250 years (McHenry et al. 1984).

Another type of investigation that was undertaken to support model development, model verification, and management decisions was the use of remote sensing technology. Previous studies indicate the use of LANDSAT images as sources of suspended sediment, chlorophyll and water temperature data. Results of these investigations indicated that LANDSAT MSS bands 5 and 6 were the best for determining suspended sediment and that reflection was a better indicator than reflected solar radiation (Ritchie et al. 1984). Chlorophyll and water temperature analyses were conducted but correlations were not strong.

WATER QUALITY MANAGEMENT

The specific management criteria for Lake Chicot are to (1) maintain a clean lake 5 out of 6 years (i.e. turbidity of 25 mg/l or less), (2) provide a minimal flow downstream from the lake, and (3) maintain a stable lake elevation. Although these criteria were developed in the early 1960's it was not until the 1980's that we had a tool in the form of a water quality model with which we could manage these variables. This model allowed several operational plans to be tested for their effects on lake water quality, stage, and outflow. Figure 3 is a representative graphic output for water year 1977, which was used in the evaluation of operating plans. Tests were conducted using 5 years of simulation and observed meteorological conditions with the project in place. If inflow were limited to maintain a lake level of 106 ft NGVD and maintain 75 to 150 cfs outflow from Ditch Bayou, the suspended solids ranged from 6 to 85 mg/l, exceeding the water quality objectives. In addition, the lake stage fluctuated between 97 and 107 ft NGVD. In another case, if the inflow is limited to maintain the low suspended solid levels and the stage of the lake is controlled, no outflow from Ditch Bayou occurs, not meeting the outflow requirements. From these simulations the relationship between the three criteria became evident, indicating that it may not be possible to meet all three in one plan.

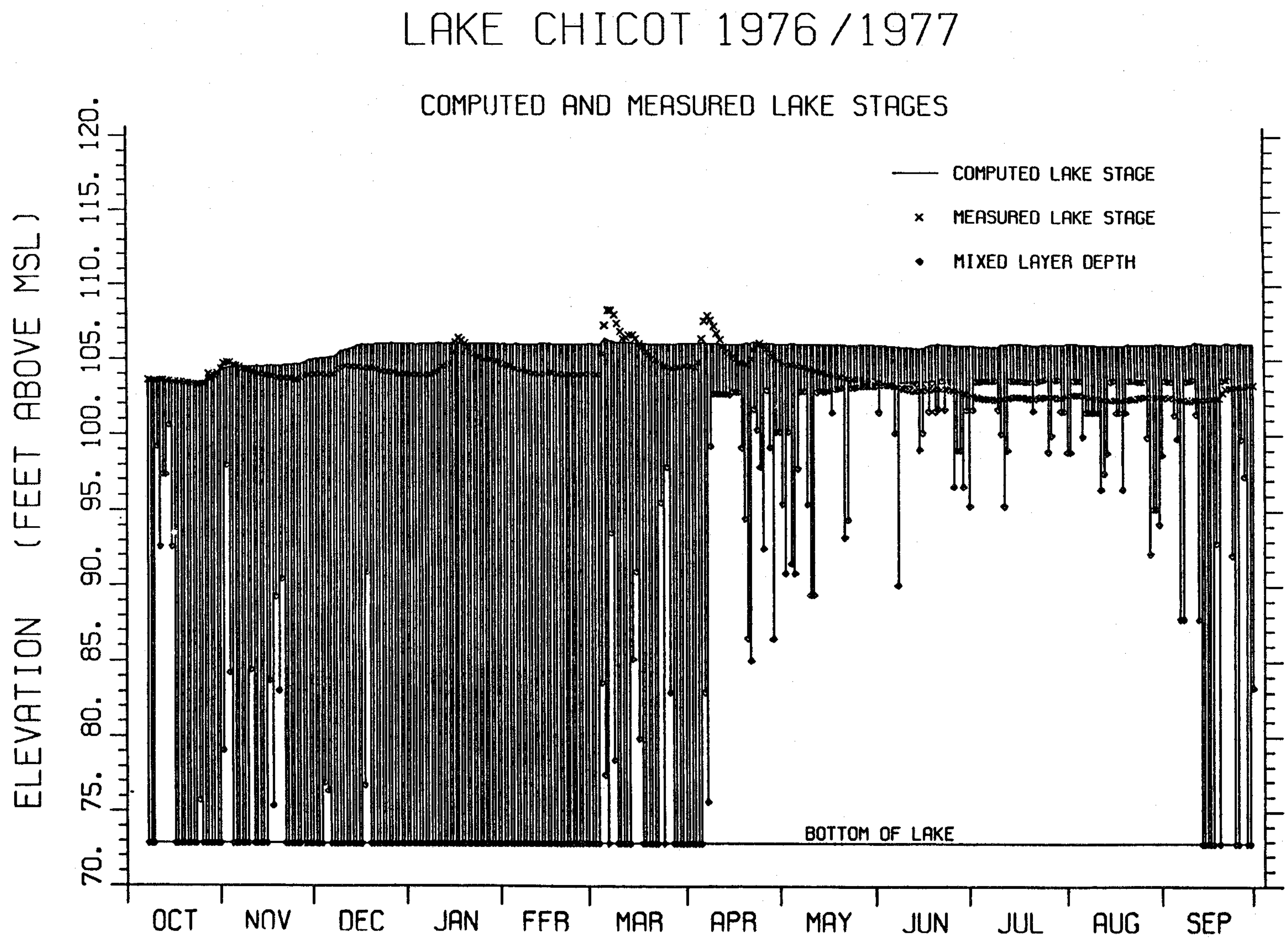


Figure 3. Representative output from RESQUAL II predicting lake stage and mixed-layer depth for the lake in water year 1977

With a math model such as this, simulation of extreme events is possible that may not be possible in prototype testing. Two examples of extremes were tested for impact of operation during such events. In an extremely dry year, lake levels dropped, which seems obvious; however, turbidity increased even though inflow was minimal, probably a result of sediment resuspension. In the second case, an extreme storm event was simulated to move across the lake in late summer. As expected, high flows occurred overtopping the overflow structure at Connerly and muddied up the lake (suspended solid concentration of 1885 mg/l). The overtopping lasted only 2 days but the effect was evident in the lake for the following 9 months.

A water control plan was developed in 1984 that was the compromise of the three criteria minimizing discharge during most of the year but increasing during irrigation season while still maintaining the suspended solids level below 25 mg/l.

The project began operation in 1985 with a severe drawdown to facilitate fisheries management and sediment consolidation. The lake is still down but is in the process of being refilled under the operation plan.

Recent developments have centered on near real-time modeling. The Lake Chicot model has been modified somewhat to allow short-term prediction based on weather and/or runoff forecasts, and modifications are currently under way to automatically retrieve satellite water control data and implement the model to predict project conditions on a daily basis.

To supplement operation a secondary or backup system has been implemented that consists of turbidity and conductivity monitors placed on the inflow and outflow of the lake to give near real-time data on existing conditions. This system, as part of the water control data collection system, has been operational for several years.

CONCLUSIONS

In the past decade since construction was begun on the Lake Chicot project, considerable developments have occurred in the water quality field. Numerical modeling techniques have been developed that can reasonably predict water quality conditions which not only allow testing of various operational plans but also provide insight into effects of hydrologic changes to the water quality. Remote sensing technology has improved to the state that it can be used as a monitoring tool as well as a diagnostic tool. Sediment deposition analysis techniques allow us to assess the impact of high suspended solid concentrations with remote water quality monitors thus allowing for near real-time monitoring. With all of these tools, effective operation of the Lake Chicot project should be possible.

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Hydropower Retrofits: A Water Quality Perspective

by

David R. Johnson*

The oil embargoes of the 70's brought upon the populace of this country a greater awareness of our energy needs. The U.S. responded to the embargoes in many ways. Included among those responses was an assessment of the untapped hydropower potential in the U.S. A follow up to this was the increased interest in lowhead hydropower, especially at existing structures. Most recently the emphasis has been on the non-Federal development of hydropower at Federal structures.

The Federal Energy Regulatory Commission (FERC) is responsible for determining the need for hydroelectric power and issuing licenses for the development of hydroelectric facilities. In the past two years the Vicksburg District has received over 25 of these applications for review. In a Memorandum of Understanding between the Corps and FERC, FERC is given the responsibility as the lead agency in all water quality matters. To this end, FERC has two individuals assigned to review all licenses with regard to water quality. Three years ago they received 60 license applications, in 1984 1200 license applications, and 2000 applications in FY 85.

The Vicksburg District has received FERC license applications for 4 areas: 1) the Yazoo River Basin Flood Control Reservoirs, 2) the Ouachita-Black River Basin, 3) the Red River Basin, and 4) the Pearl River Basin. This report will highlight some of the problems the Vicksburg District encountered concerning water quality in reviewing proposals for the Yazoo and Red River Basins. Applications for hydropower development in the Yazoo Basin in northern Mississippi were filed by the Municipal Energy Agency of Mississippi (MEAM). MEAM is a consortium of municipalities which would utilize the energy produced. Pertinent data on the 4 northern Mississippi reservoirs is on Table 1. These reservoirs are shallow advectively dominated flood control reservoirs which experience mild, thermal stratification for 2 or 3 months each summer. The degree of stratification is inversely related to the amount of rainfall received in the previous winter and spring seasons. Withdrawal from the reservoirs is from the hypolimnion and the rule curve has the lake levels dropping during summer and fall to ensure adequate flood storage in the next rainy season. As long as releases are being made, little stratification occurs. Although the periods of stratification are short compared with deeper weather dominated reservoirs, low dissolved oxygen (DO) conditions do occur in the hypolimnion.

*Vicksburg District, Hydraulics Branch, Water Quality Section

Under current conditions, the mean DO in the releases falls to 6.0 mg/l in July the worst month (Figure 1). The addition of hydropower to these reservoirs would aggrevate the DO conditions such that releases could fall below the state standard level of 5 mg/l. This potential problem was acknowledged by the contractor for MEAM in their report, "General Reservoir Water Quality Investigation for Hydropower Operations." MEAM had stated in the initial license application that DO levels would be returned to current conditions and had proposed using reaeration rings to bring the DO back up to current conditions. Modeling studies by the AE contractor had predicted that the releases would meet state standards (5 mg/l DO) under most flow conditions but failing to meet them under extreme low flow conditions (Table 2). In order to meet state standards under all conditions, they proposed spilling water through the flood control outlet (Table 3). The reaeration, obtained through the outlet works at Enid Reservoir, was the topic of a technical report from WES (TRE-82-2). Normally the releases at Enid are reaerated to 80 to 100 percent of saturation, but limiting the DO level to 5 mg/l during hydropower production would reaerate the releases to between 60 and 70 percent of saturation. In addition to the apparent 20 to 30 percent decrease in percent saturation (1 to 2 mg/l DO), the above study indicated some immediate chemical oxygen demand (H2O, Fe2O3) was also satisfied within the structure (Figure 2). The license applicant allowed for some of this immediate COD (0.5 mg/l H2S); the rest would result in a DO sag downstream. The Vicksburg District feared that a decrease of 1 to 2 mg/l DO might have an adverse impact on the large sport fisheries downstream of the reservoirs and requested that MEAM maintain current conditions for the DO in the releases.

Because of a misunderstanding of FERC licensing procedures, the Vicksburg District's earlier comments on DO were not repeated in the final license application. This mistake resulted in the inclusion in the license of a provision that allowed the contractor one year after project completion to study the DO problem and a second year to prepare a solution. The Vicksburg District objected to this and requested FERC to have the licensee complete the studies before project completion. After several meetings regarding water quality considerations, MEAM agreed to initiate the DO study before project completion. Maintaining current DO levels would be one aspect of their study.

In order for MEAM to add hydropower, they were going to line the existing outlet conduits and install bifurcation valves to divert the flow to the penstocks. To install these values, they proposed siphoning water over the dam into the outlet spillway. This construction was scheduled for late summer. Vicksburg District was apprehensive of the effect the change in withdrawal elevation would have on DO conditions in the lake. Likely results would be an increased zone of oxygen depletion and an increase in COD producing substances. When construction was completed, a sudden change in DO of the releases might occur. This change could result in stressing the downstream fishery and perhaps cause a fish kill. To avoid this, MEAM proposed initiating hypolimnetic releases with the upper most gate and subsequently opening the lower gates to mix the releases.

Hydropower add-on to the Red River Navigation Project presented an entirely different set of problems. One of the most important differences was that the project was just being started with no locks and dams completed. Current conditions were those of the unobstructed river. Water quality modeling studies had been completed, but only for the navigation project. Hydropower had not been considered during the modeling effort. The Water Quality Sections in the license applications for all five locks and dams were identical. The section labeled, "Existing Water Quality," contained the following statement:

> "Because Red River flows will either be discharged through the gated dam structure or the immediately-adjacent power plant, operation of the power plant will have no effect on significant ions, chlorophyll a, nutrients, specific conductance, pH, total dissolved solids, total alkalinity, total hardness, dissolved oxygen, bacteria, temperature, suspended sediments, turbidity or vertical illumination."

After they received the District's comments, the section was changed to read:

> "Because Red River flows will either be discharged through the gated dam structure or the immediately adjacent power plant, operation of the power plant will have no effect on significant ions, chlorophyll a, nutrients, specific conductance, pH, bacteria, temperature, suspended sediments, turbidity or vertical ilumination. A temporary oxygen monitoring station will be built downstream of the hydrogenerating plant and the gated structure by the licensee and a detailed study will be made to determine the requirements, if any, for additional reaeration to be added to the downstream flows. After the equipment determined necessary has been installed by the licensee, the monitor station will continue to operate for a minimum of two years and assure that the necessary dissolved oxygen content will be achieved and maintained."

The final license application was increased by over 100 pages in the Water Quality Section and the resulting document fully addressed the District's concerns. In the final application, they considered reaeration by turbine venting, molecular oxygen injection, air injections, and surface aerators and included the cost of each method to the project. Their studies indicated that turbine venting alone would be insufficient to return the DO levels to either state standards or post navigation project conditions.

The Vicksburg District was also conducting a hydropower feasibility study and the release DO for 5 flow conditions was calculated for each of the locks and dams using the WES model SELECT. The SELECT model can calculate the reaeration provided by several methods. In our studies we used reaeration by release through gated structures and turbine venting. The DO deficit was calculated from that for both predicted post navigation project and staged construction (Figure 3). Figure 3, part A, is a plot of DO for mean monthly flow conditions with the navigation project completed. Part B depicts the cumulative effect of no reaeration on the DO. Part C shows the DO plots if state standard conditions are met for the point of maximum sag, with the pool DO levels ignored. This method was recommended, by WES-Water Quality Modeling Group, as a means of estimating the DO in lieu of a new modeling study. The DO deficit in the pools was then obtained by scaling the difference in the pool releases (determined by SELECT) and the level needed to maintain the riverine segments above a DO of 5 mg/l. Several means of reaeration were considered in the federal study including: 1) turbine venting, 2) diffused air aeration, 3) surface aeration, 4) skimmer weirs, and 5) molecular oxygen injection. Utilizing information from the EWQOS report, "Techniques for Reaeration of Hydropower Releases," the oxygen requirement to maintain state standard conditions expressed in Kg O_2/hr was equated to Kwh to obtain a relative estimate of reaeration costs (Table 4).

Non-federal development of hydropower at Corps projects is a reality. Although construction has not begun on any projects within the Vicksburg District, several licenses have been granted. Through our experiences, we have learned that careful scrutiny of the license applications is recommended. Any objections or questions are best addressed at the preliminary permit application stage and pursued through each stage of the licensing process. Two licenses which were recently approved for the Jonesville and Columbia Locks and Dams on the Ouachita-Black System require the operator to close down hydropower operations during July through September if DO levels in the releases are below state standard levels. This type of provision will help ensure that water quality objectives at Corps facilities will continue to be met with the development of hydropower.

TABLE 1
PERTINENT DATA
YAZOO BASIN RESERVOIRS

ITEM	UNIT	ARKABUTLA	SARDIS	ENID	GRENADA
ELEVATION					
Minimum Pool	Ft.m.s.l.	209.3	236.0	230.0	193.0
Maximum power pool	Ft.m.s.l.	---	---	---	---
Flood control pool	Ft.m.s.l.	238.3	281.4	265.0	231.0
Spillway crest	Ft.m.s.l.	238.3	281.4	268.0	231.0
Surcharge pool	Ft.m.s.l.	256.3	301.0	284.0	247.5
Top of dam	Ft.m.s.l.	264.3	311.4	293.0	256.0
VOLUME					
Minimum pool	Ac.-Ft.	31,500	91,900	57,600	85,700
Flood control pool	Ac.-Ft.	493,800	1,476,000	602,400	1,251,700
Surcharge pool	Ac.-Ft	857,800	1,446,600	553,500	1,384,700
Freeboard	Ac.-Ft.	568,000	1,037,200	411,800	1,012,400
AREA					
Drainage area	Sq.Mi.	1,000	1,545	560	1,320
Minimum pool	Acres	5,100	9,800	6,100	9,800
Flood control pool	Acres	33,400	58,500	28,000	4,600
Surcharge pool	Acres	63,200	90,400	41,300	106,100
Freeboard	Acres	79,000	109,100	50,700	131,600
DISCHARGE CAPACITY					
Outlet Works, flood control pool	c.f.s.	10,000	10,000	9,400	10,000
Outlet works, regulated	c.f.s.	5,000	7,500	2,400	5,100
Spillway	c.f.s.	89,000	132,000	49,700	52,000
Penstock	c.f.s.	2,400	4,000	1,100	3,750
Turbines	c.f.s.	2,400	2,000	1,800	1,850
DIMENSIONS					
Dam, length	Feet	10,000	15,300	8,400	13,900
Dam, height above mean valley	Feet	65	97	85	80
Spillway, width	Feet	300	400	200	200
Gates, number		3	4	2	3
Gates, site	Feet	8.5X19	6X12	8X16	7.5X14
Conduits, number		1	1	2	1
Conduits, size	Feet	16X18.25	16X18.25	11.0	17.0
MISCELLANEOUS					
Type of dam		Earthfill	Earthfill	Earthfill	Earthfill
TURBINES					
Number		1	2	1	2
Type		Kaplan	Kaplan	Kaplan	Kaplan
Rated head	Feet	43	53.5	55.5	47.5
Total plant capacity	Hp	10,770	22,320	10,420	18,340

Table 2
Turbine Aeration Mitigation

Probability (%)	DO (mg/l)	Turbine Aeration (mg/l)	H S-DO Demand (mg/l)	Net DO (mg/l)
5	2.0	2.50	0.4	4.10
10	2.8	2.05	0.4	4.45
15	3.3	1.85	0.4	4.75
20	3.7	1.70	0.4	5.00
25	4.1	1.50	0.4	5.20

Table 3
Outlet Mixing Mitigation

Probability	Net DO (mg/l)	Turbine Flow (cfs)	Outlet Flow (cfs)	Percent of Design Flow
5	4.10	3,020	880	77
10	4.45	3,310	590	85
15	4.75	3,610	290	93
20	5.00	3,900	0	100
25	5.20	3,900	0	100

Table 4
Annual Cost Estimates[1]
For Several Reaeration Methods

Reaeration Method		Lock & Dam 1	Lock & Dam 2	Lock & Dam 3	Lock & Dam 4	Lock & Dam 5
Diffused Air Aeration -	O&M[2]	900	900	700	2000	1000
	C[3]	1500	1500	1200	3300	1800
Turbine Venting	O&M	600	600	1000	1000	800
	C	100	100	200	200	1100
Molecular Oxygen Injection	O&M	700	700	500	1500	800
	C	300	300	200	700	300

1 - Units are $1,000
2 - Operation and Maintenance
3 - Capital Costs

YAZOO BASIN FLOOD CONTROL RESERVOIRS
MEAN MONTHLY DO IN OUTLET CHANNELS

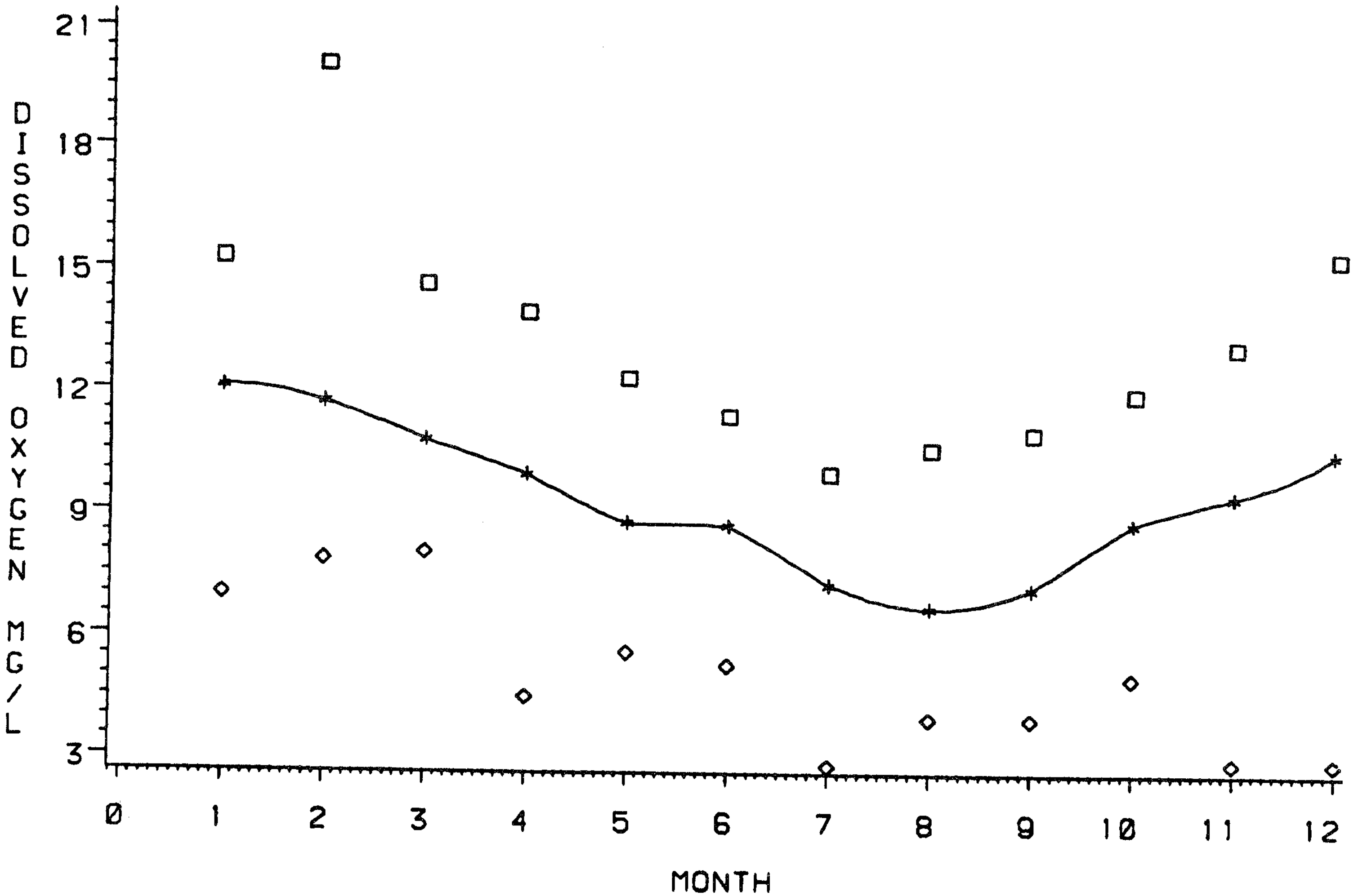


FIGURE 1

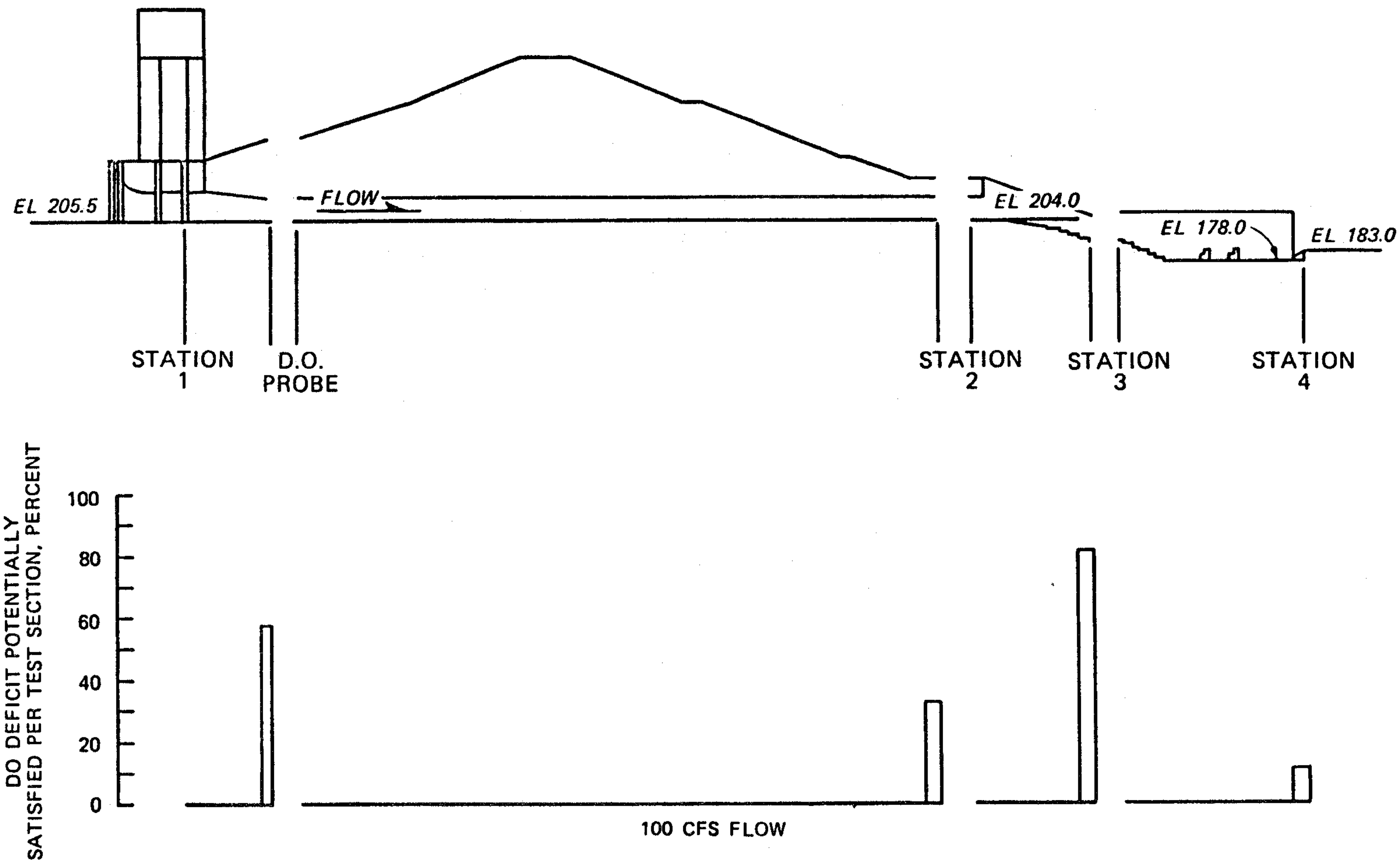
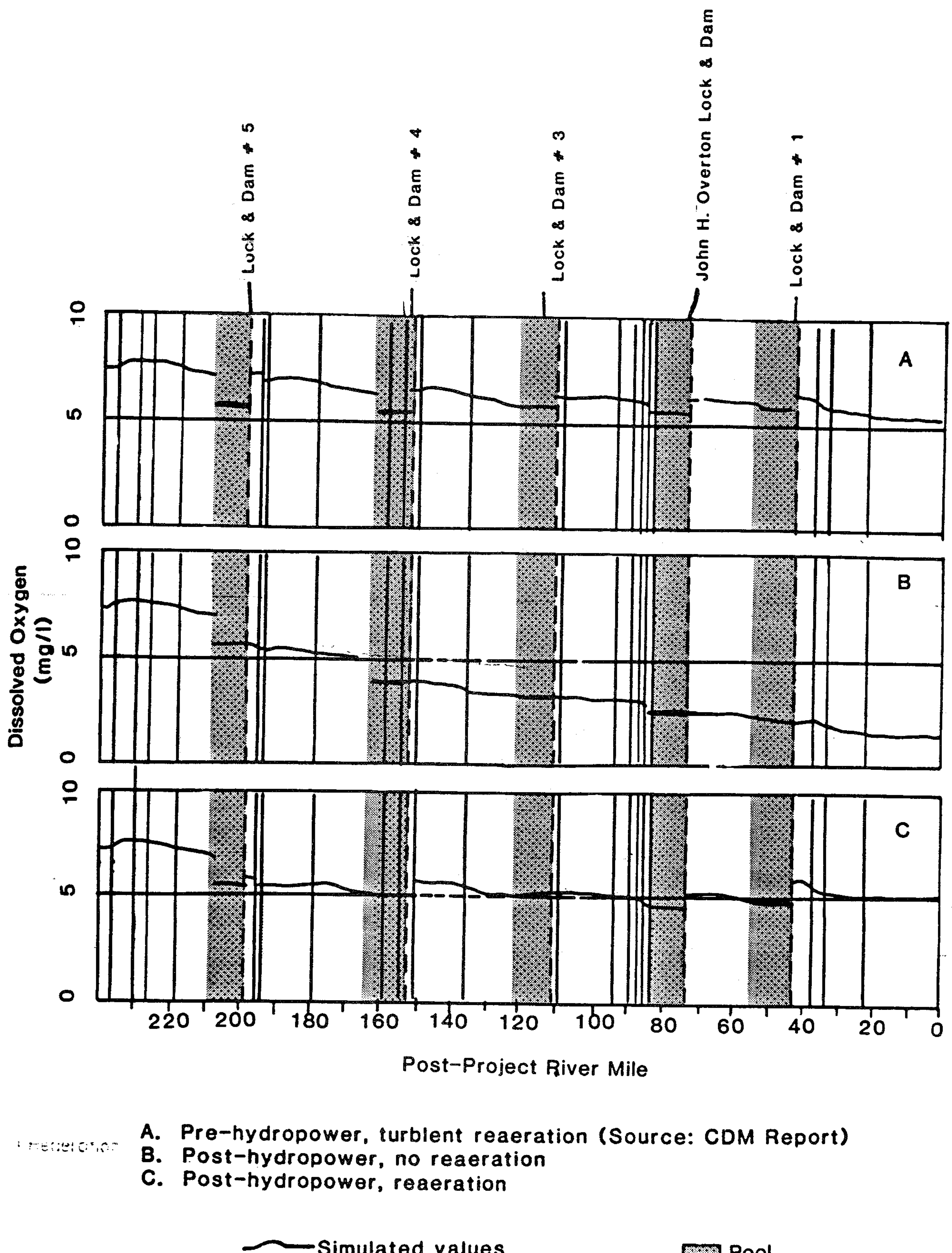


Figure 2. D.O. deficit potentially satisfied per test section



Systemwide Quality for Mean Annual Flow Condition

Figure 3

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Water Quality Studies at

Clarence Cannon Dam, Missouri

By

Thomas J. Furdek 1/

INTRODUCTION

Background

The Flood Control Act of 28 June 1938 authorized a dam and reservoir on the Salt River near Joanna, Missouri, as part of a general comprehensive plan for flood control in the Upper Mississippi Basin. A restudy of the project indicated the feasibility of a multiple-purpose development, including power, and was authorized as such by the Flood Control Act of 23 October 1962. The lake, originally named the Joanna Reservoir, was renamed Clarence Cannon Dam and Reservoir and finally named Mark Twain Lake (MTL) and Clarence Cannon Dam.

Project Description

The project consists of a lake and dam located at mile 63.0 on the Salt River in northeastern Missouri with a re-regulation dam 9.5 miles downstream from the main dam. The lake, at the top of joint-use pool elevation (606.0 MSL), has a surface area of 18,600 acres and extends upstream 25 miles into the North Fork of the Salt River. The Middle and South Fork tributaries of the Salt River form two major arms of the lake, creating a very irregular shoreline of approximately 285 miles at joint use pool elevation. The top of flood control pool is elevation 638.0 MSL with 38,580 acres of surface area. Since closure in the fall of 1983, two major floods have occurred. The lake level rose to 629.9 and 630.6 in March of 1985 and November of 1985, respectively.

The purposes of this project are to provide flood control, hydropower generation, water supply, downstream water control, fish and wildlife conservation, and recreation. There is a total storage of 1,428,000 acre feet.

The main dam consists of a compacted earth embankment, a gated concrete spillway, and concrete hydroelectric power intake section. A 24-inch pipe is provided through the powerhouse for passing the minimum downstream release. The spillway crest is at elevation 600.0 MSL.

A temperature control weir (TCW), consisting of a rolled earth embankment, is located 400 feet upstream of the main dam and extends across

1/ Environmental Chemist, Hydraulics Branch, St. Louis District, St. Louis, Missouri.

the valley of the Salt River. The top of the weir is at elevation 580.0 MSL which is 26 feet below the top of the joint-use pool.

The power installation consists of one 31,000 KW reversible unit and one 27,000 KW conventional unit.

A re-regulation dam is located 9.5 miles downstream of the main dam. This dam creates a pool to store power release for re-regulation of downstream flow and for pumpback operations during low flow periods. The dam consists of a compacted earthern embankment and a gated concrete spillway. A 30-inch pipe is provided through the control house into the stilling basin for passing the minimum downstream water release requirement of 50 CFS.

MODEL STUDIES

A hydraulic model investigation was performed by WES in 1968/69 to verify general flow conditions in the approach channel, over the TCW, at the abutments, over the spillway, etc. Five different TCW configurations were modeled with pool and thermocline elevations at 606.0 and 575.0 MSL, respectively and at 590.0 and 575.0 MSL, respectively using discharges up to 12,000 CFS through the powerhouse. The recommended TCW configuration consisted of a centerline placement of 400 feet up lake from the dam at elevation 580.0 MSL.

In 1982/83 a thermal model verification study was made prior to completion of the project. The purpose of this study was to determine if 580.0 MSL was in fact the best crest elevation for the TCW, and to evaluate the stratification of the re-reg pool. The one-dimensional model "STRATIFY" was used. It is a subset of "MANAGER" which is a modified version of CE-QUALR1. Three years were chosen for study; a wet, dry, and average year with respect to inflow. The model was calibrated using Lake Shelbyville data, an existing project in SLD as similar to MTL as possible, and then applied to MTL. Three crest elevations of the TCW were simulated; 570.0, 580.0, and 590.0 MSL. The model study indicated that the 580.0 MSL crest elevation for the TCW would be adequate for thermal release purposes. The study also indicated that the re-reg pool would not stratify when flow rates were above 500 CFS and would weakly stratify during periods of low flow.

A water quality model study was also run in 1983 on MTL. The one-dimensional model "MANAGER" was run for the same three years that "STRATIFY" was simulated utilizing the TCW at 580.0 MSL. Results of the simulations indicated:

1. Anoxic conditions would develop in the hypolimnion during the three study years and last approximately 100 days.

2. The intensity of the anoxic conditions may be moderated by high NO3-N concentrations within the pool.

3. Release D.O. concentrations did not decrease below five (5) MG/L during any of the simulated years.

4. Release un-ionized Ammonia and NO3-N concentrations would be below state water quality standards.

5. T.O.C. release concentrations would be relatively constant in the six (6) to eight (8) MG/L range.

6. Chlorophyll concentrations would range from 10-35 UG/L in the spring to 35-50 UG/L in the summer in the lake.

7. Secchi depth would range from 0.5 to 1.0 meters throughout the year and be lowest in the spring.

From these studies, the crest elevation of the TCW of 580.0 MSL was decided upon. A trapezoidal notch, originally in the TCW plans at 575.0 MSL to be utilized for lake drawdown, was eliminated to improve the efficiency of the TCW. A 72-inch culvert in the TCW used during lake filling and TCW construction to equalize pressures on both sides of the TCW was originally to be left open. This was finally closed to keep hypolimnetic water from having a direct route into the mini-lake and hence discharged downstream.

WATER QUALITY COMMITTEE ASSISTANCE

In May of 1984, the consulting services of the Water Quality Committee were utilized. It was felt that since this was our first hydropower project, we wanted to make sure we had covered all potential problem areas. This meeting was to assess potential water quality problems associated with MTL. Historical, present, and future plans and studies were discussed and reviewed. Recommendations and considerations by the Water Quality Committee were received and greatly appreciated.

WATER QUALITY STUDIES

To determine when stratification occurs, thermistor chains were installed in the lower reaches of the lake. These thermistor chains and the data collection platforms (DCPs) were designed and installed by Cold Regions Research and Environmental Lab (CRREL). They consist of an anchored buoy in the old river channel with a string of 30 thermistors at meter intervals hanging down. The data from the thermistor chain is collected via a DCP and available from GOES. Installation was completed in late September of 1985. Two sets of data are collected daily from each system.

Thermocline setup will be monitored in the future with reference to pool elevation and TCW elevation, profiles for D.O. will also be performed to quantify oxygen levels associated with the thermocline. During hydropower generation, possible thermocline fluctuations may be measured at the closer (Behrens) thermistor chain. When and if pumpback is utilized, the accompanying thermocline breakup will be monitored.

When the thermocline and oxycline are either nonexistent, or are below the TCW, we have no water quality problems with regard to hydropower releases. However, over the past two years, we have observed the thermocline and oxycline to be above the TCW from July through mid-September.

When generation occurs and the thermocline-oxycline is above the TCW, poor quality water is pulled over the TCW. This will continue until sufficient force, expressed as Q release, flexes, or bends the thermocline downward toward the TCW until mostly epilimnetic water is pulled over the TCW and released through the turbines. This phenomenon has been observed immediately up-lake of the TCW with a lowering of the thermocline elevation and also in the turbine bay with epilimnetic water eventually being released. This needs to be studied more closely. For instance, a reduction in the Q release due to a higher head or a reduction in power needed may not have sufficient force to flex the thermocline down to the TCW. WES says they can assist in calculating this force; different generating scenarios could effect this phenomenon, thereby reducing the potential for hypolimnetic discharges.

When generation is stopped, the layer of water in the mini-lake from the surface to the top of the TCW is the same as in the lake. The layer in the mini-lake from the TCW to the bottom is filled with homogenous water with temperature and D.O. characteristics approximating what is in the lake at the level of the TCW (580.0). This is true all the time. If poor quality water is at or above the TCW, a completely mixed layer of poor quality water will be in the lower area of the mini-lake. The volume of water in the mini-lake from 580.0 to the bottom of the lake is 221 acre-feet. When generation starts up again, before good quality water can be released through the turbines, this volume of poor quality water must first be evacuated. With a discharge rate of 9,000 CFS, this would take approximately 18 min. This causes a considerable amount of stress on the fish population below the dam both from low D.O. content and also thermal shock. This entity of poor quality water does not mix very well in the re-reg pool and moves downstream as a slug of poor quality water and is released through the re-reg dam. This problem of poor quality releases at generation start-up is being studied. WES is in the process of designing a hydraulic or pneumatic destratification system for the mini-lake area between periods of generation and also when minimum releases are to be made through the minimum flow bypass when the lake is below 600.0 and tainter gates cannot be used. A thermistor chain system to monitor stratification/destratification will be installed in the mini-lake. D.O. and temperature monitors will be installed below the main dam and the re-reg dam to assess water quality conditions. Remote monitoring will be done via GOES/DCS.

Pumpback tests at Truman Lake in the Kansas City District (KCD) caused great concern, especially since MTL also has pumpback facilities. The SLD utilized the expertise of KCD personnel. Mr. Ray Vandenberg (MRKED-HW) et al. installed their Biosonics Hydroacoustic System to estimate fish quantities in the MTL turbine bay. Tests were performed at various times in

1984 and 1985 under varying hydrologic and power generation conditions. These tests proved quite beneficial in assessing potential fish mortality from pumpback.

SUMMARY

In summary, the utilization of a TCW to eliminate poor quality releases during hydropower generation at Mark Twain Lake and Clarence Cannon Dam has been quite successful. A wide variety of studies and expertise is necessary to produce a good product. In this case, physical and mathematical modeling and insitu studies were utilized as well as various areas of expertise within the Corps.

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EFFECTS OF RESERVOIR REGULATION ON DOWNSTREAM VASCULAR AQUATIC PLANTS, CHANNEL FORM AND RIFFLE ECOLOGY IN THE UPPER OHIO RIVER BASIN

By

Michael Koryak[1]

INTRODUCTION

As is well known to water resource managers, the chemical quality and biology of regulated streams can be enhanced or degraded by reservoir operations. Because of engineering expediencies and day-to-day accountability, the effectiveness of reservoir operations is typically measured by more easily monitored and dramatically responsive indicator parameters such as water temperature, iron and manganese concentrations, the presence or absence of dead fish, etc. Most scientists working in this field, however, are aware of or suspect that there are probably numerous additional, longer-term, direct, and sometimes subtly indirect consequences of streamflow regulation.

In this perspective, the following paper examines some interrelationships that have become apparent to the Pittsburgh District among water quality, reservoir regulation, and a single species of aquatic plant (*Justicia americana*). Included in the discussion are secondary impacts associated with this plant that influence the physical form and substrate of stream channels and aquatic invertebrates, fishes, and other species of aquatic plants.

While much of the specific information in this discussion may be esoteric to streams of upper Ohio River drainage, it provides some general insights pertinent to planning and evaluating environmental features of flood control channel modification projects, as well as demonstrating long-term indirect impacts that can result from water quality-quantity management activities.

[1]Pittsburgh District, U.S. Army Corps of Engineers

ACID MINE DRAINAGE AND RESERVOIR REGULATION

Acid mine drainage from bituminous coal mines has been the most serious and widespread water quality problem in the Pittsburgh Engineer District portion of the upper Ohio River drainage basin. Acid mine drainage results primarily from the oxidation of pyrite and marcasite (both having the composition FeS_2). These pyritic sulfur forms occur in coal, and in rock and clay found above and below coal seams. The sulfides are uncovered in the process of coal mining, and exposed to the oxidizing action of air, water, and sulfur-oxidizing bacteria. The end products are water soluble and the basic reaction is:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4$$

Ten of the 15 Federal storage impoundments in the basin are at least periodically utilized to some degree to mitigate acid mine drainage in downstream regulated stream reaches. Six of these reservoirs are routinely operated for this purpose, and five have acid mine drainage degraded inflows which are significantly improved by inpool detention, mixing, dilution, neutralization, and settling (heavy metal oxide floculation) processes. A unique feature of another project, Stonewall Jackson Lake, now under construction on the West Fork River in northern West Virginia, is that water quality control, mine drainage in particular, is the primary authorized project purpose.

The operation of these projects has substantially reduced acid pollution problems along approximately 750 kilometers (km) of the largest and most important streams of the upper Ohio River basin. Concurrent with these water quality improvements and with mine drainage abatement related to improved mining methodologies, environmental legislation, and regional mine reclamation efforts since 1970, aquatic plants, invertebrates, and fishes have or are now recolonizing numerous regulated and unregulated streams that were formerly severely biologically depressed or essentially devoid of aquatic life. On the larger low to moderate gradient streams of the upper Ohio River basin, approximately 1,550 km of which are controlled by upstream storage impoundments, one of the most obvious signs of acid mine drainage abatement is the gradual colonization or recolonization of shoals and riffles by the aquatic emergent plant *Justicia americana*. Along approximately 600 km of the 750 km of streams in the basin where acid mine drainage has been substantially reduced by reservoir regulation, *Justicia* is now either abundant or increasing in areas of suitable habitat. Most of the remaining 150 km of regulated stream where it is absent are still water quality limited.

DESCRIPTION OF *JUSTICIA AMERICANA* AND ITS ROLE IN THE ECOLOGY OF APPALACHIAN STREAMS

Justicia americana (L.) Vahl is a stout-based colonial plant, abundant in most of the larger, low to moderate gradient streams of the upper Ohio

River basin (Koryak, 1978; and Strausbaugh and Core, 1952). In those streams where it occurs, this emergent herbaceous aquatic perennial is usually the dominant plant of gravel and cobble riffles and bars (Clovis, undated; and Koryak, 1978). The dense colonial stands are fairly uniform in height, ranging from 0.2 to 1 meter (Fernald, 1950).

The root system of *Justicia* is very extensive with abundant thick cord-like stolons and rhizomes (Fernald, 1950). These subterranean stems form a web that binds the substrate, collects sediment, and tenaciously resists scouring and other mechanical disruption. This root-stem network and entrained materials create a low but durable bench, typically elevated roughly 5 to 25 centimeters above the adjacent channel area.

The range of *Justicia americana* extends from Quebec and Ontario west to Michigan and south to Georgia and Texas (Fassett, 1975). This range overlaps the Appalachian coal fields where sulfuric acid from coal mine drainage degrades numerous streams. *Justicia americana* has been recognized as an important biological component of Appalachian streams. Hill (1981) investigated *Justicia americana* distribution and productivity in the Virginia portion of the New River where he determined that its productivity was four to five times greater than any other aquatic plant species.

Ortmann (1919), whose classic monograph is still considered the most in-depth study of the naiades (Burch, 1975), recognized the importance of *Justicia americana* to freshwater mussel habitat and noted distinct associations between the plant and a number of mussel species (Koryak and Reilly, 1984). Some species were associated with the lively currents and gravel substrates of riffles interrupted by *Justicia* patches, while others preferred the quiescent water that occurs within the shelter of the *Justicia* growths. Other investigators have also pointed out that aquatic vegetation can significantly influence invertebrate distribution and abundance. Kondratieff and Voshell (1979), for instance, noted that mayfly productivity and diversity was high where *Justicia* was abundant. For the most part, however, perhaps because it is such an ubiquitous feature of local unpolluted streams, *Justicia* and its potential influence on riffle organisms has been largely unrecognized.

DISTRIBUTION AND ACID MINE DRAINAGE

Relationships between vascular riffle flora, reservoir regulation, acid mine drainage, and riffle channel morphology and ecology became apparent during 12 years of routine water quality and riffle zoobenthos monitoring of streams in the Pittsburgh Engineer District. In the 40,000 square kilometer area of the Pittsburgh District, both chemical data and Surber invertebrate samples were collected at approximately 200 riffle stations. Observations of the riffles, including floral characteristics, were routinely made.

Since acid mine drainage is so widespread and of special interest in the basin, a considerable percentage of the sampling stations were selected to be representative of stream reaches upstream and downstream of major acid polluted tributaries.

Distributional observations of _Justicia americana_ in the upper Ohio River drainage basin indicate that this plant is very sensitive to acid mine drainage pollution. Within this basin there are 40,000 kilometers of perennial stream, and acid mine drainage is the most serious and widespread water quality problem. Both the degree of mine drainage pollution and the occurrence of _Justicia_ in suitable habitat were determined along 2,800 kilometers of 105 different reaches of the larger streams in this area. A total of 2,200 kilometers of 66 different stream reaches were observed to be free of significant acid pollution (pH greater than 5.5) and approximately 600 kilometers of 39 different reaches were found to be frequently or chronically acid degraded. Without exception, _Justicia_ was sparse or absent from all 39 of the mine drainage polluted reaches. On the other hand, it was moderately to luxuriantly abundant on riffles and gravel shoals along 1,600 kilometers of 49 stream reaches that were not acid degraded.

A single-factor analysis of variance (ANOVA) was used to examine the observed distribution in relation to the presence of mine drainage pollution. Again, using chronic or intermittent pH values of 5.5 or less to define significant acid pollution, the results of the ANOVA show that acid mine drainage degradation is clearly significant (at a 99.9 percent confidence level) in determining if a given stream can support _Justicia americana_.

The distribution of _Justicia_ then is clearly related to water quality, and its growth is encouraged by water quality improvements achieved by reservoir regulation for water quality control. It is worth noting, however, that along the upper Allegheny River downstream of Kinzua Dam which has never been influenced by acid mine drainage, the proliferation of lush growths of this plant has apparently been encouraged by aspects of streamflow regulation that cannot be related directly to water chemistry changes. It is, therefore, assumed that reductions in flood intensity and bed scouring achieved by multipurpose storage impoundments are also probable factors in the success of this aquatic plant in regulated stream reaches.

EFFECTS ON CHANNEL MORPHOLOGY AND SUBSTRATE COMPOSITION OF RIFFLES

The West Fork River of northcentral West Virginia provides an excellent example of the effects of _Justicia_ on channel morphology and substrate composition of stream riffles. The West Fork River is a sand and gravel based stream of moderate gradient (average slope 0.4 m/km). The river drains 2.283 km^2 and its main stem is 170 km long. The West Fork receives mine drainage along most of its length but 52 percent (3,360 kg/day acidity as $CaCO_3$) of the river's acid load enters from one tributary at km 36. From km 36 downstream to the km 0, the stream experiences pH limiting water quality (Sack et al, 1976).

On the West Fork River, scattered Justicia americana is first observed near km 116. From km 103 to 52 this aquatic plant is exceptionally lush on all gravel bars and riffles. It was still relatively common between km 52 and km 36, where the river receives some acid pollution. In the significantly degraded reach below km 36, gravel bars and riffles are generally barren of Justicia or any other aquatic plant except for Eleocharis acicularis (Clarkson and Moore, 1971 and Koryak and Reilly, 1984).

TABLE 1 is a tabulation of total and low-flow channel widths at riffles along the West Fork River. The measurements were taken during a low-flow period when the stream discharge was 0.0011 $m^3/s/km^2$ or 7 percent of the average annual discharge. In the Justicia colonized riffles between km 103 and km 52, the average width of the low-flow channel was 29 percent of the total channel width. Downstream of km 36, where the plant was eliminated, the average low-flow channel width of riffles increased to 71 percent of the total channel width.

TABLE 1

Total and Low-Flow (7% of Mean Annual Flow) Channel Widths at Riffles Along the West Fork River

Riffle Location (West Fork River km)	Total Channel Width at Riffle (m)	Low-Flow Channel at Riffle	
		Width (m)	% of Total Channel Width
Unpolluted Reach Upstream of km 36.2			
103.4	34	5.8	17
103.3	34	18	53
90.6	35	11	31
88.2	27	5.5	20
77.4	58	14	24
			MEAN 29%
Acid Mine Drainage Polluted Reach Downstream of km 36.2			
35.6	49	23	47
32.5	52	46	88
23.2	52	43	83
22.6	46	35	76
22.5	34	23	68
15.3	37	30	81
7.2	61	34	56
			MEAN 71%

Low-flow channel constriction of the *Justicia* colonized riffles resulted in greater low-flow water depths and increased flow velocities in the riffles, with subsequently increased localized substrate scouring and sorting. The substrate of the higher velocity *Justicia* constricted riffles of the West Fork River were relatively well-sorted, clean rocks and gravel with heavy periphyton growth. Conversely, the stream substrate of the broad, shallow riffles in the lower section of the river was generally unconsolidated with heavy deposition of fine sediment.

Another opportunity to test the major hypothesis presented in this paper will soon be available along the West Fork River. Augmentation from Stonewall Jackson Dam, now under construction at West Fork River km 117, will mitigate much of the mine drainage pollution in the lower river. Subsequent recolonization by *Justicia* and changes in riffle form and substrate are then anticipated within a few years after the project becomes operational.

RELATIONSHIP TO RIFFLE FAUNA

Acid mine drainage adversely affects aquatic organisms in several different manners. Besides direct toxicities from acid and heavy metals, mine drainage associated siltation and metal hydroxide precipitates reduce cover and cover diversity, while often smothering periphyton, benthic invertebrates, and eggs and larvae of gravel spawning fishes (Koryak et al, 1972). These adverse effects can be related directly to the physical and chemical quality of the mine drainage polluted water. Secondary biological impacts of mine drainage pollution on stream riffles include inhibition of plants such as *Justicia* and losses of cover, food, and low-flow channel definition that would otherwise be available.

An example of the degree and extent of influence *Justicia* channel constriction can have on riffle benthic macroinvertebrates can be seen in TABLE 2. This table is a summary of Surber sample macroinvertebrate results for two riffles of the Tygart River. The Tygart River drains 3,560 km^2 of north-central West Virginia. The main channel is 210 km long with an average slope of 2.5 m/km. One riffle sampled is located at km 55.5, in an intermittently and moderately acid degraded reach of the river which *Justicia* has only recently begun to colonize and where it is still sparse. The other riffle is located upstream of any significant mine drainage pollution at km 71.1 and is choked with *Justicia*. At the point of maximum constriction of the km 71.1 site, *Justicia* benches have constricted the low-flow channel to approximately 29 percent of the total channel width.

In terms of invertebrate dry weight as mg/m^2, the deepest, swiftest, and coarsest substrate portion of the km 71.1 *Justicia* constricted riffle (cobble sized rocks colonized by *Podostemum ceratophyllum*) was 600 percent

TABLE 2

Summary of Macroinvertebrate Data Collected at Three Different Habitat Types of One *Justicia americana* Constricted Riffle in the Tygart River and Also at a Downstream Riffle Mildly Degraded by Mine Drainage and Barren of *Justicia*

	At a Riffle Barren of *Justicia* (Tygart River km 55.5)	Within Different Portions of a Riffle Constricted by *Justicia* (Tygart River km 71.1)		
		At Point of Maximum Constriction of the Low-Flow Channel (29% of Total Width)	At a Less Constricted Portion of the Low-Flow Channel (55% of Total Width)	Within Stolon-Rhizome Network of Justicia Bench
Average Number of Taxa/Surber Sample	5	19	8	9
Average Number of Organisms/m^2	167	5963	431	1458
Average Dry Weight of Organisms mg/m^2	43	1376	218	367

more productive than a considerably less constricted (approximately 55 percent of total channel width) clean gravel substrate portion of the same riffle complex and 3200 percent more productive than the moderately acid polluted riffle of the Tygart River 15.6 km downstream. The average invertebrate community in the area of maximum *Justicia* constriction was also more than 200 percent more diverse than at the broader portion of the *Justicia* riffle and nearly 400 percent more diverse than the riffle in the nearby mildly acid degraded reach. The invertebrate community within the *Justicia* stem-root network was also examined. While this area was not as productive and diverse as the low-flow channel in the area of maximum constriction, it was comparable to what was found in the less constricted portion of the same riffle complex and was considerably more productive and diverse than the invertebrate community that occurred in the acid influenced downstream riffle.

The comparison of Tygart River benthic faunal communities in the area of maximum riffle constriction of the *Justicia* dominated riffle with the less constricted area of the same riffle is likely a realistic reflection of the influence of *Justicia* constrictions of riffle fauna. The comparison of any *Justicia* constricted riffle with a riffle where the plant has been inhibited by mine drainage, however, would be necessarily complicated by differences in water chemistries between such sites. Generally, the same acid pollution that inhibits the growth of the macrophyte would also be expected to suppress the faunal community of the riffle. This consistent and significant variable makes it difficult to verify the effects of *Justicia* on riffle organisms independent of water chemistry. However, when the more easily determined effects of the *Justicia* constrictions on riffle channel morphology and substrate are considered, it is possible to draw some inferences from studies of channelized and silt polluted streams, which also typically are deficient in low-flow channel definitions. The substrates of these sites frequently consist of unconsolidated, abrasive mixtures of shifting sand, silt, and small rocks not well suited for invertebrate colonization (Hynes, 1971; Congdon, 1971; Hanson and Muncy, 1971; Cordone and Kelley, 1961; and Tarpelee et al, 1971, cited in U.S. Army 1976). Conversely Brusven et al (1974) demonstrated that channel constriction in silted streams increases sediment transport and improves invertebrate and fish habitat. In terms of fish habitat, the significance of silt free riffles becomes apparent when it is considered that approximately 50 percent of the more than 100 species of fish known to inhabit the upper Ohio River drainage basin utilize clean gravel to reproduce.

Other investigators have reported large increases in growths of aquatic plants (Ridley and Steel, 1975) or extreme channel encroachments by riparian vegetation (Smith, 1976) in rivers where flow is controlled by upstream impoundments. In some cases, these impacts have been beneficial (Fraser, 1972, and Hall and Pople, 1968 cited in Ridley and Steel, 1975). In other cases, it was felt that such vegetative changes degraded habitat (Smith, 1976) and increased flooding potential (Bush, 1976). The growths of low benches of *Justicia* in regulated streams of the upper Ohio River basin are considered to be aesthetic and environmental enhancements. At present, no significant potential adverse impacts from these growths are apparent.

Under EWQOS, Nunnally and Shields (1985) made a very comprehensive review and excellent evaluation of environmental features of flood control channel modifications. Among their primary results is a recognition of the value of low-flow channels, channel sinuosity, and coarse stable substrates. Also included in their document are various design, construction, and maintenance methods for achieving these goals. In the preceding discussion, it has been demonstrated that these beneficial features can sometimes also be obtained indirectly by improving water quality, and that aquatic plant ecology can be a significant variable in both channel modification projects and in reservoir regulation.

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Travel Time, Wave Vs. Particle:

An Operational Tool

By

Daryle M. Seckar[1]

Systems operation of the reservoirs in the West Branch Susquehanna River Basin (figure 1) is of paramount importance for managing the overall water quality of the river and particularly important for controlling the acid mine pollution that continually degrades the river throughout its 175 mile length. "Acid slugs", which are generated naturally by sudden, heavy rainshowers or are induced by making large releases from upstream reservoirs, are major problems during the low flow, poor quality periods of summer and fall. If left uncontrolled, "acid slugs" can have devastating effects in the river as far downstream as Williamsport, Pennsylvania. Controlling the slug is accomplished by dumping large quantities of alkaline water from reservoirs into the West Branch Susquehanna River prior to and during passage of the slug. It is critical to time the releases properly so as not to evacuate more storage from the reservoirs than is needed to neutralize the slug. This paper discusses the development of the reservoir release timing principle as an operational tool for the West Branch Susquehanna River system.

The West Branch Susquehanna River Basin (figure 1) consists of 7,015 square miles located in the center of the state of Pennsylvania. The Baltimore District has a system of four reservoirs in the basin (figure 1). They are Curwensville Lake, George B. Stevenson Dam, Alvin R. Bush Dam, and Foster J. Sayers Dam. In total the reservoirs control approximately 17% of the drainage area of the West Branch basin. The projects are used mainly for flood control purposes, but do serve as water quality tools for the West Branch. The stream valleys in the basin above Renovo, Pennsylvania are generally narrow and quite deep. Below Renovo, Pennsylvania, the valleys are somewhat wider with less meander in the stream. The basin is characterized by numerous active and abandoned deep and strip coal mines. The major water quality problem in the basin is acid mine drainage pollution. The damage caused by acid mine drainage pollution is limited to certain streams, but the overall effects are far reaching. The costs are great in terms of loss of recreation, devastation of aquatic habit and the degradation of municipal and industrial water supply.

Approximately 1200 miles of principle and tributary streams are affected by acid mine drainage. Figure 2 shows numerous tributaries with associated water quality. The pH of the tributaries ranges from 3-4 standard units with associated net alkalinities between -12 and -108 mg/l as $CaCo_3$. Figure 3 shows the overall effects of the tributaries on the West Branch water quality. The presence of acid mine drainage has all but elimininated the beneficial uses of the West Branch Susquehanna River. Water quality management of the river entails eliminating the propagation of poor quality water further down- stream than Lock Haven, Pennsylvania.

[1] Civil Engineer, Water Control Management Section, Baltimore District, COE.

The point on the West Branch Susquehanna River where the quality begins to make a marked improvement is just below the confluence of the West Branch and Bald Eagle Creek in Lock Haven, Pennsylvania. No real improvement can be achieved in the West Branch water quality upstream of Lock Haven, Pennsylvania. The downstream improvement to the quality comes from the elimination and neutralization of "acid slugs" that course their way downstream.

An "acid slug" is basically a surge in the river upstream, either from an isolated rainstorm or a reservoir release, that causes a slug of acid to be pushed further downstream than would have occurred naturally. These slugs can be extremely detrimental to the downstream reaches. Figures 4 through 7 show the formation and propagation of an acid slug. It begins as a surge in the river upstream where the water quality is extremely bad. The slug of bad water is pushed downstream for some distance and gradually dropped out of the wave. The wave continues downstream while the acid slug remains behind, traveling downstream at the particle velocity rate. Basically a wave travels downstream faster than the particles that make up the wave. To further study this phenomenon we decided to perform a wave and particle travel time study on the West Branch Susquehanna River.

The travel time study was performed on the West Branch Susquehanna River in October 1982. The study included the use of stream gages to follow waves downstream and flourescent dye tracers to follow particles downstream.

Steady state flow travel times were collected for the West Branch from Curwensville dam downstream to Shawville, Pennsylvania and from Renovo, Pennsylvania downstream to Lock Haven, Pennsylvania. Steady state travel times were also collected for Bald Eagle Creek from Foster Joseph Sayers Dam to its confluence with the West Branch.

Waves were much easier to follow thanks to the stream gaging system on the West Branch. Reservoir releases were successfully followed downstream from all the West Branch Reservoirs.

Finally, dye injections were incorporated into reservoir releases from both Curwensville and Foster Joseph Sayers Lake. The releases were traced downstream using the stream gages while the dye was followed downstream manually. Figures 8 through 15 show the results of this phase of the study. Basically they confirm the fact that the particles are originally picked up and are part of the wave, but they are eventually dropped out. The wave then travels downstream very quickly while the particles follow along behind at a much slower rate and eventually fall back to a steady state condition.

The knowledge derived from studying acid slugs and wave and particle travel times has given the Baltimore District a basic water quality operational tool for the West Branch reservoir system. Generally, normal reservoir releases will provide adequate neutralization of the West Branch. When an upstream surge occurs, the key to our timing principle is to watch for the flow at Renovo to increase while the water quality declines. At that point we know an acid slug has formed and is on its way downstream. We then can estimate the time when the slug will pass Lock Haven. We will then schedule a release from Sayers to arrive at Lock Haven just prior to the slug and to continue until the slug has passed.

The operational tool is constantly changing and being revised as more data is analyzed. The tool allows more flexibility in our release scheme while providing a more accurate and judicious use of available storage for water quality control. The idea is not new by any means, but its use in the field is not believed to be as widespread as it could be.

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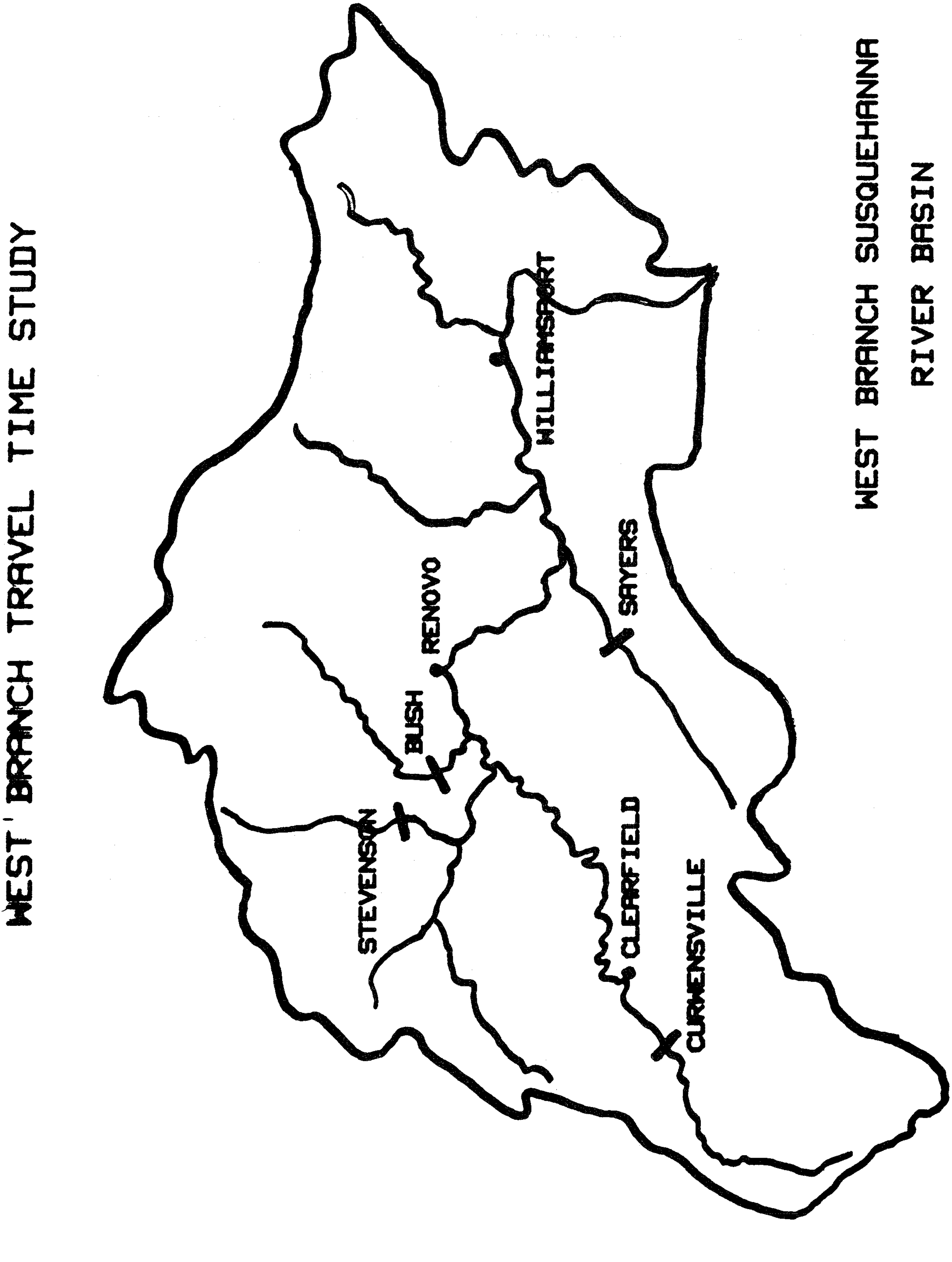
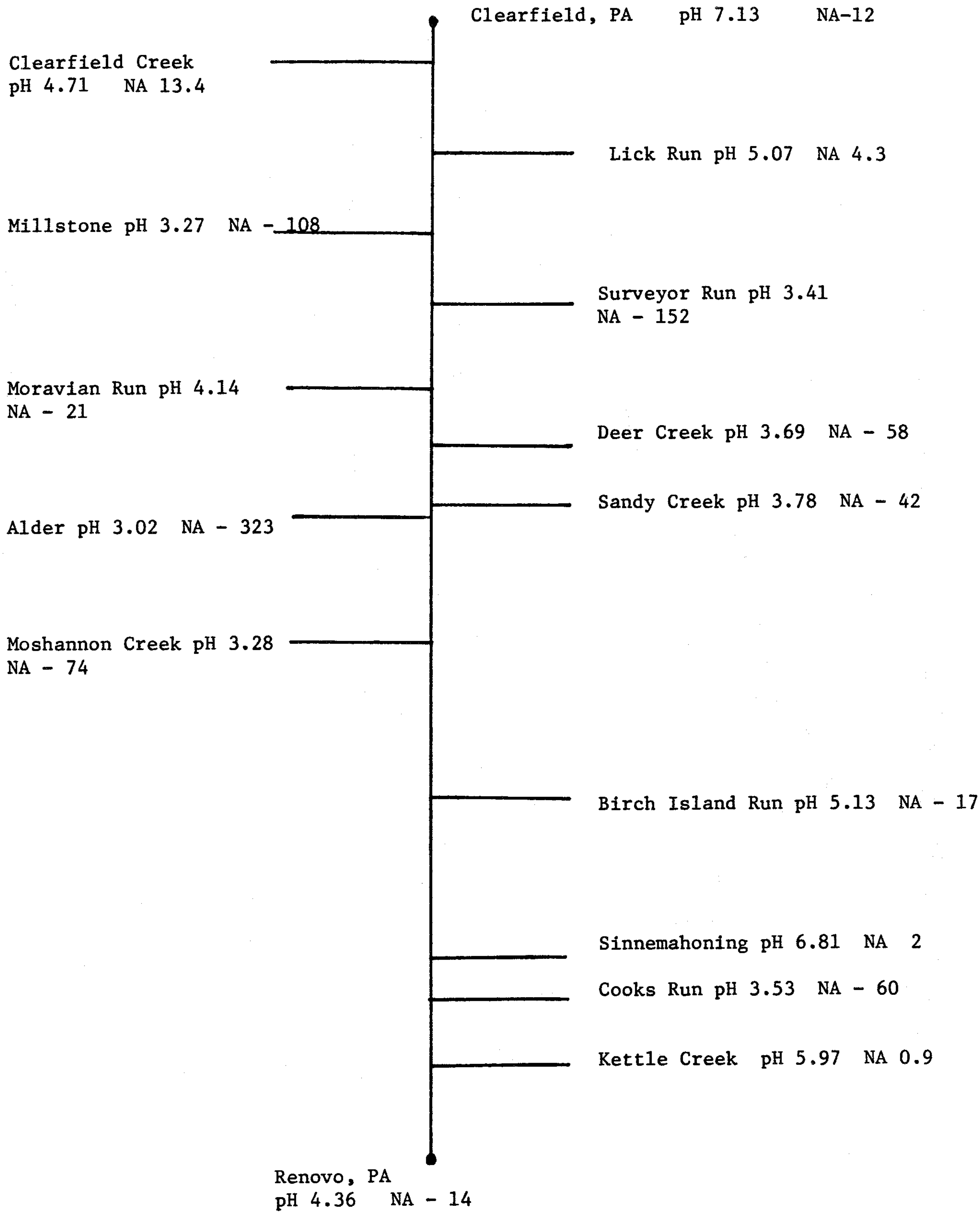

WEST BRANCH TRAVEL TIME STUDY
WEST BRANCH SUSQUEHANNA
RIVER BASIN
WILLIAMSPORT
SAYERS
RENOVO
BUSH
STEVENSON
CLEARFIELD
CURWENSVILLE

Figure 1



WEST BRANCH SUSQUEHANNA RIVER
NA - NET ALKALINITY

Figure 2

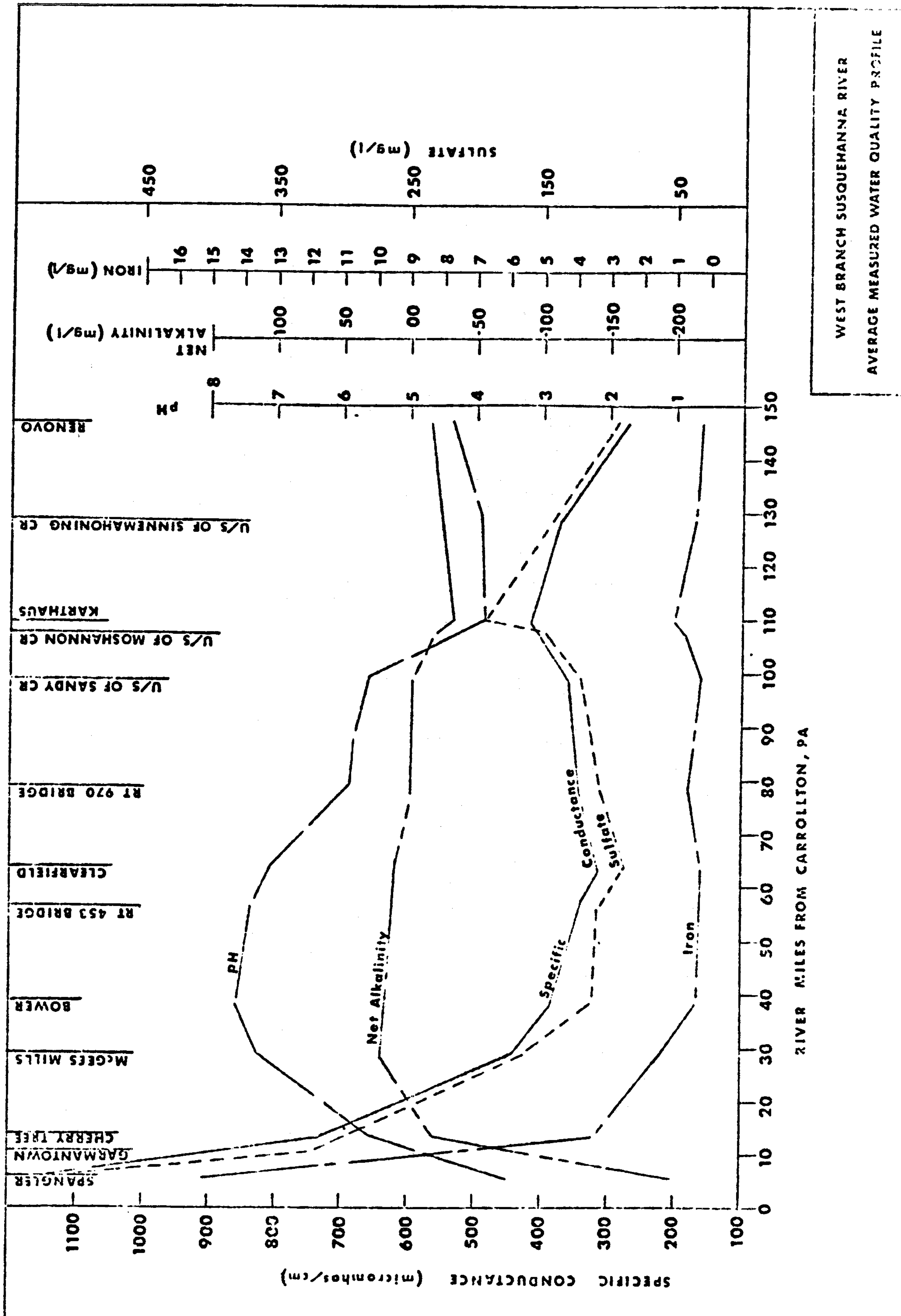

WEST BRANCH SUSQUEHANNA RIVER
AVERAGE MEASURED WATER QUALITY PROFILE
SULFATE (mg/l)
450
350
250
150
50
IRON (mg/l)
NET ALKALINITY (mg/l)
pH
RENOVO
U/S OF SINNEMAHONING CR
KARTHAUS
U/S OF MOSHANNON CR
U/S OF SANDY CR
RT 970 BRIDGE
CLEARFIELD
RT 453 BRIDGE
BOWER
McGEES MILLS
CHERRY TREE
GARMANTOWN
SPANGLER
PH
Net Alkalinity
Specific Conductance
Sulfate
Iron
RIVER MILES FROM CARROLLTON, PA
SPECIFIC CONDUCTANCE (micromhos/cm)

Figure 3

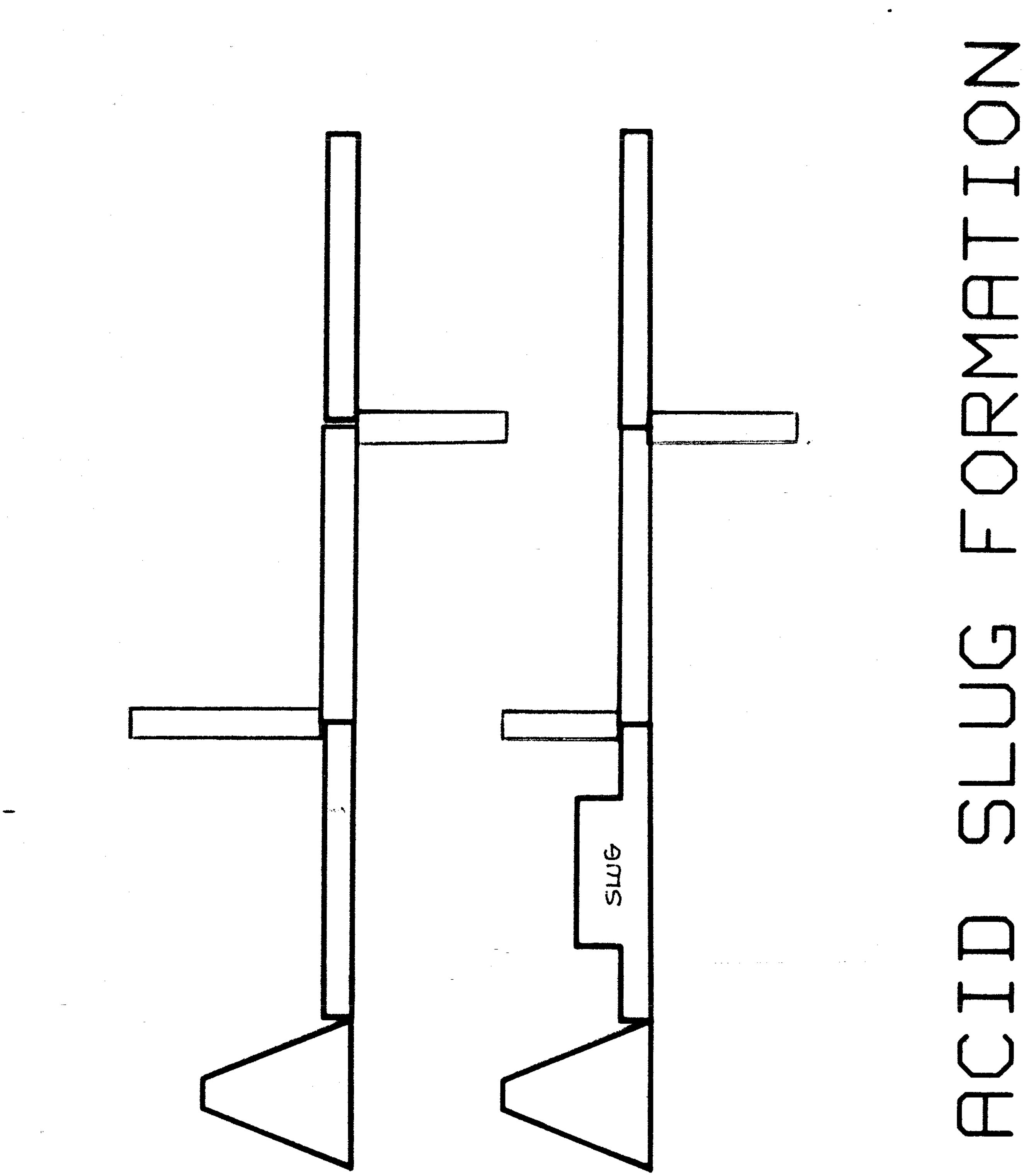


Figure 4

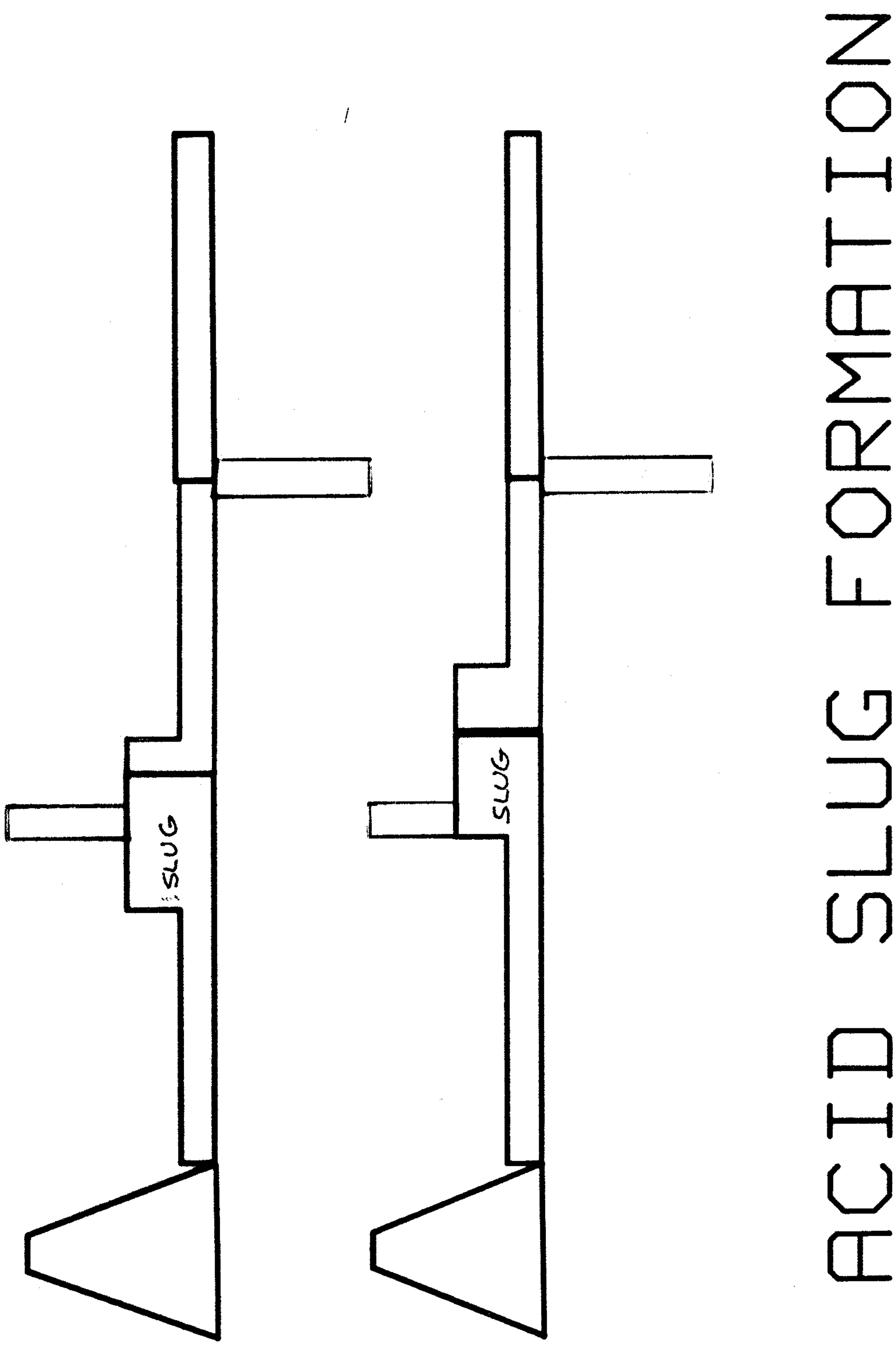


Figure 5

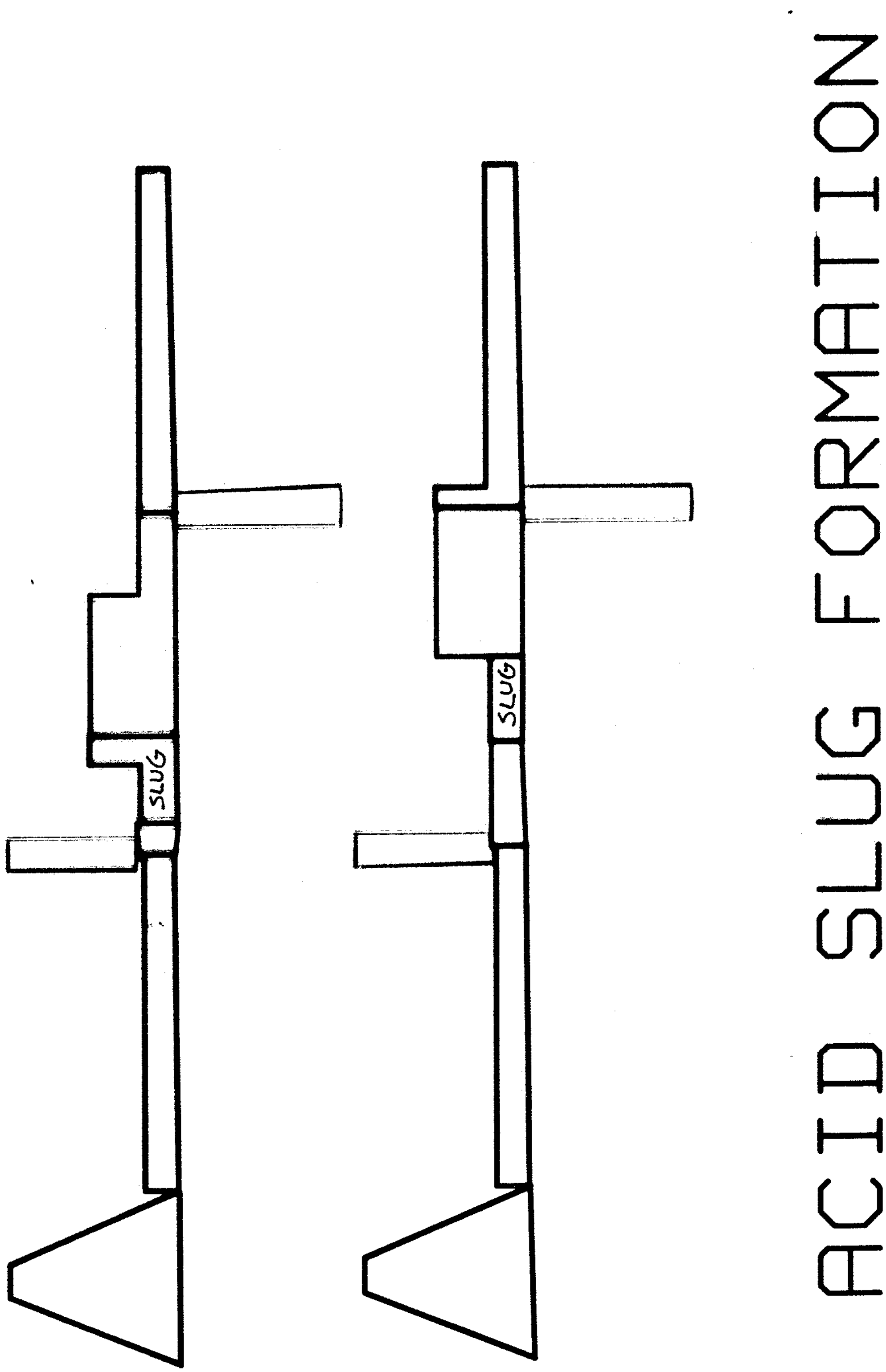


Figure 6

ACID SLUG FORMATION

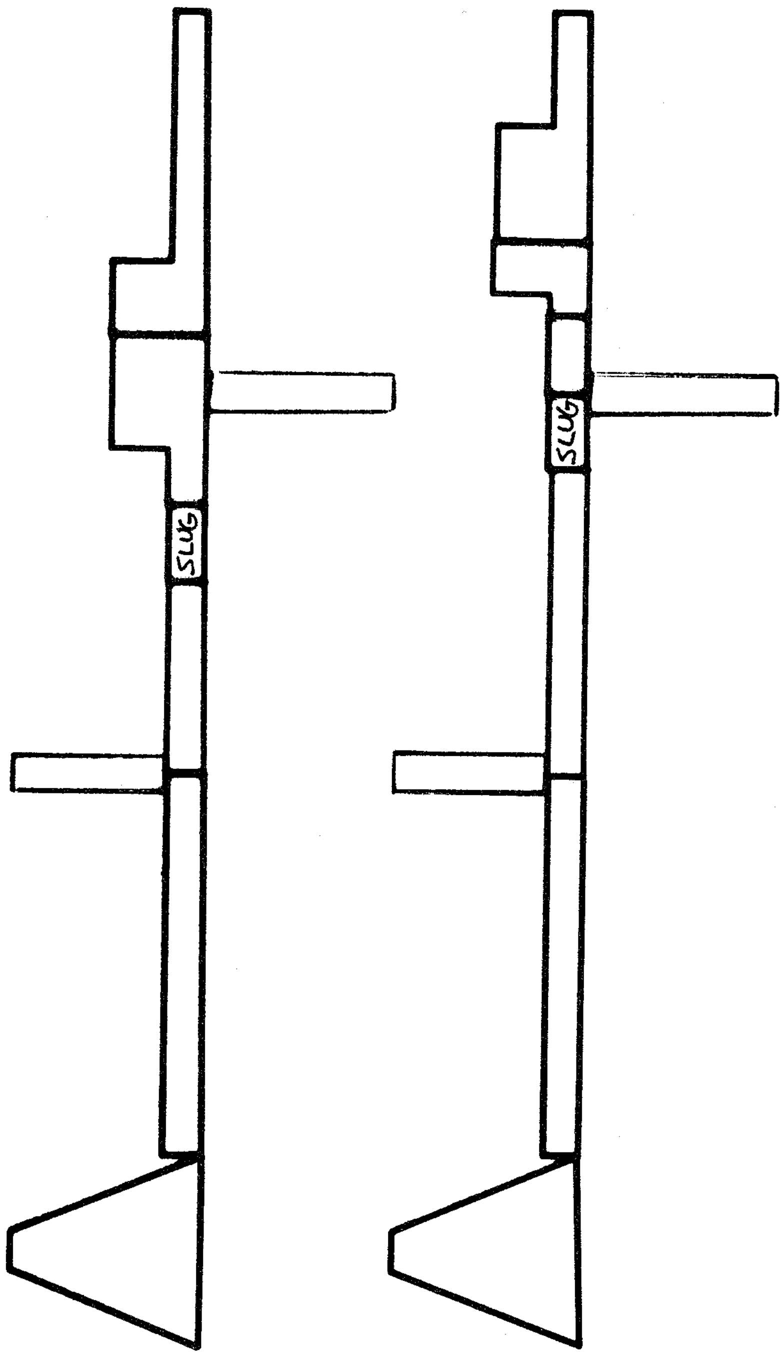


Figure 7

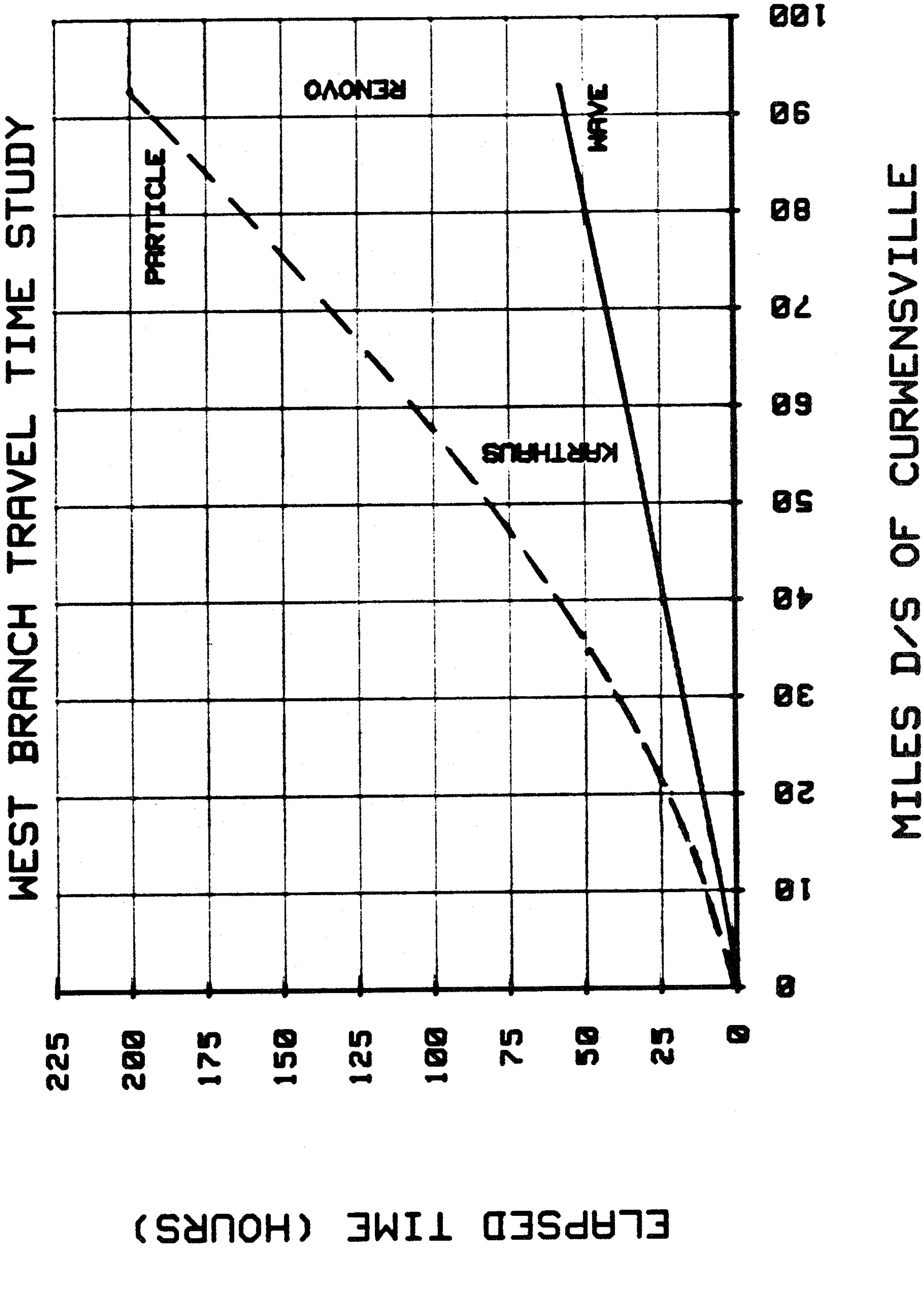

WEST BRANCH TRAVEL TIME STUDY
MILES D/S OF CURWENSVILLE
ELAPSED TIME (HOURS)
PARTICLE
WAVE
RENOVO
KARTHAUS
0
10
20
30
40
50
60
70
80
90
100
0
25
50
75
100
125
150
175
200
225

Figure 8

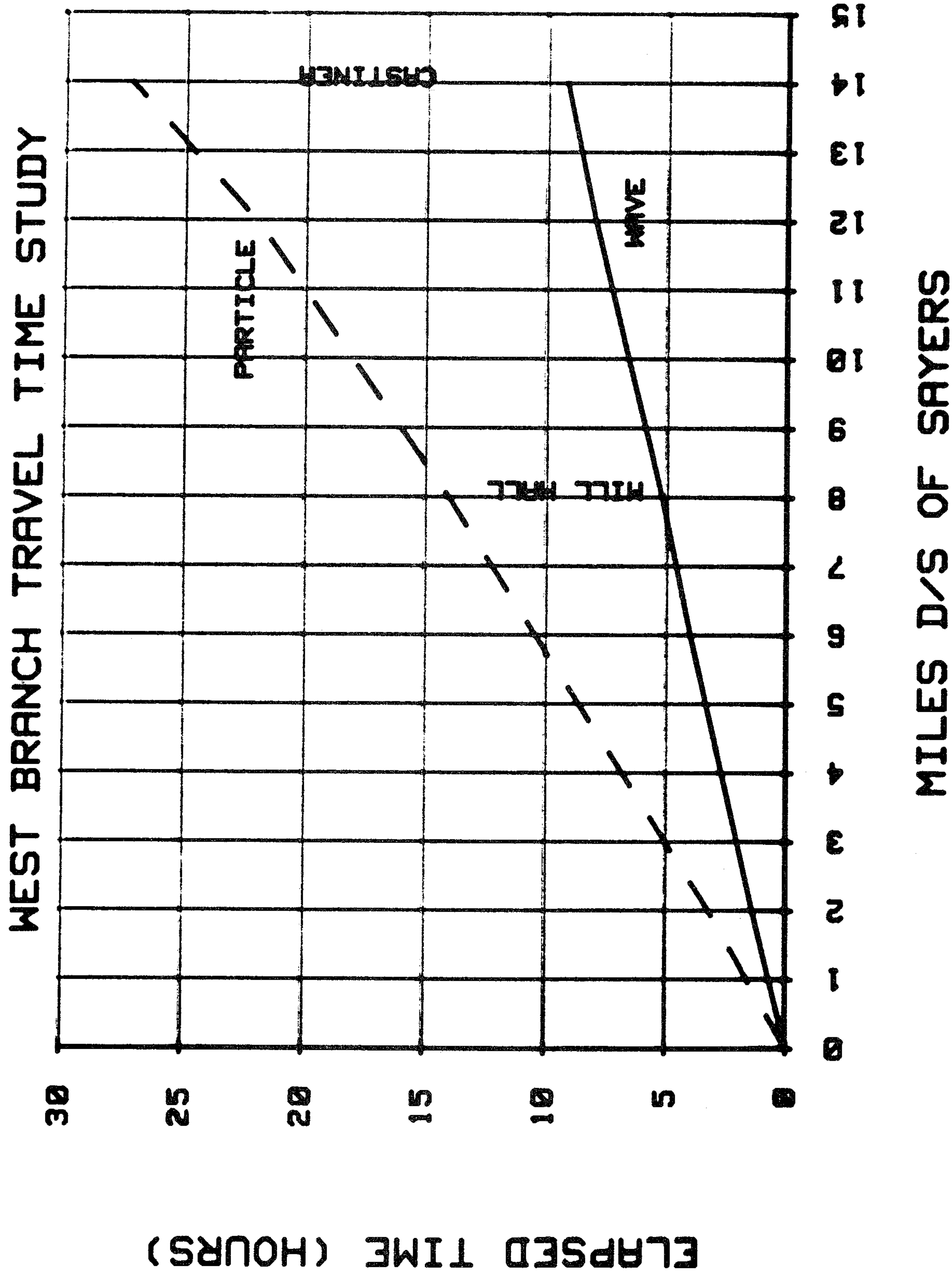
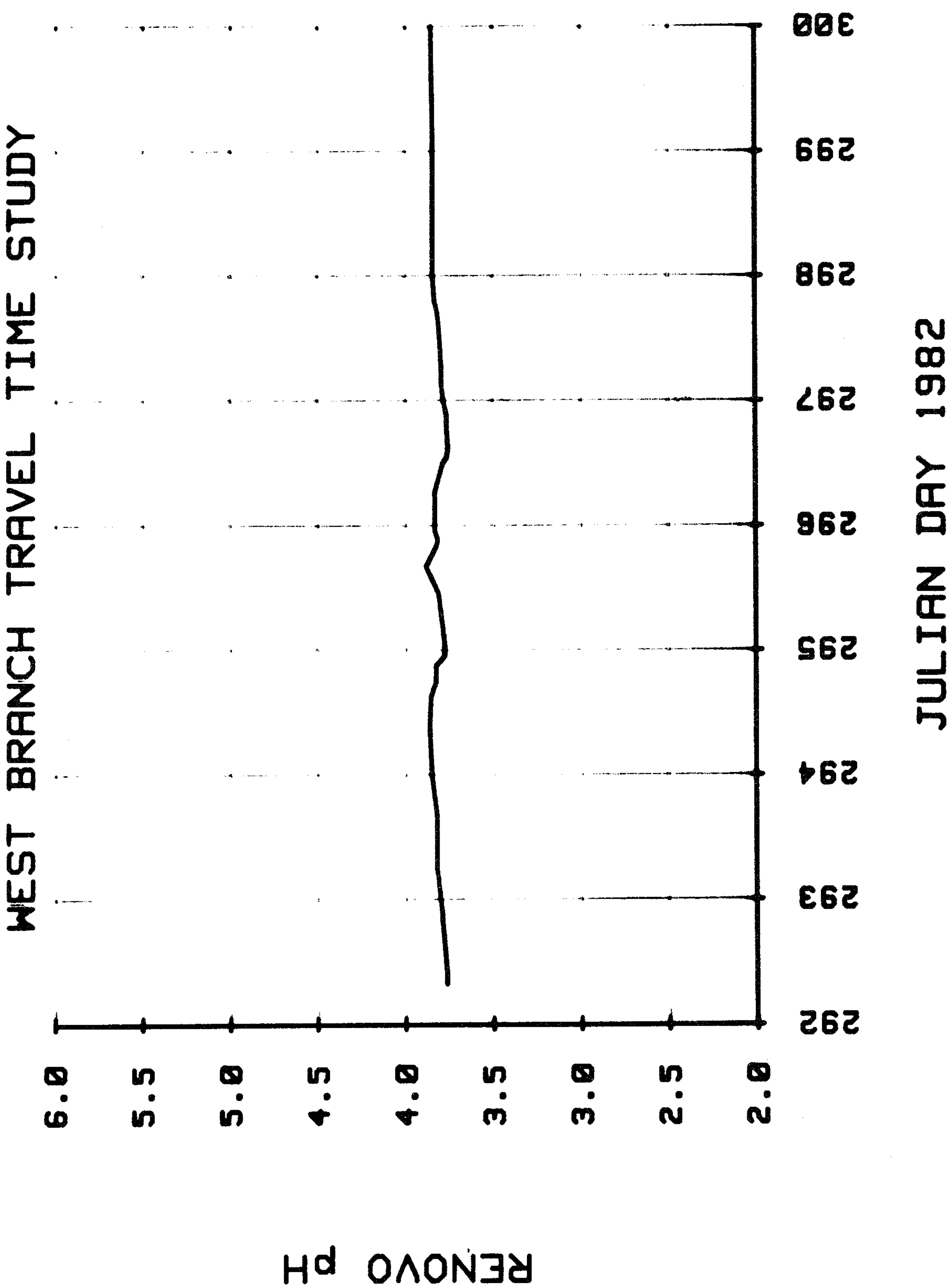

WEST BRANCH TRAVEL TIME STUDY
MILES D/S OF SAYERS
ELAPSED TIME (HOURS)
PARTICLE
WAVE
MILL HALL
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
5
10
15
20
25
30

Figure 9



WEST BRANCH TRAVEL TIME STUDY
RENOVO pH
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
JULIAN DAY 1982
292
293
294
295
296
297
298
299
300

Figure 10

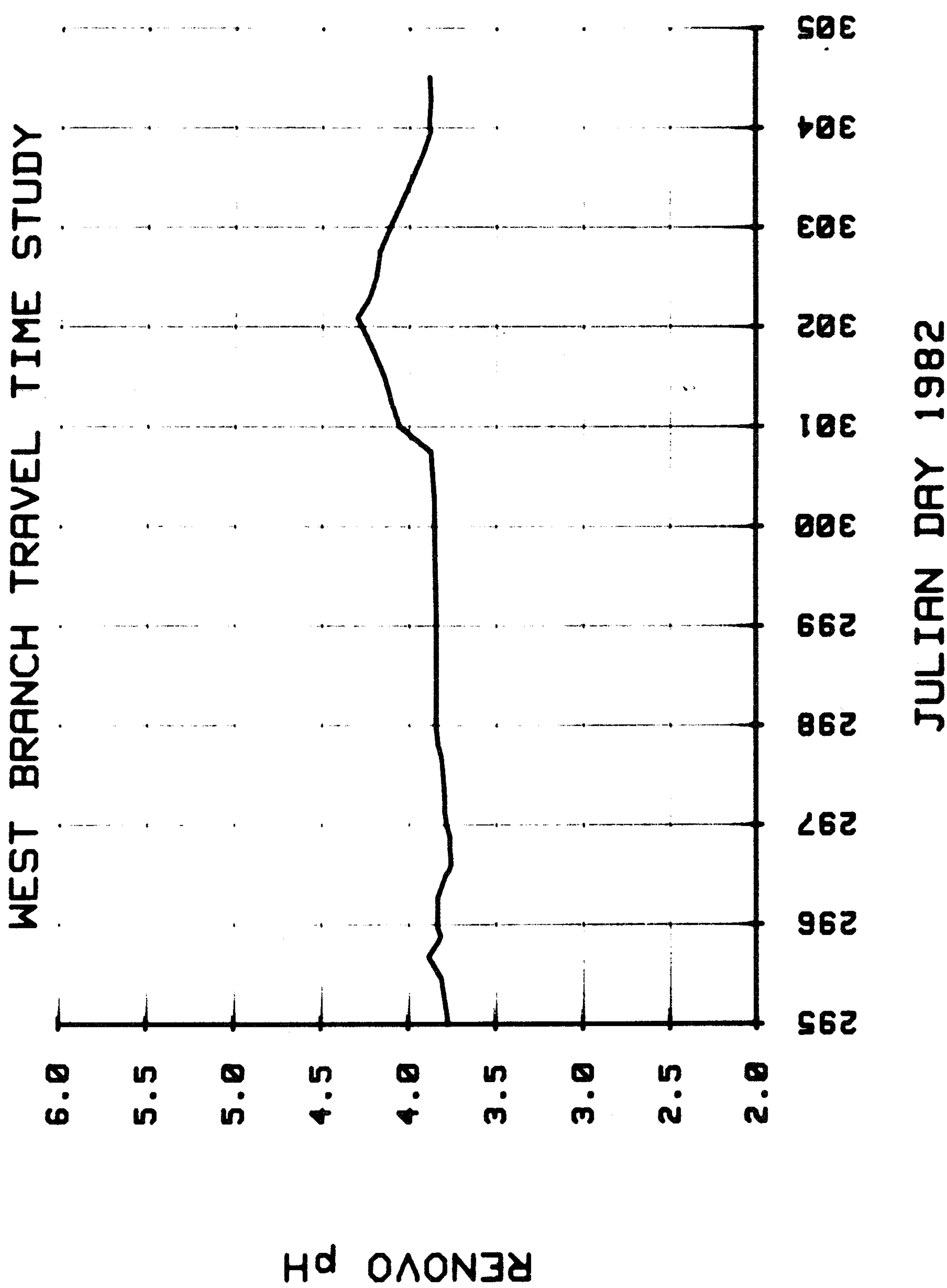

WEST BRANCH TRAVEL TIME STUDY
JULIAN DAY 1982
RENOVO pH
295
296
297
298
299
300
301
302
303
304
305
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0

Figure 11

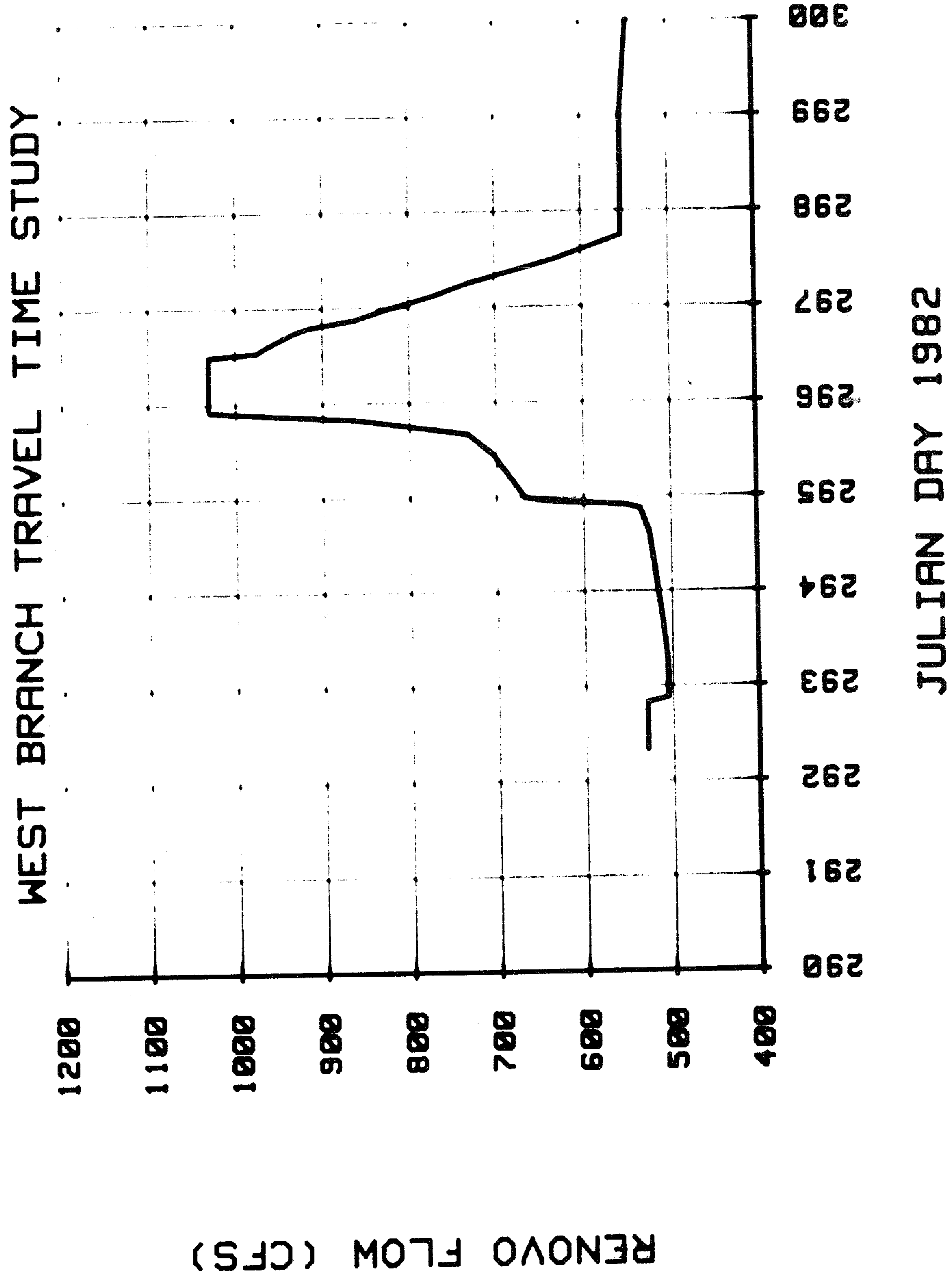

WEST BRANCH TRAVEL TIME STUDY
JULIAN DAY 1982
RENOVO FLOW (CFS)
290
291
292
293
294
295
296
297
298
299
300
400
500
600
700
800
900
1000
1100
1200

Figure 12

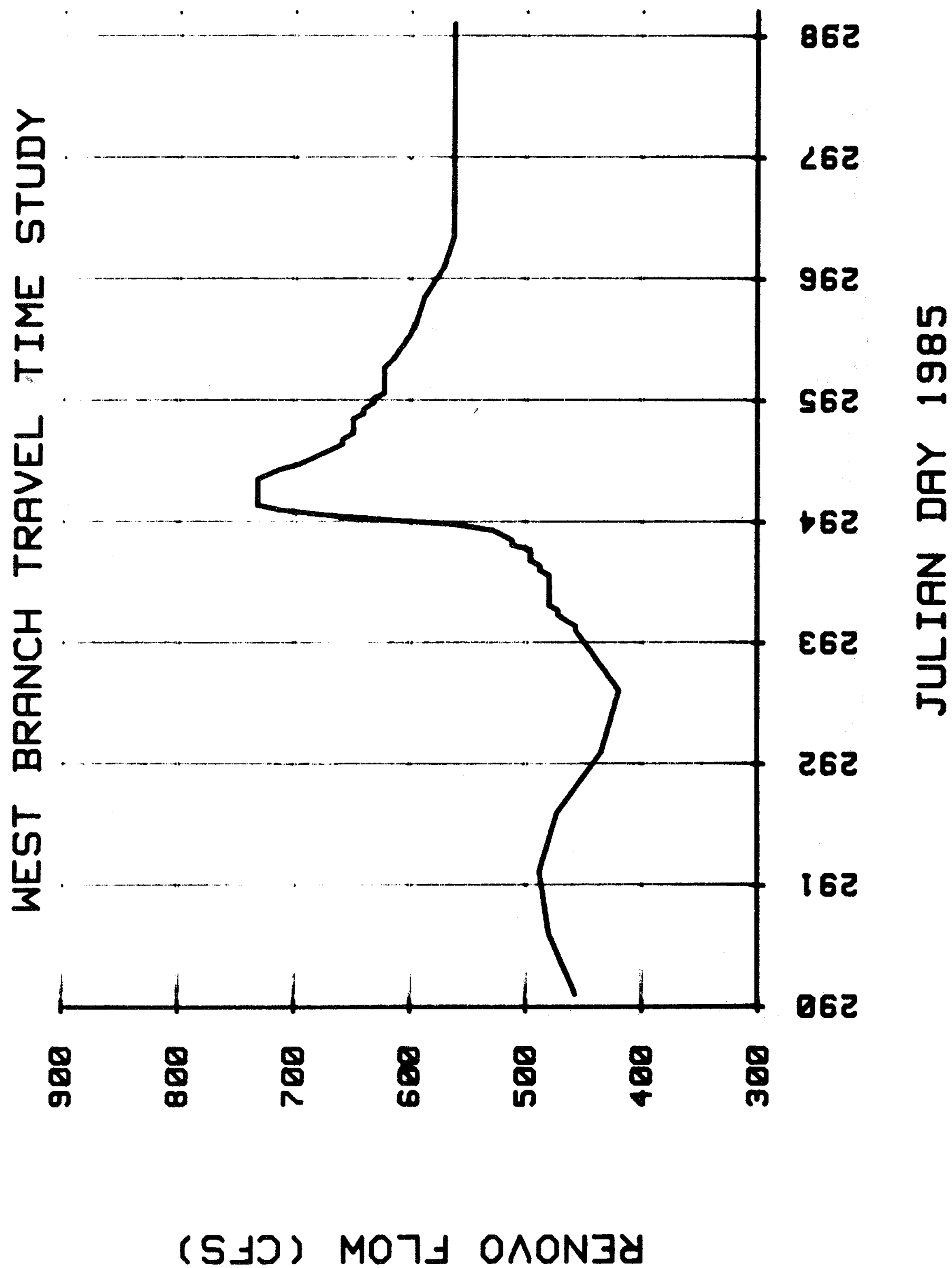

WEST BRANCH TRAVEL TIME STUDY
RENOVO FLOW (CFS)
900
800
700
600
500
400
300
JULIAN DAY 1985
290
291
292
293
294
295
296
297
298

Figure 13

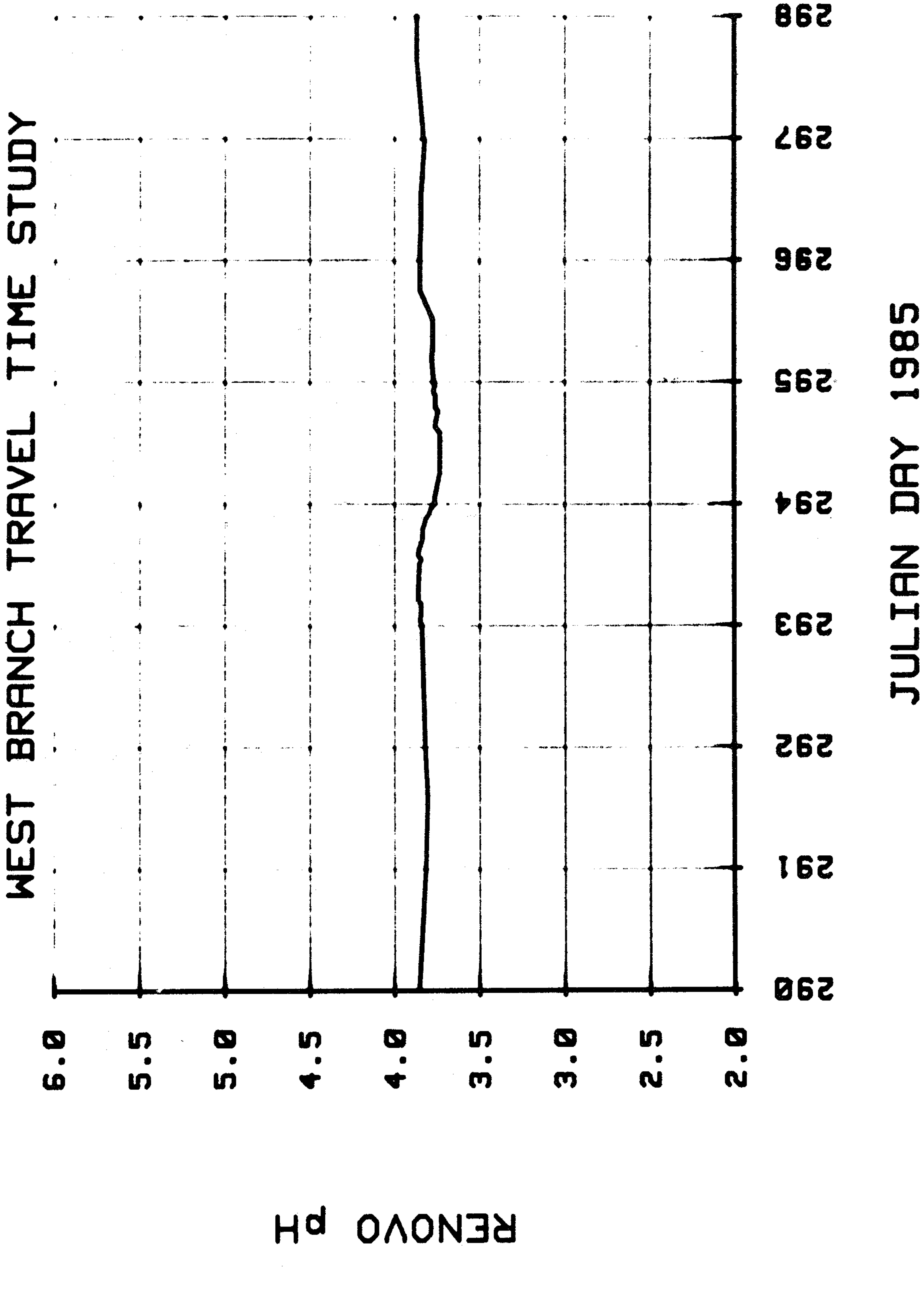
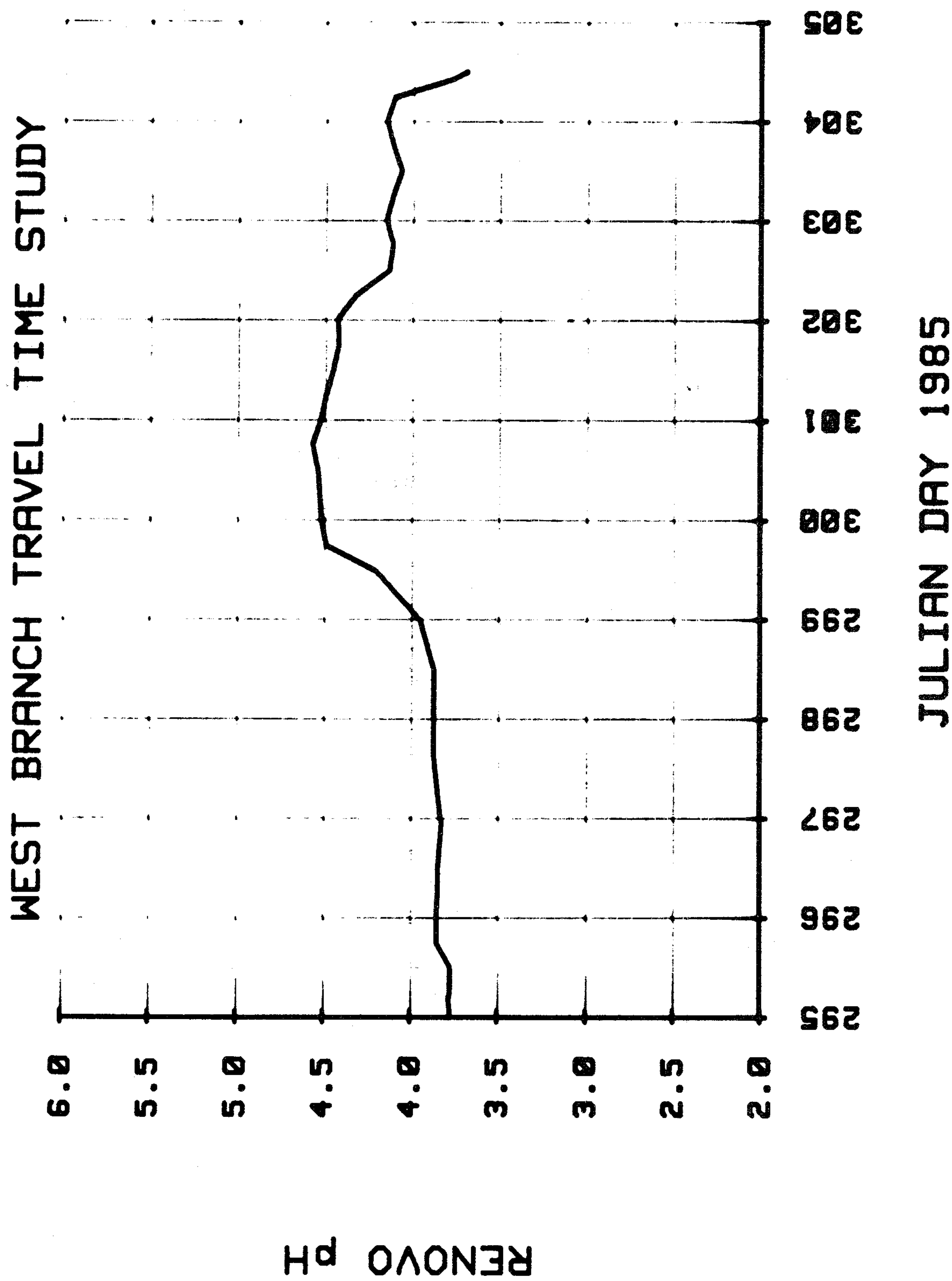

WEST BRANCH TRAVEL TIME STUDY
RENOVO pH
JULIAN DAY 1985
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
290
291
292
293
294
295
296
297
298

Figure 14



WEST BRANCH TRAVEL TIME STUDY
RENOVO pH
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
295
296
297
298
299
300
301
302
303
304
305
JULIAN DAY 1985

Figure 15

SEASONALLY VARIED LOW FLOW MANAGEMENT

By

F. B. Juhle[1]

1. It is surprising how little attention is given to low flow management. The Corps has over 650 projects, many have no low flow management objectives. A few, of course, have no opportunity for low flow control. These are the dry projects that function only for flood storage. There are many that have never been evaluated for low flow management. In many cases because it was assumed they had no potential for flow enhancement. Often this assumption is invalid. Arguments such as there is no water available for flow enhancement, all storage is tied up for other project purposes, the project is too small, the project is not authorized for low flow enhancement are all wane excuses not to develop a low flow objective or to manage the available resource for that objective. There is often opposition to changing project management strategy, the opposition is usually founded on ignorance or a reluctance to admit that the present way may not be the best way. This is not to proclaim change for the sake of change, but change for the sake of better, more efficient management of valuable resources. The first step in successfully changing a reservoir management plan is involving as many of the potential objectors to the change as possible, educating them and making them part of the decision process. Make sure they know and understand what you want to accomplish. If the concept is reasonable, valid, and understood, it will usually be accepted. Keep them involved throughout the decision process.

2. There are many projects that are not being utilized to their maximum potential for low flow enhancement. As a matter of fact, it is doubtful if there are any projects that are truly delivering their maximum benefit. One of the most common ways of developing a low flow management plan at the District level is to go see the resident Hydrologist and tell him you want a low flow plan for a certain lake and then sit back for a few weeks while he develops one. He, being trained in the Corps school of ultimate conservatism, will look at the lakes hydrologic past, develop a few low flow frequency curves, perhaps route a few droughts through the project and return with a minimum release value. He will tell you that the lake will never have a problem delivering "x" amount of water and at the very worst it may produce a 6" drawdown in a 100 year frequency drought. Extremely pleased with this, you write it into the water control manual which is then reviewed by higher authority, who know relatively little about the hydrology let alone the downstream environment of your project. The manual is approved and the low flow minimum release numbers are cast in stone, to be adhered to by all future water control managers. In other words, if you expect it to be done right, you must do it right yourself. Don't expect the review process to fill in your errors or oversights. It is not their job.

[1]Chief, Water Control Management Section, Baltimore District, Corps of Engineers

3. Each stream has a low flow footprint that is the basic structure on which all streams potential productivity is based. In general, the larger the low flow footprint the better. If you push the reservoir beyond its low flow safe yield to, say, a 75% or 80% success level, you get a much larger stream footprint in 8 out of 10 seasons. The low flow plan must address the downstream environment. There are some streams that need high flow in early summer to keep fish spawning beds covered. Others may need late summer flow enhancement to keep an adequate area submerged to allow aquatic plants to grow. Often, increased low flow benefits can be achieved by progressively increasing flow as downstream feeder streams dry up. Low flow management is not just a job for hydrologists, but requires input from the biologist, the recreation planner, and the other users of particular projects. Before a low flow plan can be developed, it is imperative that you know and understand the needs and potential of the stream reach affected. This takes time, study, and a lot of coordination.

4. A seasonally varied flow plan often produces significantly greater benefit than a constant flow plan. It also provides benefits to a substantially greater reach of stream. It requires a bold approach in the sense that as supplies of water become lower in the reservoir, the releases must become greater and greater. This is often very difficult to accomplish and the natural tendency to cut back as supplies diminish is often almost overwhelming. Remember, it will rain someday. It must also be accepted that in some cases, there will not be enough water to carry through. In that case, it will be necessary to drastically reduce outflow, perhaps to an inflow equals outflow basis. This can be accepted in most cases as conditions are still no worse than without the project. Remember, you only expect success 75-80% of the time. The value of 7 or 8 exceptionally successful seasons plus 1 or 2 poor seasons far outweighs the value of 10 mediocre seasons.

PREDICTED VS. ACTUAL WATER QUALITY
B. EVERETT JORDAN LAKE, NORTH CAROLINA

By

Christina E. Correale[1]

INTRODUCTION

As part of a Consent Judgment in a court case over whether or not the Corps' decision to impound B. Everett Jordan Lake, NC, was arbitrary and capricious, the Wilmington District conducted a study to determine whether or not water quality in the reservoir would be suitable for project purposes - flood control, water supply, downstream water quality control, recreation, and fish and wildlife conservation. The water quality emphasis was on eutrophication, due to the plaintiffs' contention that "...massive algal growths in the lake are inevitable." (Corps of Engineers 1971).

Pre-impoundment predictions of the manifestations of eutrophication are compared to post-impoundment data for B. Everett Jordan Lake, NC, to determine the validity of the predictions.

PRE-IMPOUNDMENT

Two models were used to predict the trophic state of B. Everett Jordan Lake: the Vollenweider model and the Larsen-Mercier model (Corps of Engineers 1975 and Corps of Engineers 1976b). Both models predicted that B. Everett Jordan Lake would be eutrophic (Corps of Engineers 1976b).

At the time the models were applied to B. Everett Jordan Lake, it was recognized that the model assumptions of steady state conditions and complete mixing would be violated. It was also recognized that application of models developed from data on northern temperate lakes to southeastern reservoirs would be useful only in providing a relative comparison among "known" reservoirs.

The comparison was necessary for two reasons. The first was to bridge the gap between the model predictions and the possible manifestations of high nutrient loading in B. Everett Jordan Lake.

[1]Chief, Water Quality Section, Wilmington District

The second was to provide a reference within the experience of the public affected by the project of a reservoir which had high nutrient loadings, but unimpaired water uses.

The "known" reservoirs used for comparison were the 53 southeastern United States reservoirs in the National Eutrophication Survey (NES). Lake Jackson, Georgia, had the highest mean influent total phosphorus concentration (410 ug/l) of the 53 southeastern reservoirs in the NES (Corps of Engineers 1976b). The predicted mean influent total phosphorus concentration for B. Everett Jordan Lake (whole lake), in comparison, was 602 ug/l (table 1).

A reservoir closer to the B. Everett Jordan Lake project area and with a higher mean influent total phosphorus concentration was needed for comparison. John H. Kerr Reservoir, located in the Roanoke River Basin about 50 miles northeast of B. Everett Jordan Lake (figure 1), had a detailed and recent data base on nutrient loading and nutrients, phytoplankton and associated parameters in the water column. Although the whole lake mean influent total phosphorus concentration for John H. Kerr Reservoir was only 94 ug/l, the mean influent total phosphorus concentration for the Nutbush Creek arm of John H. Kerr Reservoir above secondary road (S.R.) 1308 was 706 ug/l, higher than the values projected for B. Everett Jordan Lake and segments I, II and III of B. Everett Jordan Lake (table 1). Consequently, the Nutbush Creek arm of John H. Kerr Reservoir above S.R. 1308 (figure 2) was used in an attempt to judge how B. Everett Jordan Lake would respond to its high nutrient load and to explain that response to the public.

The data for John H. Kerr Reservoir showed that the constrictions caused by road fills restricted circulation and contributed to the water quality gradient in the reservoir (Weiss et al 1978). This led to the division of B. Everett Jordan Lake into segments, based on road fills and the natural constriction of the New Hope River just upstream of its confluence with the Haw River, for modeling (figure 3). Weiss et al (1978) demonstrated that, during the growing season, the portions of John H. Kerr Reservoir closest to the nutrient-laden inflows had the highest values of nutrients, productivity and algal cell densities, and that values decreased with distance downstream. Furthermore, the John H. Kerr study showed that phosphorus retention in the reservoir was greater than that predicted by the Kirchner and Dillon (1975) equation (39% vs. 50% for the whole reservoir and 43% vs. 96% for the Nutbush Creek arm above SR 1308) (Weiss et al 1978).

Based on comparison with the Nutbush Creek arm of John H. Kerr Reservoir above S.R. 1308, it was concluded (summer conditions May - October) that segment IV of B. Everett Jordan Lake would support luxurious growth of algae and aquatic macrophytes; segments II and III would support algal populations indicative of highly enriched conditions, but somewhat lower than the Nutbush Creek arm of John H. Kerr Reservoir above SR 1308; and segment I would support algal populations indicative of enriched conditions, and essentially as existed in the Haw River at the time the predictions were made (Corps of Engineers 1976b).

In the District Engineer's Notice of Decision to Impound B. Everett Jordan Lake, it was acknowledged that algae blooms would occur from time to time (Corps of Engineers 1976a). The Notice indicated that algae blooms (defined as 10^6 cells per liter or 10^3 cells per milliliter) occur frequently at John H. Kerr Reservoir, "throughout the lake, including areas of intense recreation use, without significantly detracting from enjoyment of the lake." The conclusion was that except for segment IV, B. Everett Jordan Lake would be suitable for boating, primary contact recreation and raw water supply (Corps of Engineers 1976a).

Even after the litigation on the project, there were other attempts to predict how B. Everett Jordan Lake would respond to its high nutrient load using pre-impoundment data (Corps of Engineers 1981, NCDEM 1983). Phosphorus retention, spring total phosphorus and chlorophyll a were estimated (NCDEM 1983, Chapra and Tarapchak 1976, Sakamoto 1966, Dillon and Rigler 1975, Dillon and Rigler 1974). The predictions are not included in this paper for brevity, but none of the conclusions regarding the manifestations of eutrophication in B. Everett Jordan Lake changed based on the additional modeling.

POST-IMPOUNDMENT

The gates on the dam were closed to begin impoundment of B. Everett Jordan Lake in September 1981. Four years of post-impoundment data (December 1981 - November 1985) are now available for the reservoir.

The results of the pre-impoundment modeling cannot be compared to post-impoundment modeling due to differences in water years. However, measured post-impoundment phosphorus loading data can be used to predict in-lake total phosphorus and chlorophyll a and measured in-lake total phosphorus can be used to predict chlorophyll a. The predicted in-lake total phosphorus and chlorophyll a concentrations can then be compared to measured in-lake total phosphorus and chlorophyll a concentrations to determine how well the models work.

Weiss et al (1984, 1985) have used the Rast-Lee, Jones-Bachman, and Dillon-Rigler/Larsen-Mercier phosphorus loading models and chlorophyll a regression relationships to predict in-lake total phosphorus and chlorophyll a concentrations for B. Everett Jordan Lake. First, measured loading data was used to predict in-lake total phosphorus, which was then used to predict chlorophyll a. Second, measured in-lake total phosphorus was used to predict chlorophyll a. None of the models adequately predicted total phosphorus or chlorophyll a measured in B. Everett Jordan Lake (Weiss et al 1984, 1985).

The results of Weiss et al (1984, 1985) are consistent with those of Pearse (1984), who tested 8 models, including Dillon and Rigler (1974) and Jones and Bachman (1976), for predicting chlorophyll a on South Carolina lakes. None of the models tested adequately predicted chlorophyll a in the South Carolina lakes. Pearse (1984) indicated that the failure of the models on South Carolina lakes was probably due to high non-algal turbidities. However, there was no distinction between organic (e.g. algae) and inorganic (e.g. suspended sediment) turbidity in the data in Pearse's (1984) paper. Like the South Carolina lakes, B. Everett Jordan Lake is subjected to a high suspended sediment load. However, the data collected to date in the reservoir do not distinguish between organic and inorganic suspended particles.

Secchi disk depth and turbidity are indicators of suspended particles in water. Secchi disk depth is a measure of water transparency and turbidity is a measure of water clarity. Both provide an indication of the esthetic appeal of water.

Mean Secchi disk depths increased with distance downstream on the New Hope River arm of the reservoir in all four growing seasons (table 2). The lowest Secchi disk readings during the growing seasons occurred in segment IV in 1982 and in segment I in 1983, 1984, and 1985.

Mean turbidities decreased with distance downstream on the New Hope River arm of the reservoir in the 1982, 1984, and 1985 growing seasons (table 3). In the 1983 growing season, the mean turbidity for segment II was slightly higher than the mean turbidity for segment III. The highest mean turbidities occurred in segment I in the 1982, 1983, and 1984 growing seasons and in segment IV in the 1985 growing season. The highest turbidities occurred in segment I in all four growing seasons.

The Reckhow-Clements model for southeastern U.S. reservoirs was applied to B. Everett Jordan Lake (Reckhow and Clements 1984). It was used with extreme reservation because the annual mean influent total phosphorus concentrations for B. Everett Jordan Lake were higher than the maximum of the data set used to develop the model. The other characteristics of B. Everett Jordan Lake and segments I and IV were within or judged to be within the range of the data used by Reckhow and Clements (1984) to develop the model (table 4). The in-lake total phosphorus predicted by the Reckhow-Clements model did not compare well with the measured average annual total phosphorus for segments I and IV. The model overestimated the total phosphorus for segment IV and underestimated the total phosphorus for segment I. However, the in-lake total phosphorus predicted by the Reckhow-Clements model did compare well with the average annual total phosphorus measured for the whole lake (table 4). The Reckhow-Clements model predicted the whole lake average annual total phosphorus concentration for the nearby Falls Lake well also.

In 1983, the North Carolina Division of Environmental Management ranked 32 lakes in North Carolina by biomass and algal densities. B. Everett Jordan Lake had the highest biomass and algal density of the 32 lakes (ranked 32 of 32) (NCDEM 1984). In contrast, the Nutbush Creek arm of John H. Kerr Reservoir was ranked 17 of 32 by biomass and 11 of 32 by algal density. Comparison to pre-impoundment predictions is not appropriate because segments II and III of B. Everett Jordan Lake were compared to the Nutbush Creek arm of John H. Kerr Reservoir above SR 1308. DEM's 1983 data for ranking John H. Kerr Reservoir was based on a station at the mouth of the Nutbush Creek arm of John H. Kerr Reservoir, well downstream of SR 1308 (figure 2).

Measured phosphorus retention for the reservoir and phosphorus retention predicted by the Kirchner-Dillon equation are shown in table 5 (Kirchner and Dillon 1975). The Kirchner-Dillon equation underestimated phosphorus retention.

Some large patches of duckweed occurred in segment IV of the reservoir during 1982. However, segment IV has not experienced the luxurious growth of aquatic macrophytes which was predicted prior to impoundment.

Chlorophyll *a*, a characteristic algal pigment, is an indicator of algal biomass. Chlorophyll *a* means and ranges for the growing season (April 1 - November 30, which includes the recreation season of May - September) are shown in table 6. In all four growing seasons, mean chlorophyll *a* decreased in downstream direction on the New Hope River arm of the reservoir. The highest mean chlorophyll *a* occurred in segment IV in all four growing seasons. The highest growing season chlorophyll *a* concentrations occurred in segment III in 1982, segment I in 1983 and 1985, and in the Beaver Creek arm in 1984.

The North Carolina water quality standard for chlorophyll *a* is 40 ug/l. The standard is applicable from April 1 to November 30. In 1982, all growing season means exceeded 40 ug/l. In 1983, the growing season means for segment IV and the White Oak Creek arm exceeded 40 ug/l. In 1984, the growing season means for segments III and IV and the White Oak and Beaver Creek arms exceeded 40 ug/l. In 1985, the growing season mean for segment IV exceeded 40 ug/l. A summary of the chlorophyll a values which exceeded the 40 ug/l standard is shown in table 7. In the 1982 growing season, 60 percent of all chlorophyll a concentrations exceeded 40 ug/l. In the 1983 to 1985 growing seasons, chlorophyll a concentrations exceeded 40 ug/l in 32, 34, and 38 percent of the samples.

In all four years, segment I of the reservoir (Haw River arm) has had a noticeably green color, whereas the New Hope arm of the reservoir has not. The difference is attributed, at least in part, to the naturally more highly colored waters of the New Hope arm of the reservoir (Corps of Engineers 1983).

As shown in table 8, mean algal densities decreased in downstream direction on the New Hope arm in the 1982, 1983, and 1985 growing seasons. In 1984, the mean density during the growing season was slightly higher in segment III than segment II. The highest mean growing season densities occurred in segment IV in all four years. All mean growing season densities were above the 10^3 units per milliliter used to define an algae bloom. The highest densities during the growing seasons occurred in segment IV in 1982 and 1984 and in segment I in 1983 and 1985. A summary of the densities which exceeded 10^3 per milliliter during the growing season is shown in table 9. In all four growing seasons, only 4 of 488 samples had densities less than 10^3 per milliliter.

Algal densities in segment I (the Haw River arm) after impoundment have been much higher than were anticipated before impoundment. In fact, algae blooms with potential to interfere with water uses developed on the Haw River arm of the reservoir in 1982, 1983, 1984, and 1985. In May 1982, a bloom, dominated first by Anabaena felisii and then replaced by Anabaena spiroides and Aphanizomenon flos-aquae (all filamentous, mat-forming blue-green algae), occurred throughout the reservoir, and clumps of the filaments were visible to the unaided eye in the water column (Weiss et al 1984). On the Haw River arm, the filaments formed a mat of about 4 feet by 6 feet in late May. High inflows to the reservoir in late May and early June were believed to have flushed the bloom out of the reservoir (Weiss et al 1984). On August 3, 1983, the North Carolina Division of Environmental Management reported "some visible surface accumulation" near the middle of the constriction between the Haw and New Hope River arms of the reservoir, an area heavily influenced by water from the Haw River. In early July 1984, colonies of Anacystis cyanea (Microcystis aeruginosa/Polycystis aeruginosa) (coccoid, mat-forming blue-green algae) could be seen floating on or near the surface in the middle portion of the Haw River arm of the reservoir with the unaided eye (Corps of Engineers 1985). Increased inflows due to rainfall a few days after observation of this alga prevented continued buildup and possible surface mats (Corps of Engineers 1985). In June 1985, the water of the Haw River arm had a granular appearance to the unaided eye. This condition was caused by high densities of algae dominated by *Anacystis cyanea* (*Microcystis aeruginosa*/*Polycystis aeruginosa*). Densities peaked by June 21-24 and by June 26, after 2 days of strong wind mixing, densities were declining. This bloom died off even though nutrients were not limiting and there was no heavy rainfall which could cause a reservoir washout as occurred in July 1984.

CONCLUSIONS

None of the models used to predict total phosphorus and chlorophyll *a* in the reservoir from pre-impoundment nutrient loading data were accurate when used with post-impoundment nutrient loading data. Use of total phosphorus measured in the reservoir after impoundment to predict chlorophyll *a* was unsuccessful as well. The Reckhow-Clements model predicted mean annual total phosphorus for the whole reservoir well for water years 1983-1985. It appears useful for gross characterization of the reservoir. However, a model specific to B. Everett Jordan Lake will be necessary for nutrient loading management decisions.

The Kirchner-Dillon equation underestimated phosphorus retention in the reservoir as expected.

Comparison among known reservoirs showed that B. Everett Jordan Lake had the highest algal biomass and algal densities of 32 lakes in North Carolina in 1983.

As expected, chlorophyll *a* concentrations and turbidities declined and Secchi disk depths increased with distance downstream on the New Hope River arm of the reservoir in all four growing seasons. Algal densities declined with distance downstream on the New Hope River arm in 1982, 1983, and 1985.

If densities of 10^3 per milliliter are used to define an algae bloom, algae blooms occur in B. Everett Jordan Lake throughout the growing season.

So far, many of the judgments made about the manifestations of eutrophication in the reservoir prior to impoundment appear to have been reasonable. The exceptions, as stated previously, are that the Haw River arm of the reservoir has much higher algal populations than were projected and segment IV has not experienced luxurious growth of aquatic macrophytes. It appears that when algae blooms occur that interfere with recreational use of the reservoir, they are likely to occur on the Haw River arm of the reservoir before they occur on the New Hope River arm.

None of the manifestations of eutrophication have impaired recreational use of the reservoir to date (the reservoir is not being used for water supply yet). Visitation for the reservoir is shown in table 10. The figures are not indicative of expected visitation, because camping facilities at the reservoir are not open yet. Visitation at B. Everett Jordan Lake is similar to visitation at W. Kerr Scott and Philpott Lakes, fully operational reservoirs in the Wilmington District with very low potential for the problems usually associated with eutrophication.

Table 1
Vollenweider and Larsen-Mercier Models
John H. Kerr Reservoir and B. Everett Jordan Lake
(Corps of Engineers 1976b)

Lake	Mean Depth $\bar{z}$(m)	Residence Time T_w (yr)	Areal Phosphorus Loading Rate L_p (g/m^2/yr)	Measured R_p	Predicted R_{exp}	Mean Influent $[\bar{P}]$* (ug/l)
JH Kerr	9.2	0.23	3.76	0.50	0.39	94.0
JH Kerr Above SR 1308	5.1	0.16	22.50	0.96	0.43	706.0
BE Jordan	5.0	0.14	21.5	-	0.41	602.0
Segment I	6.7	0.03	113.5	-	0.08	508.0
Segment II	6.7	0.46	4.68	-	0.46	321.0
Segment III	4.0	0.25	9.74	-	0.42	609.0
Segment IV	2.1	0.13	19.18	-	0.41	1,187.0

$$*[\bar{P}] = \frac{L_p}{(\bar{z})(T_w)^{-1}}$$ (Larsen and Mercier 1975)

Table 2
Mean Secchi Disk Depth (in.)
April 1 - November 30
B. Everett Jordan Lake, NC

	1982			1983			1984			1985		
Segment	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range
IV	39	23.5	(3- 39)	17	22.2	(14-31)	16	20.2	(11- 29)	48	15.4	(9- 25)
III	61	32.5	(17- 53)	17	31.1	(20-46)	32	29.1	(14- 45)	32	28.4	(19- 37)
II	90	32.6	(16- 69)	34	31.6	(10-48)	48	32.2	(21- 47)	48	33.0	(21- 45)
I	67	29.4	(4- 66)	50	26.4	(6-49)	47	23.7	(7- 39)	48	23.4	(6- 32)
White Oak	26	35.0	(21- 54)	17	28.9	(20-40)	14	27.8	(19- 35)	30	23.9	(12- 36)
Beaver	32	35.0	(18- 59)	14	32.6	(22-44)	14	30.9	(25- 38)	30	26.3	(16- 40)
Whole Lake	315	31.2	(3- 69)	149	28.5	(6-49)	171	27.7	(7- 47)	236	24.8	(6- 45)

Table 3
Mean Turbidity (FTU)
April 1 - November 30
B. Everett Jordan Lake, NC

	1982			1983			1984			1985		
Segment	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range
IV	15	9.1	(5- 15)	17	13.9	(5- 31)	16	16.4	(6- 60)	48	17.9	(7- 33)
III	31	7.3	(4- 13)	16	8.1	(4- 15)	32	9.9	(4- 34)	29	6.6	(4- 11)
II	46	7.2	(4- 29)	34	10.8	(4- 58)	48	9.0	(4- 20)	45	6.5	(4- 13)
I	48	24.3	(3-216)	34	18.9	(4-118)	48	18.6	(4- 84)	48	15.8	(6- 83)
White Oak	15	5.5	(3- 9)	-	-	-	15	8.9	(4- 19)	30	10.6	(5- 22)
Beaver	16	6.6	(3- 13)	-	-	-	15	8.4	(4- 19)	30	9 6	(5- 20)
Whole Lake	171	12.0	(3-216)	101	13.6	(4-118)	174	12.4	(4- 84)	230	11.8	(4- 83)

Table 4
Reckhow-Clements Model
B. Everett Jordan Lake, NC

Variable	Data Set Characteristics* Minimum	Median	Maximum	B. Everett Jordan Lake WY 1983	WY 1984	WY 1985
A (km^2)	0.81	19.74	447.59	56.42**	56.42**	56.42**
$\bar{z}$ (m)	1.50	9.35	41.30	4.7**	4.7**	4.7**
T_w (yr)	0.016	0.118	1.65	0.181	0.124	0.275
L (g/m^2-yr)	0.06	4.23	93.3	9.36	12.96	7.16
q_s (m/yr)	2.30	66.65	650.20	25.97	37.90	17.09
R	-0.11	0.41	0.89	0.53	0.47	0.60
P_{in} (mg/l)	0.015	0.063	0.259	0.360	0.342	0.419
P (mg/l)	0.007	0.033	0.143	0.120	0.113	0.111
P_{pred} (mg/l)	-	-	-	0.100	0.107	0.100
P_o (mg/l)	0.007	0.040	0.145	0.143	0.154	0.155

* Table 1 from Reckhow and Clements (1984)

** At conservation pool elevation 216 ft, msl

WY = water year

P = measured average annual total phosphorus concentration in the reservoir

P_{pred} = average annual total phosphorus predicted by the model

Reckhow-Clements Model (Reckhow and Clements 1984):

$$\log P_{pred} = - 0.887 - 0.278 \log T_w + 0.717 \log P_{in}$$

Table 5
Predicted and Measured Total Phosphorus Retention
B. Everett Jordan Lake, NC

	WY 1983	WY 1984	WY 1985
Predicted*	0.45	0.40	0.49
Measured	0.53	0.47	0.60

* Kirchner-Dillon equation (Kirchner and Dillon 1975):

$$R = 0.426 \exp(-0.271 q_s) + 0.574 \exp(-0.00949 q_s)$$

WY = water year

Table 6
Mean Chlorophyll a (ug/l)
April 1 - November 30
B. Everett Jordan Lake, NC

	1982			1983			1984			1985		
Segment	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range
IV	38	108.7	(12-262)	17	49.7	(13-80)	16	57.3	(6-131)	46	61.9	(29-109)
III	59	65.6	(3-312)	17	34.4	(12-52)	32	42.6	(11-101)	32	32.2	(16- 80)
II	90	50.8	(2-211)	34	25.7	(8-53)	48	33.2	(10-129)	48	25.0	(11- 43)
I	69	49.7	(2-212)	51	29.8	(5-86)	48	27.5	(4- 69)	48	35.7	(5-113)
White Oak	26	61.1	(7-180)	17	40.1	(17-29)	15	51.5	(8-123)	30	39.4	(17- 94)
Beaver	32	62.3	(2-231)	14	29.9	(8-59)	15	56.9	(8-187)	30	35.6	(19- 68)
Whole Lake	314	62.4	(2-312)	150	32.8	(5-86)	174	39.2	(4-187)	234	38.6	(5-113)

Table 7
Growing Season (April 1 - November 30) Violations
North Carolina Water Quality Standard for Chlorophyll a
B. Everett Jordan Lake, NC

Year	n	No. of Violations	Percent Violations
1982	314	188	60
1983	150	48	32
1984	174	60	34
1985	234	88	38

Table 8
Mean Algal Density (units/ml)
April 1 - November 30
B. Everett Jordan Lake, NC

	1982			1983			1984			1985		
Segment	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range	n	$\bar{x}$	range
IV	15	54533	(3934-155238)	17	45618	(8296- 87613)	16	34702	(3565-103008)	15	67645	(32122-113966)
III	30	44573	(1497-150935)	17	35266	(7882- 78596)	16	21745	(5253- 43745)	15	45553	(11036- 87287)
II	46	31249	(1769- 91007)	34	28465	(4927- 78215)	32	22003	(7586- 54329)	30	40021	(9867-125214)
I	48	22241	(466- 64320)	34	30695	(1696- 87658)	32	20927	(2942- 65945)	32	62074	(4908-230967)
White Oak	15	33935	(1052- 83962)	-	-	-	-	-	-	14	50918	(14362- 94214)
Beaver	16	32427	(2936- 95097)	-	-	-	-	-	-	14	36839	(12693- 70333)
Whole Lake	170	33459	(466-155238)	102	33201	(1696 - 87658)	96	23717	(2942-103008)	120	50947	(4908-230967)

Table 9

Algal Densities $\geq 10^3$ per Milliliter

April 1 - November 30

B. Everett Jordan Lake, NC

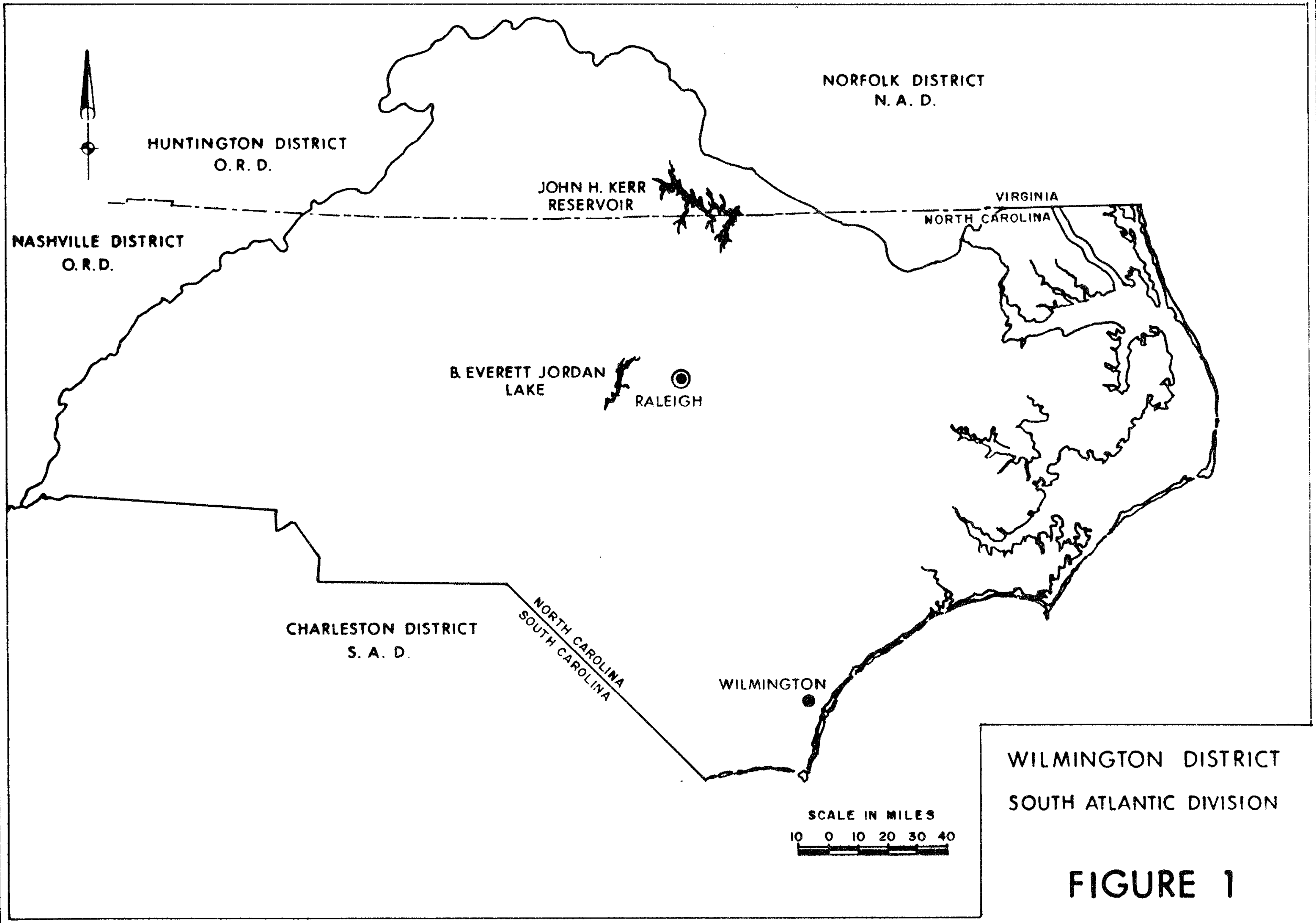
Year	n	No. $\geq 10^3$ per ml
1982	170	166
1983	102	102
1984	96	96
1985	120	120

Table 10

Annual Visitation

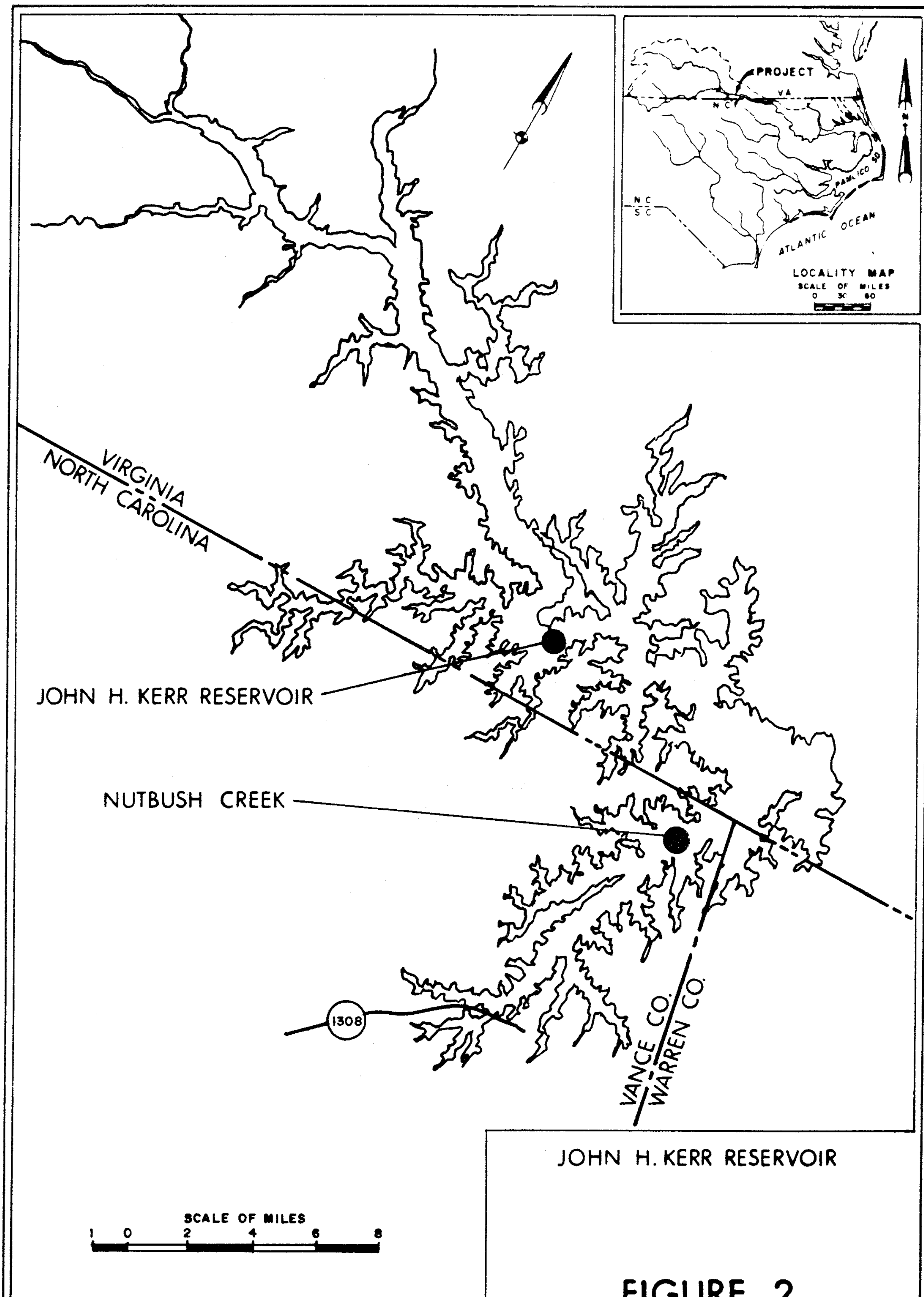
B. Everett Jordan Lake, NC

Year	Number
1982	870,000
1983	1,180,600
1984	1,194,200
1985	1,505,200



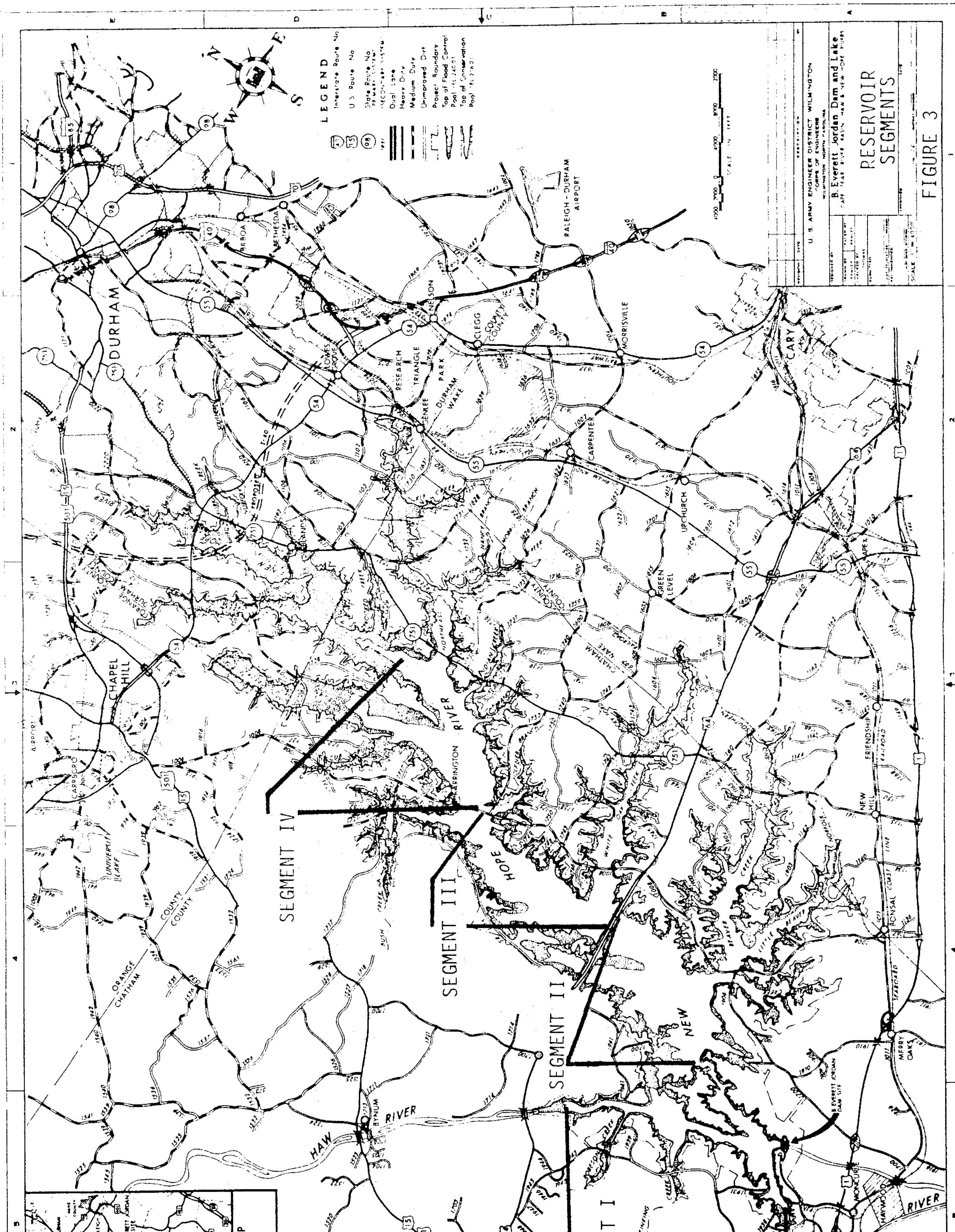
WILMINGTON DISTRICT
SOUTH ATLANTIC DIVISION

FIGURE 1



JOHN H. KERR RESERVOIR

FIGURE 2



U. S. ARMY ENGINEER DISTRICT, WILMINGTON
CORPS OF ENGINEERS
WILMINGTON, NORTH CAROLINA
B. Everett Jordan Dam and Lake
RESERVOIR SEGMENTS
FIGURE 3
LEGEND
Interstate Route No.
U.S. Route No.
State Route No.
Dual Lane
Heavy Duty
Medium Duty
Unimproved Dirt
Project Boundary
Top of Flood Control
Top of Conservation
SCALE IN FEET
RALEIGH-DURHAM AIRPORT
DURHAM
CHAPEL HILL
CARY
APEX
MORRISVILLE
RESEARCH TRIANGLE PARK
NELSON
BETHESDA
CARPENTER
UPCHURCH
GREEN LEVEL
FRIENDSHIP
NEW HILL
MERRY OAKS
MONCURE
HAYWOOD
PITTSBORO
BYNUM
UNIVERSITY LAKE
SEGMENT I
SEGMENT II
SEGMENT III
SEGMENT IV
NEW HOPE
HAW RIVER
DEEP RIVER
ORANGE
CHATHAM
DURHAM
WAKE
LEE COUNTY
VICINITY MAP
SCALE IN MILES

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SUCCESSFUL BRIDGING BETWEEN THEORY AND APPLICATION IN SELECTIVE WITHDRAWAL DESIGN AND OPERATION

Richard A. Cassidy

INTRODUCTION

The Rogue River Basin Project can be used as a case study to show how theory and applied research in civil engineering and environmental science have improved the design of outlet works, and have thereby improved the usefulness of the water released from dams. Use of selective withdrawal outlet works, a relatively new water resources application, has helped to reduce the negative environmental impacts of dams on the Rogue River system.

The Rogue River Basin Project of southwestern Oregon consists of Lost Creek Lake (completed in 1977), Applegate Lake (completed in 1981), and Elk Creek Lake (currently under construction). They are a system of multiple purpose dam projects that have reservoirs authorized for flood control, irrigation, hydropower, fish and wildlife enhancement, water supply, and water quality. Lost Creek Dam has single wet well outlet works while the Applegate Dam has a double wet well structure. The Elk Creek selective withdrawal structure is currently being physically modeled with a single wet well.

Pre-construction selective withdrawal research for the Rogue River Project, during the design phases, consisted of both Corps and non-corps research efforts. Corps research included physical and numerical modeling; non-corps research included numerical modeling and fisheries research. Physical models were built, and studies were performed, by the North Pacific Division (NPD) Hydraulic Laboratory and the Waterways Experiment Station (WES) Hydraulics Laboratory. Corps numerical modeling included use of the Hydraulics Laboratory WESTEX model. Non-corps numerical modeling included using the Water Resources Engineers, Incorporated temperature model. Fisheries research included studies by the Oregon Department of Fish and Wildlife (ODFW) to investigate Rogue River salmon and steelhead population dynamics downstream of Corps projects, and an analysis of downstream sport fisheries changes.

Following construction, the operation of the projects has also included the use of research products developed by the Corps and by others. The WES (Hydraulics Laboratory) has performed physical model studies to assist the Portland District in evaluating operating guidelines for Lost Creek Lake. The Portland District has also used numerical models developed by the Corps' Hydrologic Engineering Center such as HEC-5 and the Stochastic Analysis of Drought Phenomena for operational studies. The WES (Environmental Laboratory) has used a U.S. Environmental Protection Agency numerical model called QUAL II to evaluate the downstream water temperature impacts of the individual Rogue Basin projects for the Portland District. Also, based upon ODFW fisheries research, the Portland District has modified the original target water temperatures to be released from the projects, and concomitantly the regulation practices of the projects.

Chief, Reservoir Regulation and Water Quality Section, Portland District, U.S. Army Corps of Engineers.

The Portland District has played an active role in field research efforts at the Rogue River Basin projects. Empirical studies, such as determining the hypolimnetic dissolved oxygen consumption rates at each new reservoir, provide the Corps research laboratories with important scientific documentation about limnological changes that have occurred at new reservoirs with selective withdrawal capability.

Technical transfer of information, therefore, becomes two-way communication. Communication concerning theory and applied research comes from the Corps research laboratories. Corps field offices (districts or divisions) comment, suggest modifications, and fund applied research during the design and construction phases of the projects. Further applied research can be performed by the research laboratories during the operational phases of the projects to assist districts and divisions in solving regulation problems. Empirical studies by the field offices, in turn, can lead to the extension of theories or affect the creation of new theories by the research laboratories.

DISCUSSION

Lost Creek Lake

Physical and numerical modeling have a complex history at Lost Creek Lake. The NPD Hydraulic Laboratory performed physical modeling from 1969 through 1975, with most of the work being performed in 1971 and 1972. Physical model studies of the outlet works started before dam construction and continued during the construction period. One of the purposes of the physical modeling was to investigate the hydraulics of the selective withdrawal intake by examining the characteristics of flow as water was drawn into the penstock. The physical model studies of the 1:40 scale intake tower established the basic zones of withdrawal and showed that no change in the basic tower design was necessary.

Physical modeling was also utilized for operational studies in the mid-1980s. Based on fisheries research in the Rogue River by ODFW, the Portland District was requested to investigate the possibility of changing the fall season regulation schedule to reduce accelerated spring chinook salmon egg development downstream of the project. A physical model of the single wet well selective withdrawal structure was constructed by the WES Hydraulics Laboratory in 1984 to evaluate various regulation scenarios. This study is still underway at the WES Hydraulics Laboratory.

Numerical modeling of Lost Creek Lake began with water temperature and turbidity studies in the early 1970s. Two numerical models were used to evaluate the impact of selective withdrawal releases on the reservoir. The Water Resources Engineers, Incorporated model was used to characterize water temperatures in the reservoir. The WESTEX model was used to characterize the turbidity regime in the reservoir. The results of both numerical models were presented in a district report entitled Rogue River Basin Water Temperature and Turbidity Report, dated July 1974. The report also discussed another proposed reservoir, the neighboring Elk Creek Lake project.

The WES Hydraulics Laboratory will be using the WESTEX model for the Portland District through FY 1986 as the second part of the 1984 operational study mentioned previously. A dynamic option will be used to help determine the best seasonal regulation scheme in the late summer to provide as cool a turnover water temperature as possible in the reservoir.

Non-corps research has also had a significant affect on reservoir regulation practices for Lost Creek Lake. Since 1974, the Portland District has funded the Oregon Department of Fish and Wildlife to evaluate the effects of the Rogue River Basin projects on the salmonid and steelhead fisheries of the basin and to develop regulation recommendations to provide benefits, as authorized for the projects. Target release water temperatures from Lost Creek Lake were originally established at 45oF (7.2 oC) for much of the summer period. Based on ODFW research, new target release water temperatures more closely resembling natural (pre-project) water temperatures were recommended.

The ODFW research efforts have resulted in the Lost Creek Phase I Completion Report (August 1985). A portion of the report contained a mathematical regression model for optimization of spring chinook salmon production based on Lost Creek Dam regulation. However, the water temperature portion of the multiple regression model was found to be unsatisfactory. Consequently, the Portland District requested that the WES Environmental Laboratory apply a U.S. Environmental Protection Agency numerical model, called QUAL II, to predict the downstream water temperature effects of Lost Creek Lake regulation practices. Future studies will also include QUAL II modeling of the Applegate Lake project.

Recently, the Portland District has begun using another Corps research product developed by the Hydrologic Engineering Center called HEC-5. The Portland District has been using the numerical model to provide a systems evaluation of various water release scenarios from Lost Creek and Applegate Lakes on the Rogue River. Every spring season, the Portland District holds a public information meeting to discuss probable regulation plans for the upcoming summer and fall seasons. The meeting involves coordinating with Federal fisheries agencies, a state water resources agency, a state fisheries agency, county agencies, and special interest groups. The use of HEC-5 allows the Portland District to quickly evaluate important water stage changes at various key locations along the Rogue River under different regulation schemes.

The Portland District has been monitoring the water quality characteristics at Lost Creek Lake since completion of dam construction and filling of the reservoir in 1977. The results of these empirical studies have been presented in district specialty reports, Corps annual reports, and published in the proceedings of international conferences. For instance, the district has documented the hypolimnetic dissolved oxygen consumption rate of Lost Creek Lake when the soils were newly inundated. The district has documented the water quality changes in the reservoir during the maturing process. This type of district documentation of empirical studies could lead to new questions at the Corps research level.

Applegate Lake

Like at the Lost Creek Lake project, the Portland District has used several research products associated with physical and numerical modeling at the Applegate Lake project. Physical model studies were performed by the NPD Hydraulic Laboratory in the late 1970s and early 1980s on the regulation outlet conduit. Although the modeling involved mostly hydraulic considerations, there were water quality implications associated with the design of the outlet works. The conduits from the dual wet well selective withdrawal structure were designed to merge with the regulating outlet that transport flood flows. Physical model studies were needed to determine whether full flow in the transition zone would occur. Design of the conduit successfully accommodated both high flow conditions during flood releases and water quality releases during relatively low flow situations.

The proposed Applegate Lake was the first of the Rogue River Basin projects that had numerical modeling studies performed. The Portland District contracted with Water Resources Engineers, Incorporated in 1969 to apply their water temperature model to determine the selective withdrawal port elevation locations. Like at Lost Creek Lake, fisheries research efforts by ODFW provided new release water temperature guidelines for the Applegate River. The dual wet well selective withdrawal structure at Applegate Lake also proved to be versatile enough to be able to accommodate a new set of target release water temperature goals that were recommended following construction. Water temperatures in the downstream Applegate River could not only be controlled for the existing spring chinook salmon fishery but also could be used to help establish a new fall chinook salmon fishery that previously did not exist.

The Portland District has also used Hydrologic Engineering Center research products to help regulate the releases from Applegate Lake. As was mentioned in discussing Lost Creek Lake, the HEC-5 numerical systems model has recently been used to evaluate various water release scenarios from the two reservoirs. Because of drought-like conditions during the winter of 1985-86, the Portland District also worked closely with HEC to use their Stochastic Analysis of Drought Phenomena model to help make conservation releases throughout the critical period.

The Portland District has also performed empirical water quality studies at Applegate Lake since project completion in 1981. Characterization of the water quality changes in this new reservoir will help provide some guidance for future research at a Corps-wide level. The empirical studies at Applegate Lake also have been presented in district specialty reports, Corps annual reports, and published in the proceedings of international conferences.

Elk Creek Lake

The Elk Creek Lake project has been the most controversial of the three Rogue River Basin projects. Construction of the project was stopped in 1975 because of water quality concerns. Elk Creek Lake is currently under construction and is scheduled for completion in September 1989.

The two major water quality concerns at the future Elk Creek Lake have been water temperature and turbidity. Following completion of an Environmental Impact Statement in 1971, these two issues were re-evaluated in the Portland District report entitled Rogue River Basin Water Temperature and Turbidity Report, dated July 1974. Because of a controversy over the soil conditions in the Elk Creek Basin and a lack of confidence in the WESTEX model by local and regional interests, a draft supplemental Environmental Impact Statement was not issued by the Portland District until 1975. After further study of the controversial environmental conditions, the Governor of Oregon withdrew the state's support of the project and requested that work be suspended until the effects of Lost Creek Lake on the Rogue River could be evaluated. After studying the actual water quality effects of Lost Creek Lake and verifying the WESTEX numerical model with actual Lost Creek Lake data, the Portland District prepared another supplemental Environmental Impact Statement that was finalized in 1980.

In 1982, additional WESTEX modeling was performed to evaluate the affect of probable new target release water temperatures. As a result of the ODFW fisheries research studies performed in the Rogue River, the 1974 target release temperatures for the proposed project were no longer considered valid. The 1982, water quality studies, using new target temperatures, were performed as part of the overall redesign of the dam's structure to a concrete dam, spillway, and outlet works. An Environmental Assessment and a Finding of No Significant Impact were completed in 1983 on the new design changes.

As part of the redesign effort, the Portland District engaged the WES Hydraulics Laboratory to perform a 1:20 scale physical model of the single wet well selective withdrawal structure. The physical model study began in 1985 and it will evaluate the mixing characteristics and the potential for hydraulic blockage when water is withdrawn from more than one level in the single wet well.

In 1985, the Oregon Natural Resources Council, and others, filed a lawsuit in the Oregon District Court to stop construction of the Elk Creek Dam project. They claimed that the Corps should prepare another supplemental Environmental Impact Statement because there was significant new information relevant to the environmental concerns. The Portland District engaged the WES Environmental Laboratory to modify the existing QUAL II modeling study of the effects of Lost Creek Lake on the Rogue River to include some evaluations of the proposed Elk Creek Lake. The QUAL II modeling results were used to support the Corps position in court. In January 1986, the District Court ruled that the Corps clearly demonstrated compliance with the National Environmental Policy Act in the development and the design of the Elk Creek Dam project.

CONCLUSION

Water resources development associated with the construction of Corps dams in the Rogue River Basin of southwestern Oregon during the 1970s and 1980s occurred because there was successful bridging between theory and application in selective withdrawal design and operation. The success reduced the negative environmental impacts of dams on the river system.

Corps-wide research efforts in selective withdrawal technology, including physical and numerical modeling, coupled with non-corps research in numerical modeling and fisheries studies have been successfully applied to overcome significant environmental issues. Successful water resources development in the Rogue River Basin has been due, to a large degree, to the two-way communication between the Corps research laboratories and the Corps field offices.

FIELD EXPERIENCE WITH SKIMMING WEIRS
IN THE KANSAS CITY DISTRICT

By

Walter M. Linder[1]

INTRODUCTION

Skimming weirs are being used by the Kansas City District to achieve selective withdrawal of the warmer, well oxygenated surface waters of stratified lakes. In each case the skimming weir was not included in the initial design, but was added in response to water quality problems that surfaced during the final phases of construction. This paper describes the events that led to the construction of skimming weirs at two lakes with hydropower installations. Field data show the weirs to be effective in limiting the release of cold deoxygenated water from the hypolimnion over a significant range of pool elevations and discharge rates.

STOCKTON DAM AND LAKE

Stockton Dam, a multipurpose project located on the Sac River in south-western Missouri, Figure 1, controls a drainage area of 1,160 square miles. The multipurpose pool volume of 875,000 acre feet (AF) has a corresponding surface area of 24,900 acres. The depth from the top of the multipurpose pool to the valley floor is slightly less than 90 feet (ft). The power facility consists of a single Kaplan turbine capable of discharging 11,000 cubic feet per second (cfs) at maximum drawdown of the power pool. However, downstream channel capacity limits the maximum release to 8,000 cfs.

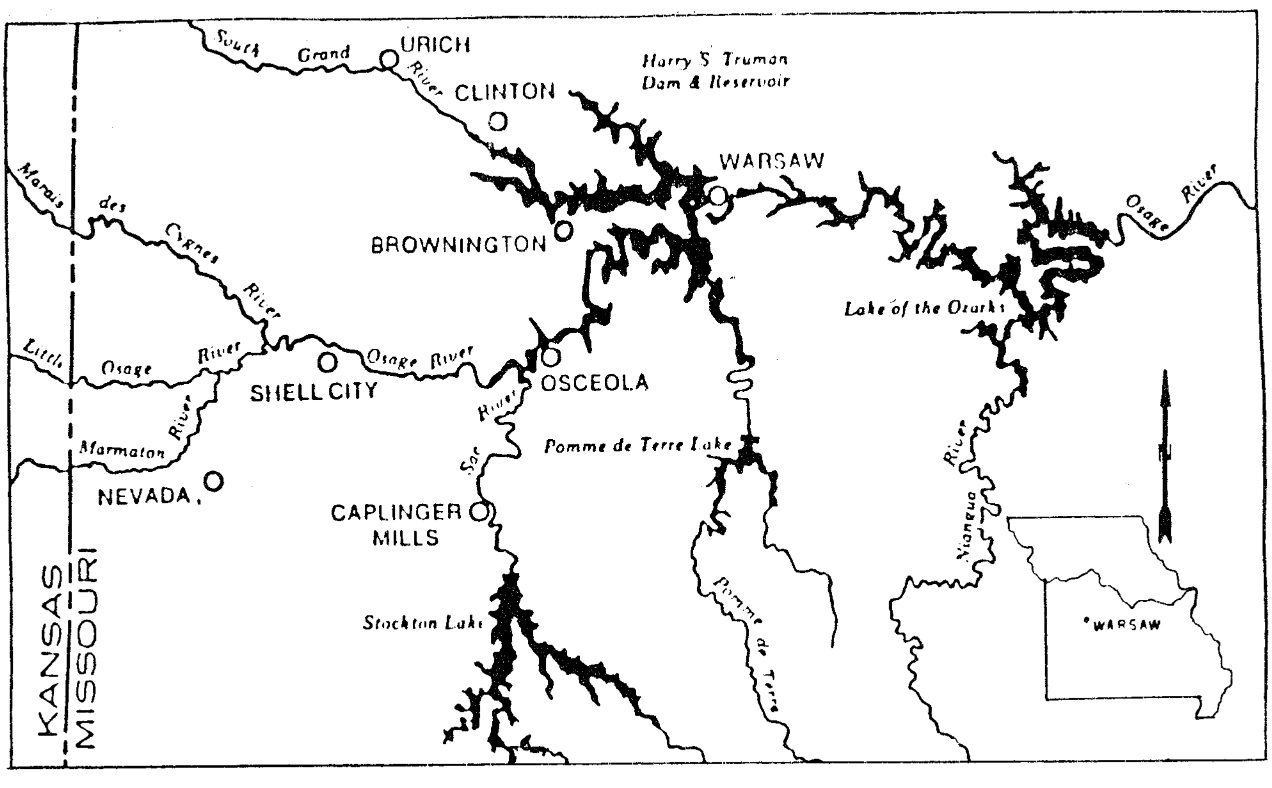

Figure 1 - Area Map

[1]Chief, Hydrologic Engineering Branch, U.S. Army Corps of Engineers, Kansas City District

The plant is operated as a peaking power facility with the frequency and duration of generation dependent upon power demands and pool elevations. Generation may vary from a few hours several times a day when the lake level is within the power pool to 24-hours a day during flood control releases. Discharges are normally between 5,000 and 8,000 cfs, with releases of 40 cfs during non-generation periods. Both the low flow and power intakes are located at the bottom of the lake.

Stockton Water Quality Problems

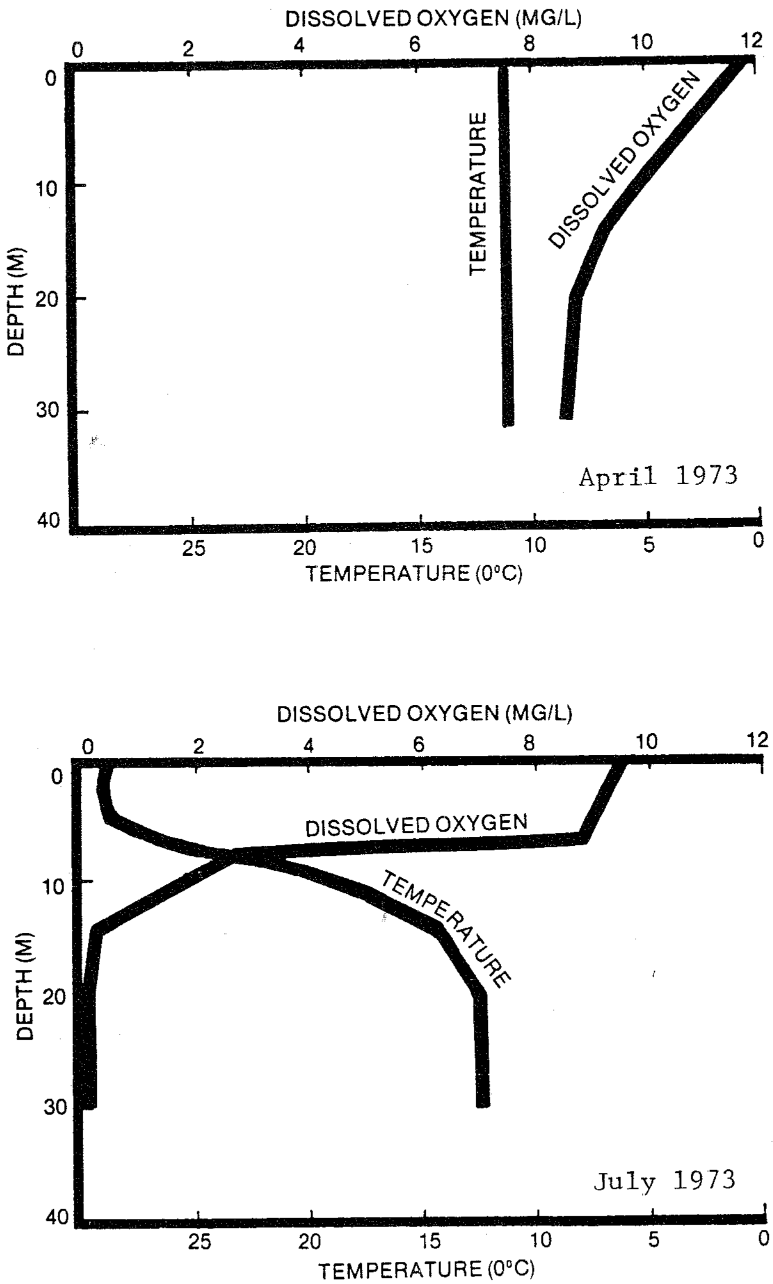

Figure 2 - Stockton Lake Temperature and Dissolved Oxygen Profiles

Although preimpoundment surveys were made, the studies concentrated on existing conditions and did not make an analysis of the probability of thermal stratification in the lake. Impoundment of the lake began in December 1969 and stratification was first documented in June of 1970. A significant downstream fish kill occurred as a result of low water temperature and low dissolved oxygen (DO) concentrations during low flow releases in July 1970 prior to the lake reaching multipurpose level. Odor and pH levels were also in violation of Missouri State water quality standards which specify that the water temperature should not vary more than 5°F from normal seasonal levels and DO should be above 5 milligrams per liter (mg/l). Figure 2 illustrates the stratification that develops in Stockton Lake. A solution to the problem had to be found since power generation with much larger releases was scheduled to begin in 1973.

Stockton Lake Skimming Weir

Among the various alternatives considered, the most cost effective solution was construction of a skimming weir across the approach channel to the powerhouse. Thermal modeling was used to evaluate various weir crest elevations. The optimum elevation was found to be 840 ft, mean sea level (m.s.l.), or 27 ft below the multipurpose pool level of 867 ft, m.s.l. Thermal modeling of a range of pool elevations showed release temperature criterion would be met except during the fall when releases would be somewhat warmer than natural stream temperatures. There would also be a brief period in the spring when releases would be slightly colder than natural stream temperatures.

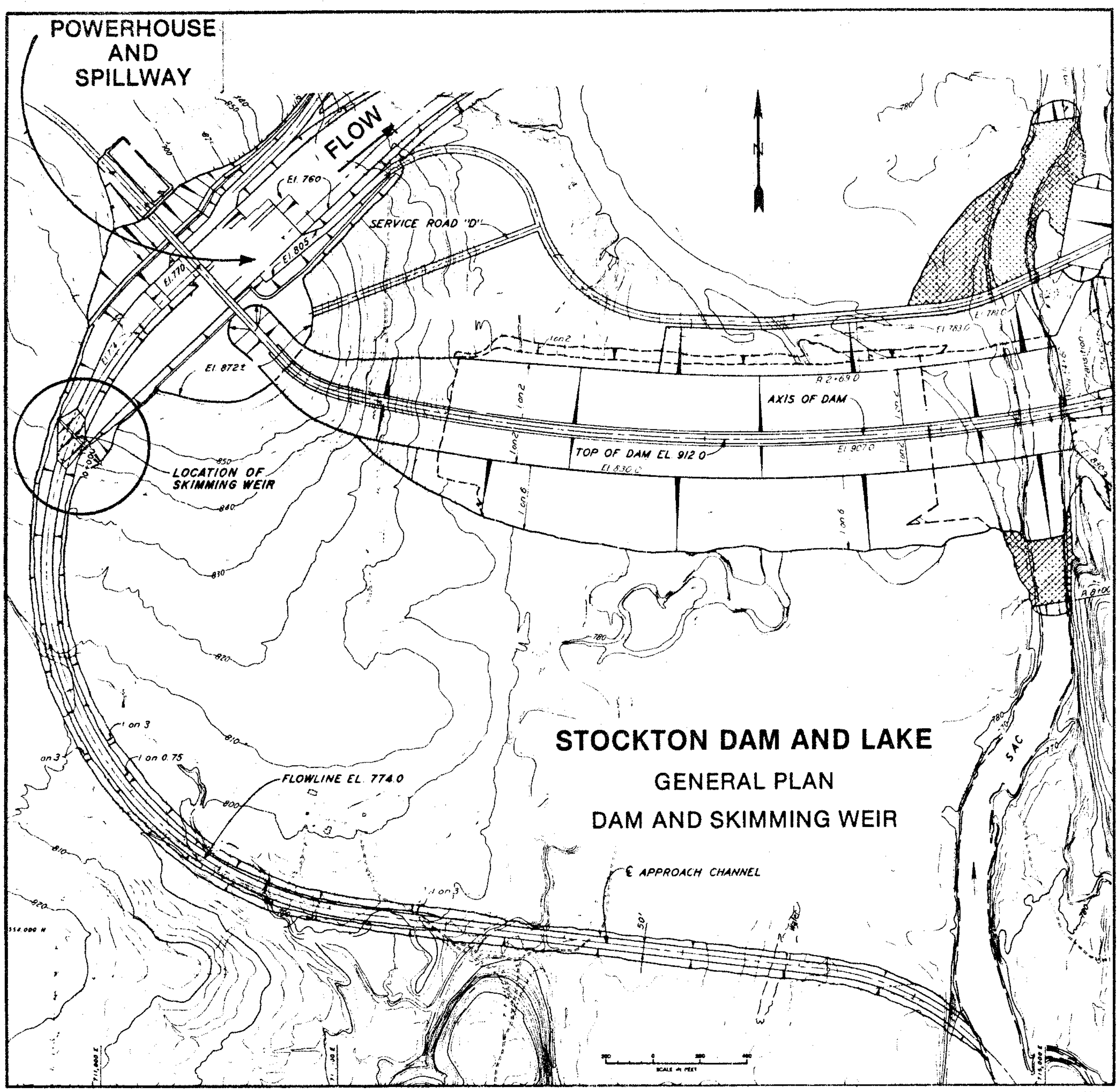

Figure 3 - Stockton Lake General Plan Dam and Skimming Weir

A 66 ft high rock filled, broad crested weir was constructed in the spring of 1973 at a location approximately 1,000 ft upstream of the powerhouse and spillway structure, Figure 3. Rock was obtained from a lakeside quarry, barged to the site, and dumped in place. The 260 ft long, 5 ft wide crest ties to natural ground elevations on both sides of the approach channel.

Skimming Weir Performance

The crest of a skimming weir should be placed well above the expected thermocline elevation in order to minimize withdrawal of hypolimnetic water over the weir. However, at Stockton the weir crest had to be placed low enough to provide for adequate drawdown of the power pool. With the weir crest at elevation 840, drawdown of the power pool is limited to about 845 ft, m.s.l., instead of 838 ft, m.s.l., the original bottom of the power pool. This somewhat reduces the number of hours of generation available during critical drought years.

The skimming weir at Stockton has been successful in meeting the adopted release criteria. Figure 4 shows dissolved oxygen and temperature profiles obtained during power generation in August of 1973 shortly after completing construction of the skimming weir. Upstream of the weir the lake was highly stratified with little or no dissolved oxygen below about 10 meters of depth (33 ft). Between the weir and the powerhouse the water temperature was nearly isothermal at about 25 degrees Centigrade. The DO concentration was about 8 mg/l in the upper 15 meters (49 ft) of the water column and then decreased to about 4 mg/l near the bottom.

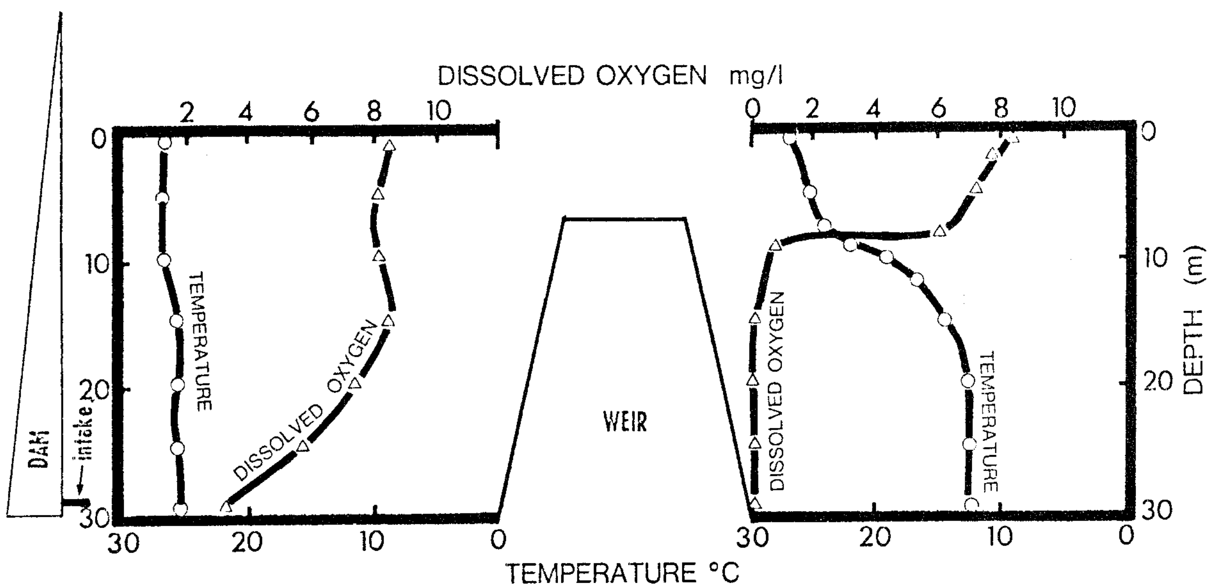

Figure 4 - Stockton Lake Temperature and Dissolved Oxygen Profiles During Generation August 27, 1973

Restratification can develop between the weir and the powerhouse, resulting in brief periods of low downstream DO concentrations at the start of generation. If generation occurs on a frequent basis, there is insufficient time for restratification to develop between the weir and powerhouse. However, if there is a longer period of time, such as a week or more, between generation cycles, restratification may occur and result in depressed downstream DO levels at the start of the power generation cycle. There are also occasions when the thermocline is slightly above the weir crest and some of the hypolimnetic water is drawn over the weir during generation. This also results in lowered downstream DO levels. However, due to mixing, the downstream DO concentrations generally range from 5 to 6 mg/l. The lowest downstream DO levels that have been observed have been in the 4.0 to 4.5 mg/l range. This indicates the weir is effective in preventing the release of water with little or no dissolved oxygen which would occur without the weir. The problem of restratification between the weir and the powerhouse also seems to be diminishing with time.

HARRY S. TRUMAN DAM AND RESERVOIR

Harry S. Truman Dam, a multipurpose project located in west-central Missouri on the Osage River, Figure 1, includes facilities for pump storage and power generation. The Lake of the Ozarks, which is created by Bagnell Dam and forms the tailwater of Truman Dam, is an extremely popular midwestern recreation area. Its shoreline is crowded with both permanent and vacation homes, boat docks, resorts, and commercial marinas, and includes the city of Warsaw, Missouri, located about 1½ miles below Truman Dam. An excellent warm water fishery has developed in the tailwaters of Truman Dam.

The project controls 11,500 square miles of drainage area, of which approximately 1,600 square miles are controlled by five upstream reservoirs. The storage capacity at the multipurpose pool elevation of 706 ft, m.s.l., is 1,040,000 AF with a surface area of 55,600 acres. Depth to the average valley floor, elevation 660 ft, m.s.l., at the dam, is 46 ft. The depth to the invert of the power intakes at elevation 603 ft, m.s.l., is 103 ft. The powerplant at Truman Dam consists of six reversible slant type pump turbines. Discharge from power generation can be as high as 65,000 cfs and 27,500 cfs can be discharged in the upstream direction during pumping operations. Only a 2 ft increment of storage, elevation 706 to 704 ft, m.s.l., was specifically provided for power purposes, since the intent was to rely on pumpback for maintaining the power pool. Large fish kills during pumpback testing resulted in a moratorium on pumping until technology for adequate fish protection becomes available.

Harry S. Truman Water Quality Problems

Thermal simulations of the Harry S. Truman Reservoir were conducted in the early 1970s to predict the degree of thermal stratification in the reservoir and the effect of power releases and pumpback on downstream water temperatures. These studies assumed no excavated channel between the river and the powerplant intake and the natural overbank would function as a broad crested weir. Results of these simulations for an average runoff year are shown on Figure 5.

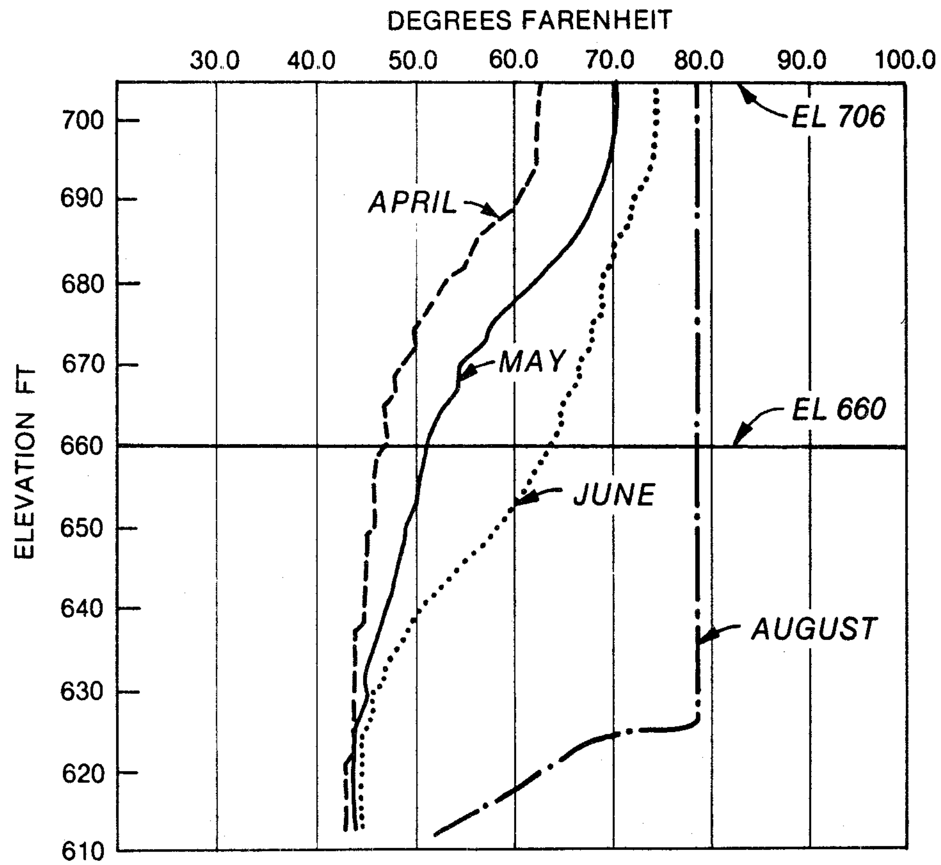

Figure 5 - Harry S. Truman Reservoir Results of Thermal Simulations for Average Runoff Year

Conclusions reached were as follows:

a. The reservoir would be essentially isothermal above elevation 660 ft, m.s.l., by the first week of August during most years.

b. The reservoir would not have a well-defined thermocline. Instead there would be a more gradual change of temperature with respect to depth below the water surface.

c. During the spring months releases would be cooler than natural stream temperature. During most of the summer release temperatures would be nearly the same as natural conditions, and during late summer and early fall release temperatures would be warmer than natural stream temperatures.

d. Due to the shallow temperature profile above elevation 660 ft, m.s.l., and the hydraulics of the flow over the assumed natural weir, most of the outflow from the reservoir would come from above elevation 660 ft, m.s.l.

e. There would be very little change in the thermal structure of the downstream Lake of the Ozarks.

Several higher weir crest elevations were investigated, but it was found there would be no significant improvement in downstream water quality.

The embankment was closed in July 1977 and flows diverted through the uncompleted spillway structure which had a top elevation of 660 ft, m.s.l., at that time. Raising the spillway started in the fall of 1978, and the final crest elevation of 692.3 ft was attained in October 1979. The multipurpose pool elevation of 706 ft, m.s.l., was reached in November 1979.

Temperature and DO profiles obtained in 1978 and 1979 at a location about 1 mile upstream of the dam showed stratification with severely depleted DO levels well above elevation 660 ft, m.s.l. In July 1979 when the lake level was approximately 689 ft, m.s.l., essentially anoxic conditions existed below elevation 676 ft, m.s.l., while the temperature gradient was nearly uniform from about 28°Centigrade (C) at the surface to 17°C at the bottom. Figure 6 presents temperature and DO profiles obtained in May, June, and July 1979.

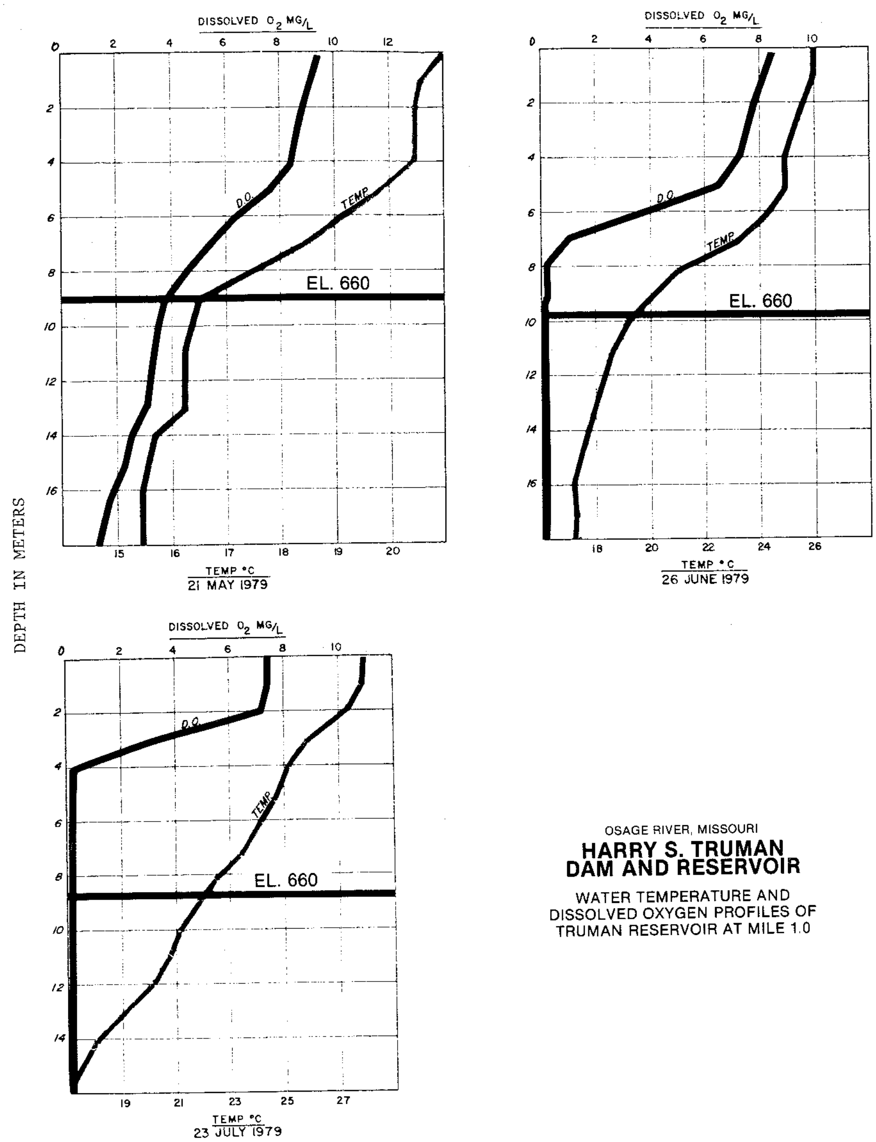

Figure 6 - Temperature and Dissolved Oxygen Profiles,
Harry S. Truman Reservoir, May, June, and July 1979

It is also interesting to note that these profiles show the oxycline lying well above the thermocline. This illustrates that very low oxygen levels and anaerobic conditions can exist with a weakly stratified lake. A comparison of the temperature profiles in Figures 5 and 6 shows observed water temperatures were generally warmer than predicted by the thermal model. From the observed conditions it was clear some method was needed to prevent the release of water with low DO levels during power generation at Harry S. Truman Dam.

Harry S. Truman Skimming Weir

The embankment closure section was located adjacent to the left abutment, while suitable borrow material was located at the right side of the valley upstream of the dam. The contractor constructed a haul road across the valley just upstream of the dam to transport the fill material to the closure section. The haul road was constructed to elevation 703 ft, m.s.l., well above pool levels expected during completion of the dam embankment. A bridge was used to span the approach channel to the uncompleted powerhouse and spillway. It was intended the contractor would remove the bridge and degrade the haul road as much as possible after completion of the embankment.

When it became apparent some means of selective withdrawal would be required, it was decided to partially degrade the haul road and let it function as a skimming weir. Evaluation of actual temperature and DO profile data indicated the weir crest should be about 20 ft below the multipurpose power pool, or at elevation 686 ft, m.s.l. However, delays in construction and a rapidly rising pool prevented degrading the haul road below elevation 693 ft, m.s.l. The bridge was removed and the opening filled by dumping quarried rock from barges. Operating experience has shown the higher weir crest provides better selective withdrawal than would have occurred at the lower elevation. Figure 7 shows a plan view of the dam and the upstream haul road converted to a skimming weir.

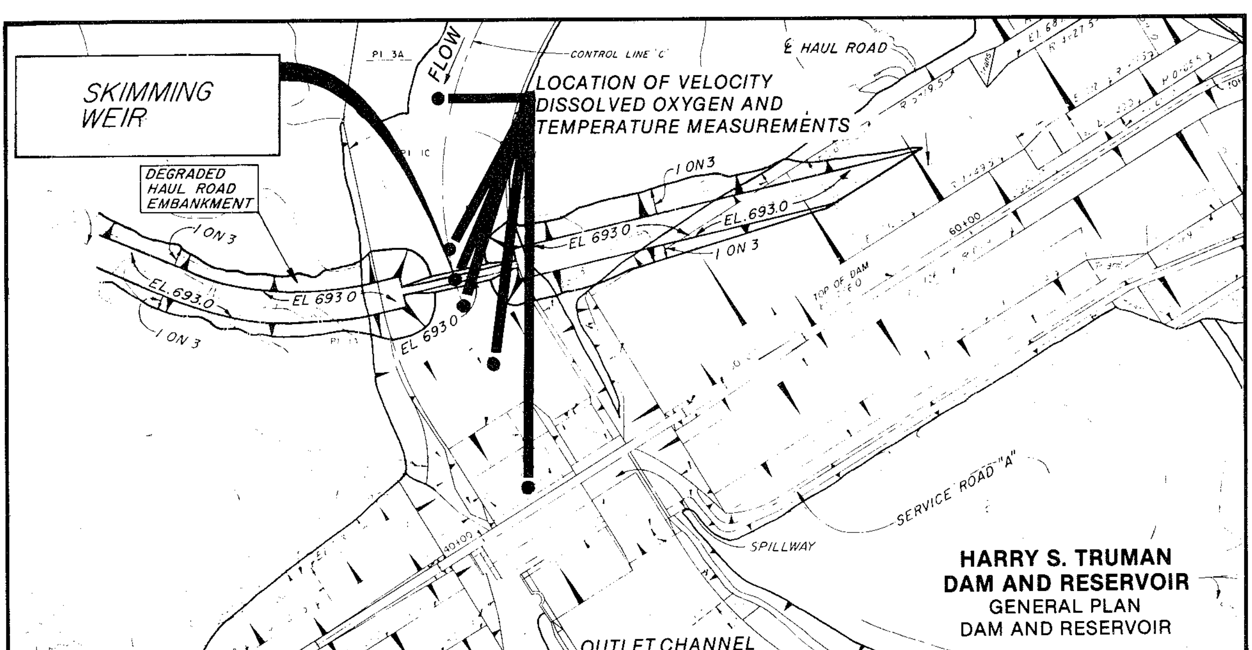

Figure 7 - Plan View of Harry S. Truman Dam and Upstream Skimming Weir

Skimming Weir Performance

Field data show the skimming weir is effective in limiting the release of water with a low dissolved oxygen content during periods of lake stratification. Temperature, DO, and vertical velocity profile data have been collected in the upstream lake, the vicinity of the weir, and near the powerhouse spillway structure under a variety of flow conditions and lake elevations. Figure 7 shows the locations of data collection near the weir and powerhouse. Data have been obtained with one through 5 power units in operation. On several occasions flow conditions changed during the measurement period in spite of efforts to coordinate with the power marketing agency and powerplant operators. However, even with changing flow conditions, the data show only minimal amounts of water drawn from below the oxycline.

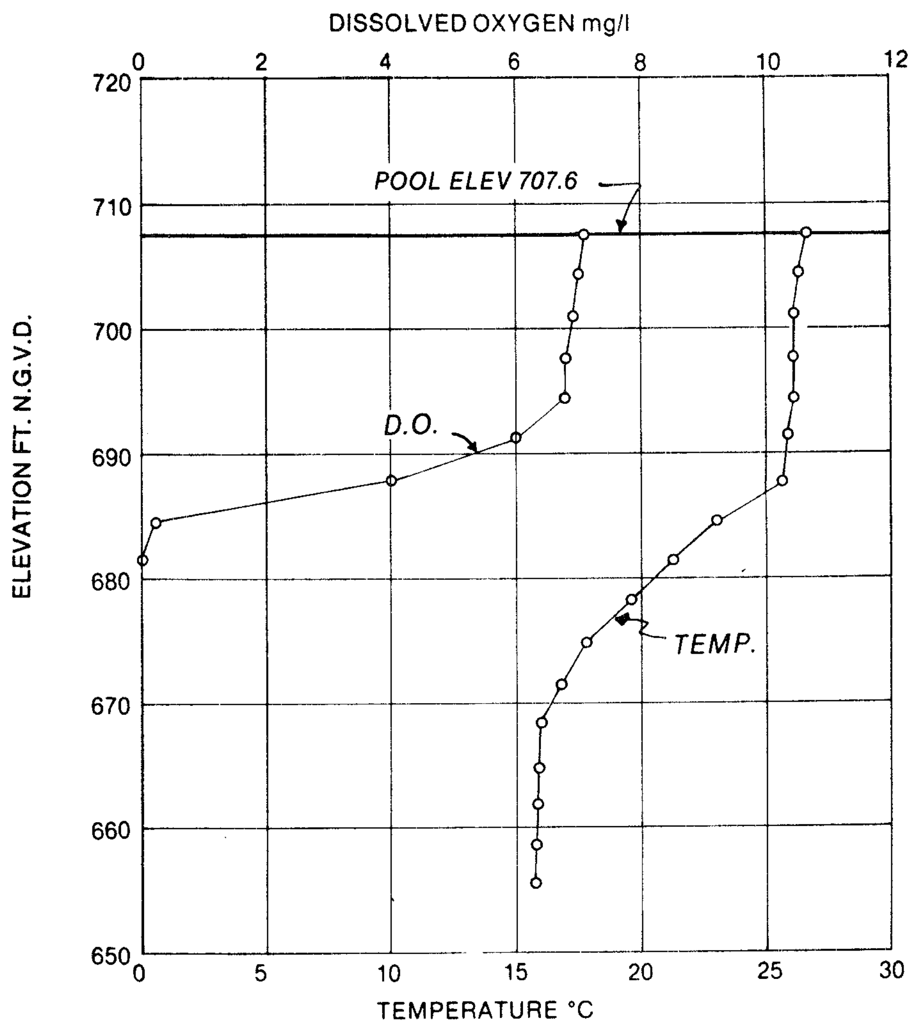

Figure 8 - Dissolved Oxygen and Temperature Profiles 11 August 1981, Harry S. Truman Reservoir 1 Mile Above The Dam

The first power unit had just been placed in operation and was undergoing testing in August 1981. The lake was 1.6 ft above the multipurpose pool level and was stratified. Figure 8 shows temperature and dissolved oxygen profiles obtained August 11, 1981 about 1 mile upstream of the dam. Contrary to the thermal simulations which indicated the thermocline should be below elevation 660 ft, m.s.l., it was nearly 30 ft above that elevation. The oxycline was even higher and very near the elevation of the weir crest.

Figure 9 shows temperature and DO profiles at the weir crest and about midway between the weir and the powerhouse with one unit discharging approximately 7,400 cfs. Measurements at the weir crest found DO concentrations varied from 7.1 mg/l at the surface to slightly less than 4 mg/l a few feet above the weir crest, indicating some withdrawal of water from below the oxycline. Midway between the weir and the powerhouse, mixing occurred and the temperature and DO were nearly constant from top to bottom. Data obtained in the downstream discharge channel earlier in the day showed DO levels varying from 5.6 mg/l at the surface to 5.3 mg/l at the bottom.

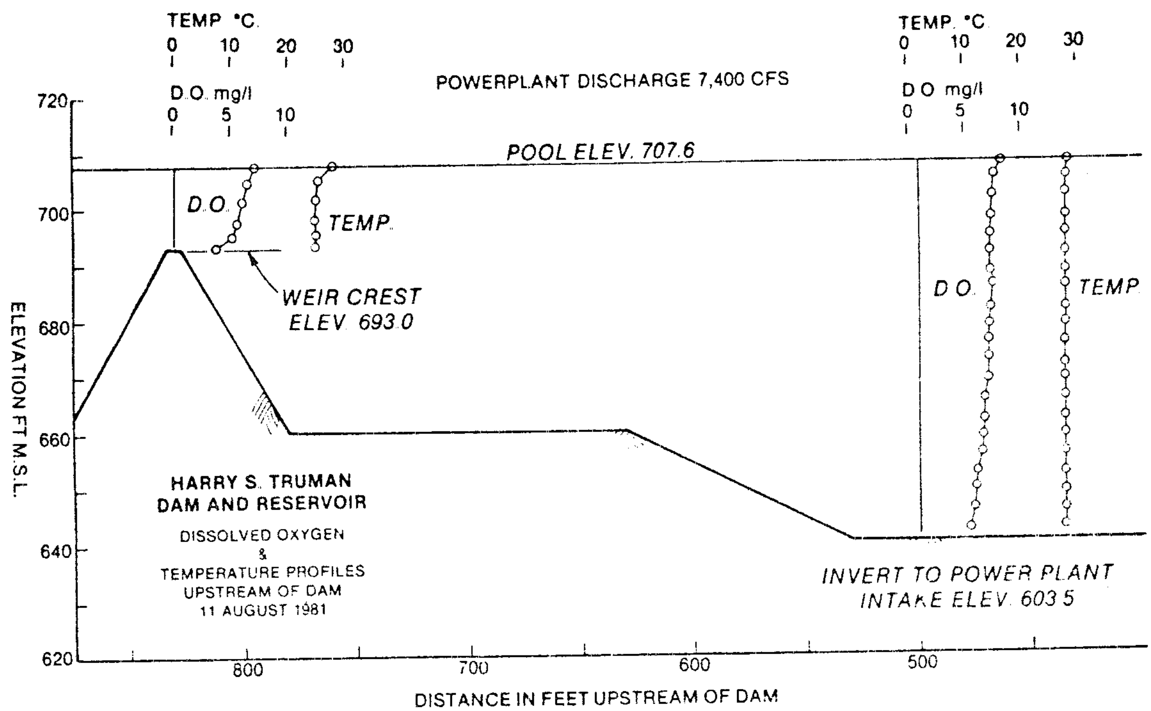

Figure 9 - Dissolved Oxygen and Temperature Profiles With One Power Unit Operating

A second set of measurements were made on June 13, 1983 with four power units in operation and discharging approximately 30,600 cfs. An additional 1,300 cfs was being released from the spillway as high inflows had raised the pool to elevation 715.6 ft, m.s.l. Figure 10 shows conditions that existed 1 mile upstream of the dam. A weak thermocline had developed at about elevation 685 ft, m.s.l. A much stronger oxycline also existed at the same location.

Figure 11 shows DO and temperature profiles at the weir and near the upstream face of the powerhouse. DO concentrations at the weir crest were about 7 mg/l in the upper 14 ft of the water column and then declined to about 1 mg/l just above the weir crest, again indicating some withdrawal of water from below the oxycline. Midway between the weir and the powerhouse, DO levels were about 7 mg/l to about elevation 670 ft, m.s.l., and then declined. Water temperature

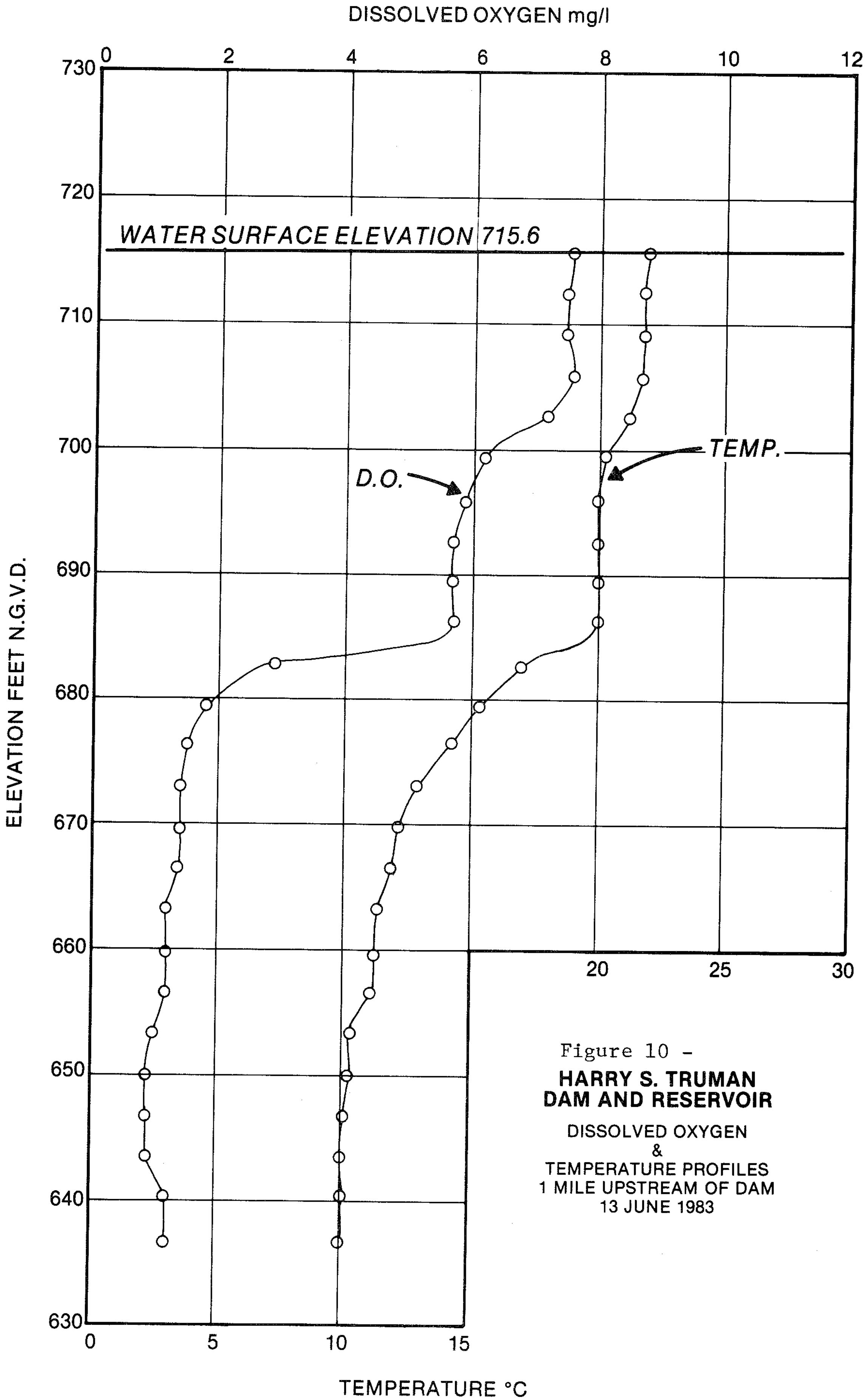

Figure 10 -

HARRY S. TRUMAN DAM AND RESERVOIR

DISSOLVED OXYGEN
&
TEMPERATURE PROFILES
1 MILE UPSTREAM OF DAM
13 JUNE 1983

was isothermal at about 11°C to the same elevation. In front of the powerhouse DO concentrations were between 7 and 8 mg/l to at least elevation 650 ft, m.s.l., with isothermal water temperatures at about 11°C. For some unknown reason, profiles downstream of the weir were not extended to the bottom. However, the data indicates significant mixing is occurring between the weir and the powerhouse.

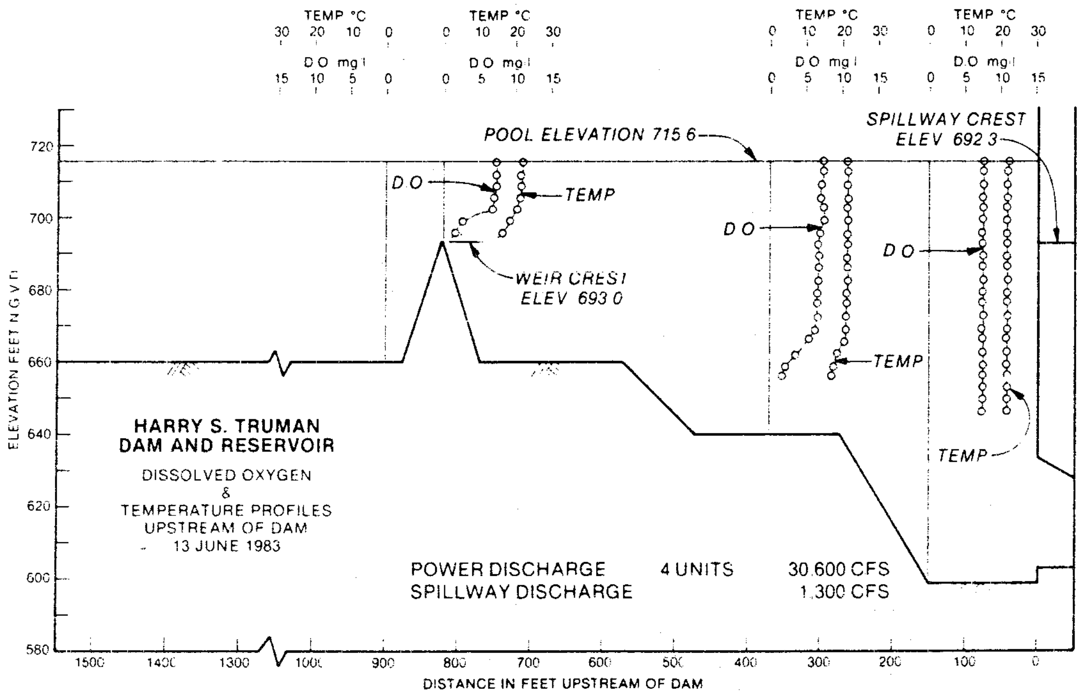

Figure 11 - Dissolved Oxygen and Temperature Profiles With Four Power Units Operating

Measurements were made in May 1985 with the intent to obtain data with three power units operating. However, flow conditions changed during the measurements and the discharge varied from approximately 17,500 cfs with two units generating to 26,700 cfs with three power units in operation. Figure 12 shows conditions in the lake 1 mile upstream of the dam on May 20, 1985. The pool elevation was slightly above the multipurpose pool level of 706.0 ft, m.s.l. There was little in the way of a well developed thermocline, but oxygen levels were severely depleted below elevation 670 ft, m.s.l.

Figure 13 shows temperature and dissolved oxygen profiles obtained on the 23rd of May in the vicinity of the weir and powerhouse, with two power units in operation. DO concentrations just upstream of the weir varied from 11 mg/l at the surface to between 1 and 2 mg/l at the bottom, elevation 660 ft, m.s.l. DO concentrations at the weir crest varied from approximately 10 mg/l at the surface to slightly over 5 mg/l just above the weir crest. A short distance upstream of the power plant the DO varied from 10 mg/l at the surface to 6 mg/l in front of the power intakes. Water temperatures varied from 25°C at the surface to about 20°C at the bottom. The DO level in the outlet channel during the time of the measurements was approximately 7.0 mg/l.

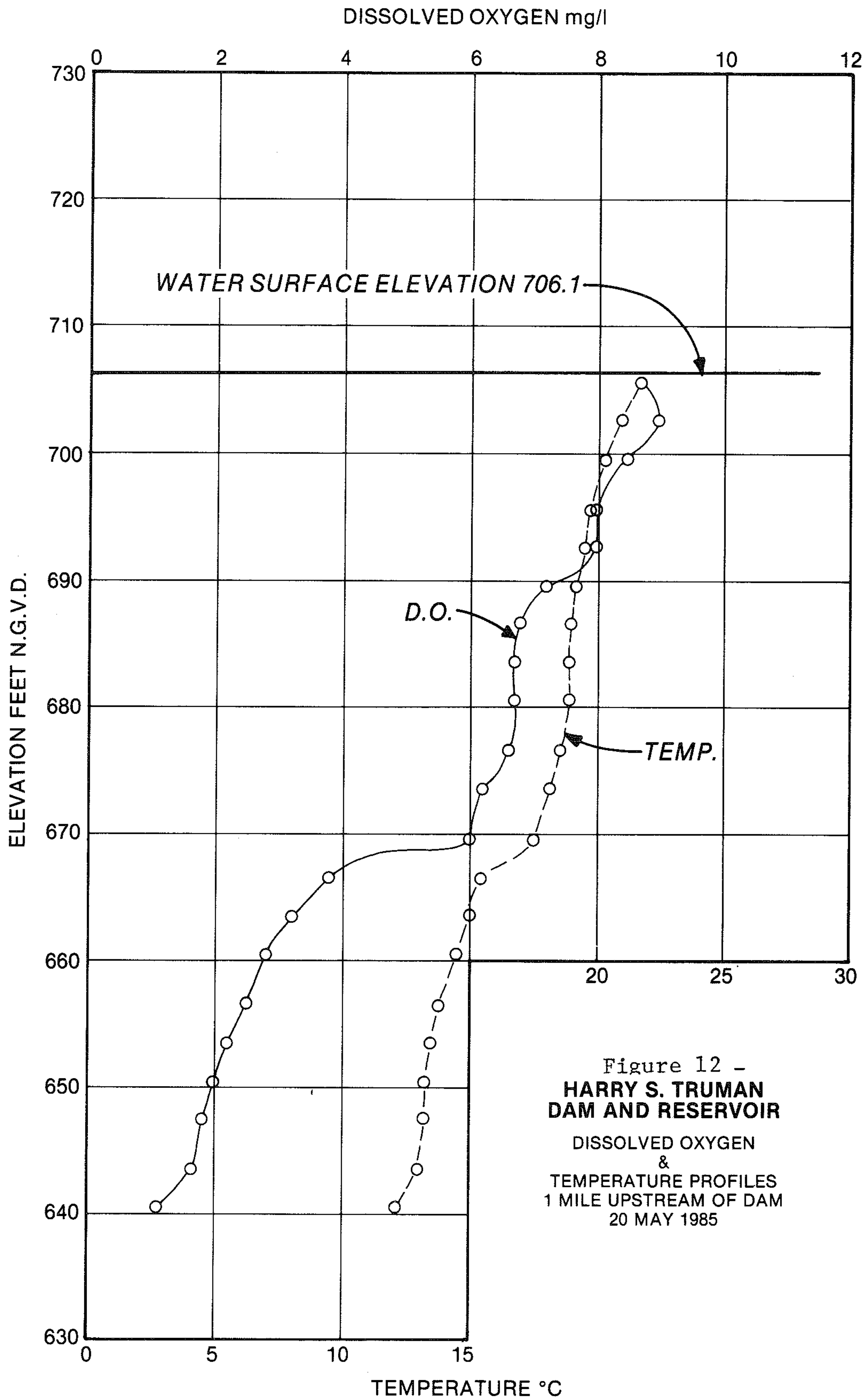

Figure 12 –
HARRY S. TRUMAN DAM AND RESERVOIR
DISSOLVED OXYGEN & TEMPERATURE PROFILES 1 MILE UPSTREAM OF DAM 20 MAY 1985

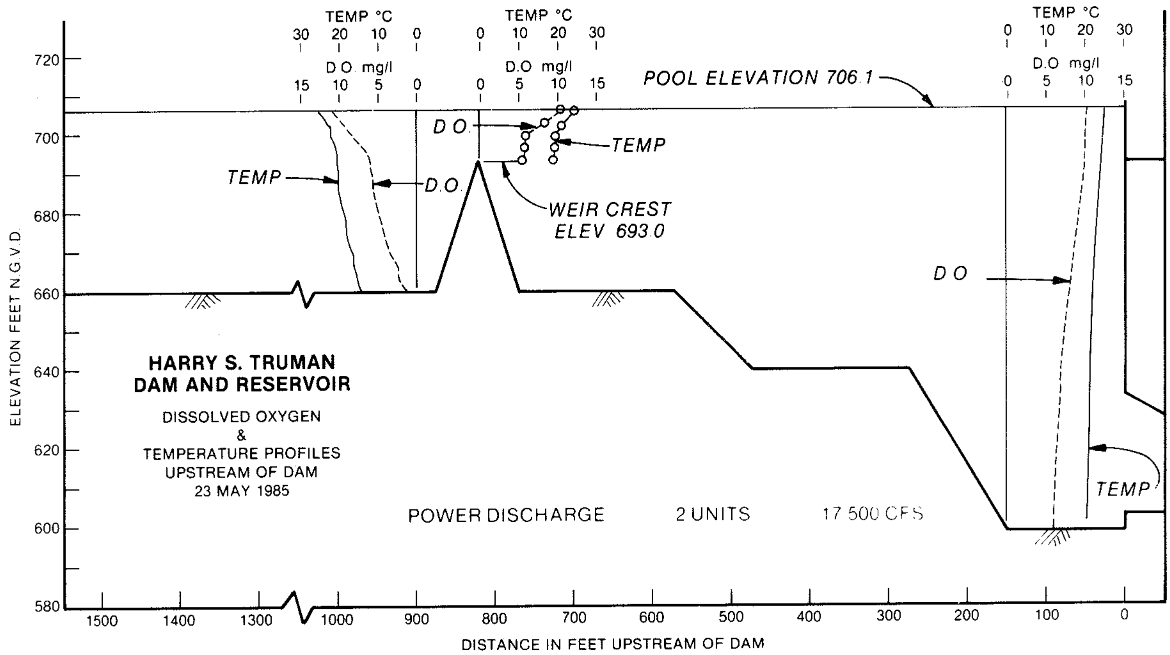

Figure 13 - Temperature and Dissolved Oxygen Profiles With Two Power Units in Operation

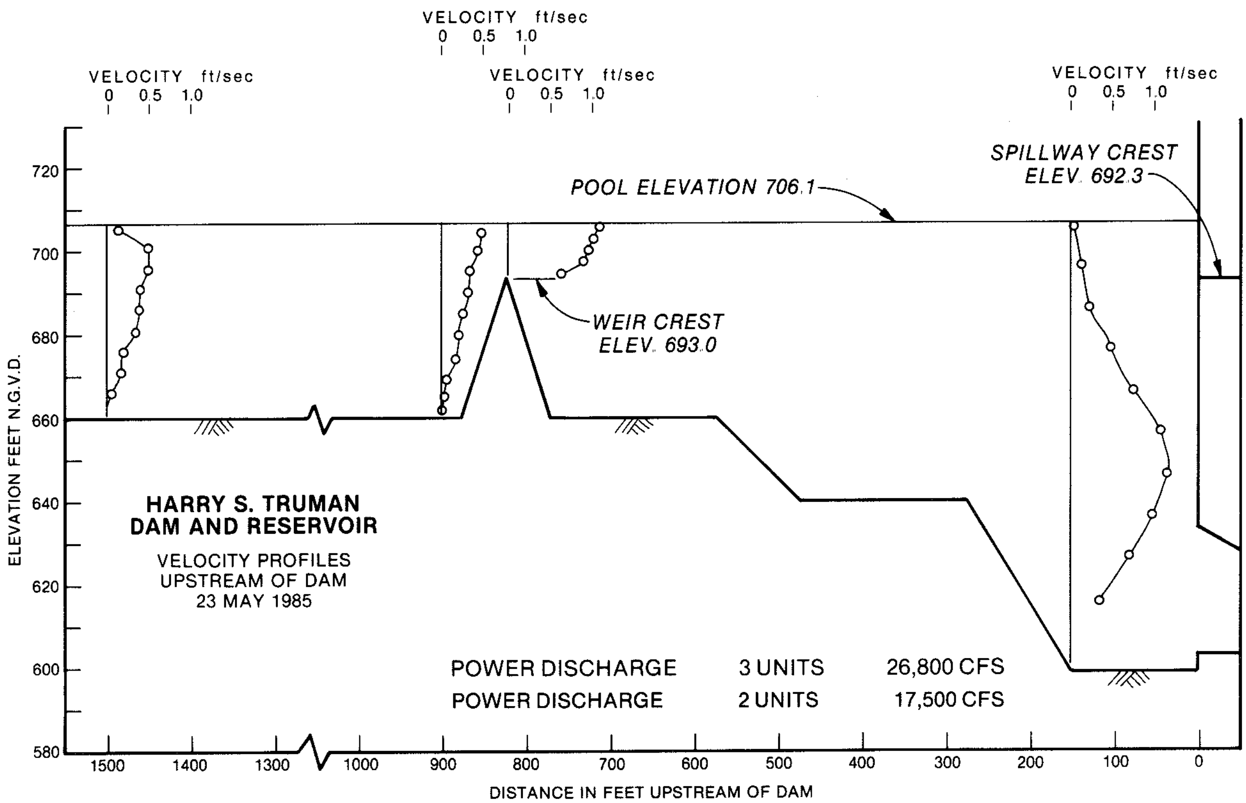

Figure 14 - Velocity Profiles

Flow velocity measurements were also obtained in the vicinity of the weir and the powerhouse on May 23, 1985. These are shown on Figure 14. Unfortunately, power releases increased during these measurements. Measurements at and just in front of the weir were made with two power units discharging 17,500 ft/sec. The measurements several hundred feet upstream of the weir and those just in front of the powerhouse were made with three power units in operation and discharging approximately 26,800 cfs. These profiles provide a good illustration of the weir's effectiveness in surface withdrawal.

Heavy rains over the Osage basin during the first week of June 1985 resulted in a 13-foot rise in the Truman Reservoir. Temperature and DO profiles were obtained on June 20 to obtain data at a higher pool level and high releases. Again flow conditions varied during the measurements. Figures 15 and 16, respectively, show conditions in the lake 1 mile upstream of the dam and at a location about 600 ft upstream of the weir. Note that the lake did not show a well defined thermal stratification, but oxygen levels were severely depleted below elevation 670 ft, m.s.l.

A short distance upstream of the weir DO levels were just under 4 mg/l at the elevation of the weir crest, and were near zero below elevation 670 ft, m.s.l. Some withdrawal of water with reduced DO levels should occur under these conditions.

Figure 17 presents temperature and DO profiles obtained in the vicinity of the weir and between the weir and the powerhouse. The profiles are numbered in the sequence in which they were obtained and the associated number of power units operating and discharge noted.

At the upstream toe of the weir, DO levels were near zero below elevation 680 ft, m.s.l., between 2 and 3 mg/l between elevations 680 and 700 ft, m.s.l., and then increased to 6.5 mg/l at the surface. DO levels were below the desired 5 mg/l 10 to 12 ft above the weir crest. At the weir crest, the lower one-half to one-third of the water column had DO levels between 3 and 4 mg/l. Just downstream of the weir, the higher oxygen levels were near the surface, with DO levels slightly below 3 mg/l below elevation 700 ft, m.s.l. Mixing occurred as the flow plunged toward the power intakes and resulted in DO levels of 5 mg/l or greater from the surface to near the bottom. The line representing 5 mg/l DO on Figure 17 illustrates the surface withdrawal and mixing that takes place between the weir and the power intakes. Measurements downstream of the powerhouse in the outlet channel showed DO levels varied from 5.9 to 5.1 mg/l along the right bank. DO levels were slightly lower on the left side of the channel where flow velocities are lower and varied from 5.0 mg/l to 4.6 mg/l.

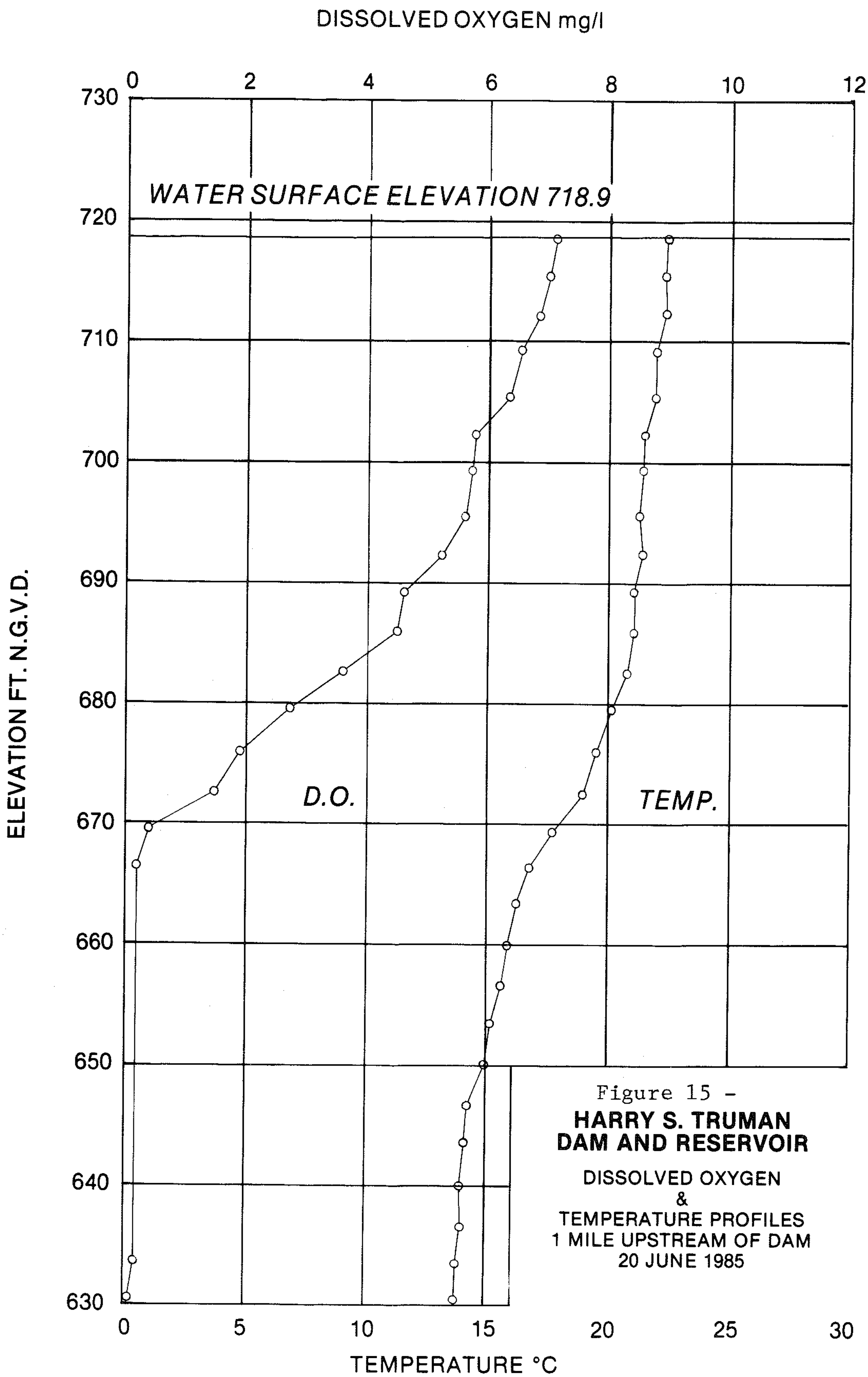

Figure 15 -
HARRY S. TRUMAN DAM AND RESERVOIR
DISSOLVED OXYGEN & TEMPERATURE PROFILES
1 MILE UPSTREAM OF DAM
20 JUNE 1985

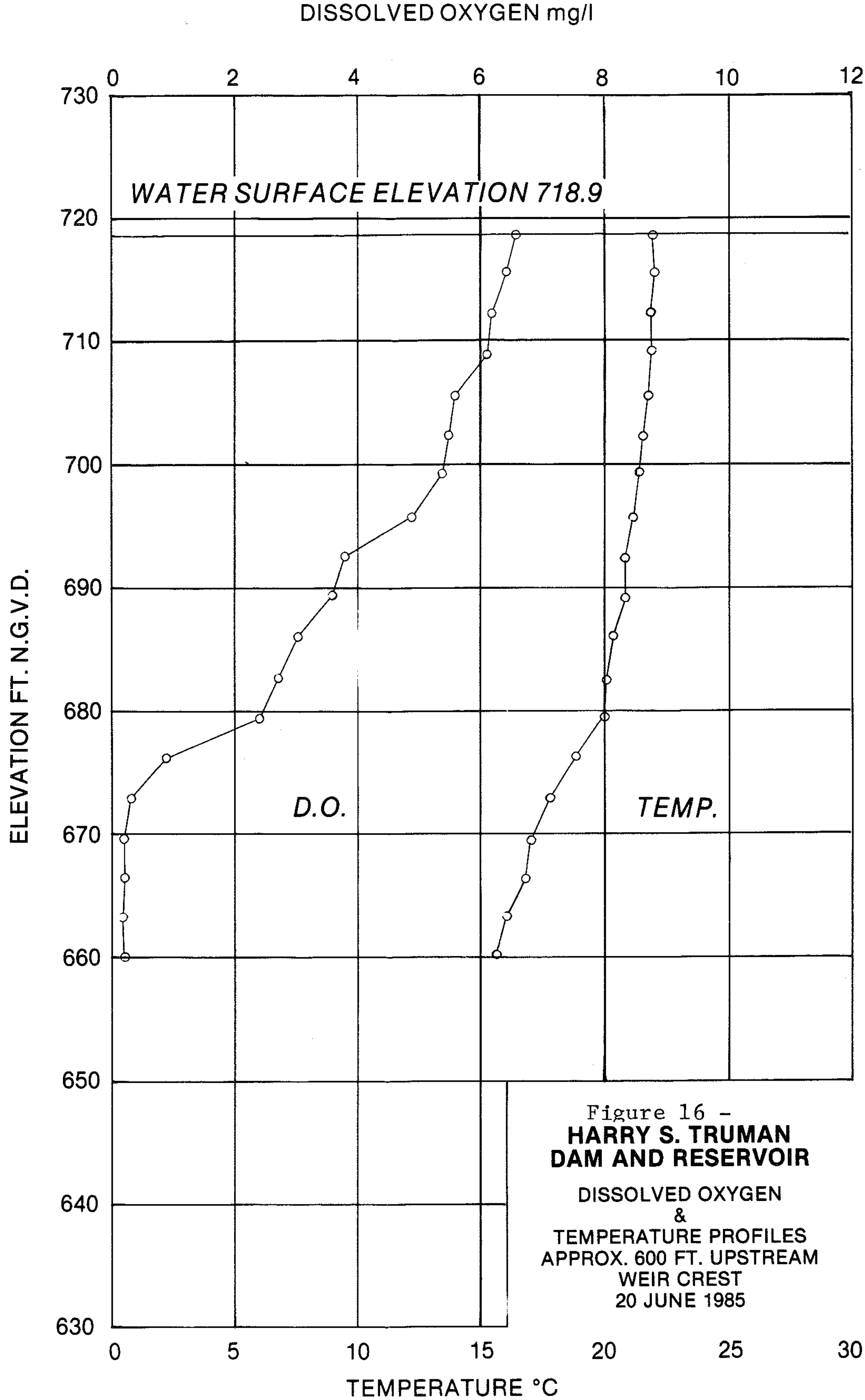

Figure 16 -
HARRY S. TRUMAN DAM AND RESERVOIR

DISSOLVED OXYGEN & TEMPERATURE PROFILES APPROX. 600 FT. UPSTREAM WEIR CREST 20 JUNE 1985

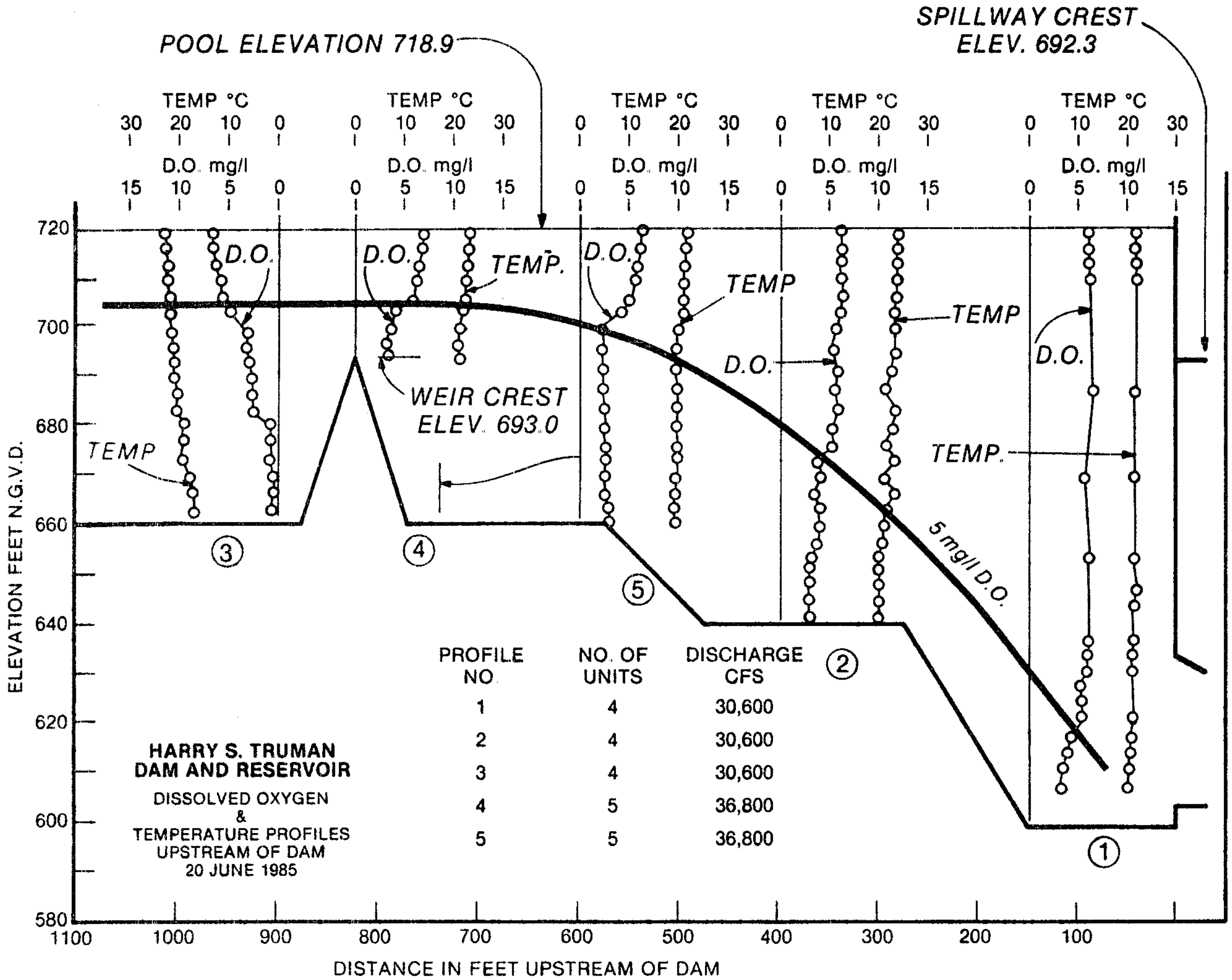

Figure 17 - Temperature and DO Profiles Vicinity of Weir and Skimming Weir, June 20, 1985

SUMMARY

Operating experience at Stockton and Truman Dams has shown skimming weirs are very effective in providing withdrawal of the warmer, well-oxygenated surface waters. At times when the oxycline is near or above the crest elevation of the skimming weir, some water with reduced DO levels will be drawn over the weir. However, sufficient mixing occurs between the weir and power intakes to result in acceptable downstream water quality. Skimming weirs cannot be expected to provide a release of well-oxygenated cold water such as might be desired for a downstream cold water fishery.

Selection of the proper crest elevation requires consideration of several factors. If the crest is placed too high, it can encroach on the ability to utilize the available storage. If placed too low, excessive amounts of water with low DO levels may be withdrawn.

Selective withdrawal modeling can be useful in selecting a crest elevation, particularly if the model also considers the oxygen balance. Thermal modeling alone may lead to incorrect conclusions as the oxycline can often be located well above the thermocline or there may be a gradual thermal gradient from top to bottom with a well defined oxycline and low DO levels relatively close to the surface.

FRESHWATER DIVERSION INTO SELECTED ESTUARIES OF LOUISIANA AND MISSISSIPPI

by

Dennis L. Chew[1]

INTRODUCTION

Louisiana is experiencing an alarming loss of coastal wetlands that include wooded swamps and fresh to saline marshes. Gagliano and van Beek (1970) reported a land-loss rate of about 16.5 square miles per year. More recent data indicate that conversion of wetlands to open water is occurring at a rate of about 50.0 square miles per year (Gagliano, 1984). Natural processes such as subsidence, compaction, erosion, and sea level rise have converted large areas of coastal wetlands to open water. Man's activities, including leveeing, channelization, and petroleum exploration, have also caused serious loss and often tend to accelerate the natural loss rate. Land loss is occurring across the entire coastal area, with the rate being more severe in some areas than others. The only area experiencing a net gain in land is the Atchafalaya Delta.

Saltwater intrusion is a serious problem in the coastal wetlands. Fresh, intermediate, and brackish marshes are being converted to intermediate, brackish, and saline marshes, respectively, and large areas of wooded swamp are being eliminated entirely. Wooded swamps are not very tolerant of salt water. According to reports by Wicker et al. (1981) and van Beek et al. (1982), prolonged salinities in excess of 2.0 parts per thousand (ppt) eventually cause mortality to wooded swamps. Chabreck (1972) reported a mean water salinity of 1.9 ± 0.7 ppt to be the tolerance limit for baldcypress. Saltwater intrusion alters marsh types and can cause marsh loss. As salt water intrudes into a fresher area, vegetation is gradually killed. Before more salt-tolerant plant species can revegetate, open water areas are created because the root systems of the vegetation that helped to hold the substrate together have been lost. The greatest damage to marsh plants occurs when fresh marshes with highly organic soils are subjected to greater salinities as well as strong tidal action. Plants in these areas are killed by the elevated water salinity and the organic substrate becomes loose and disorganized. Organic soils are flushed from these areas and open ponds and lakes replace emergent marsh. As marsh is lost and open water areas are created, the total area of interface between the water and marsh is increased, leading to increased erosion. The marsh remaining in the areas affected by saltwater intrusion is more saline than the original marsh. In general, land loss and saltwater intrusion create an ever-increasing cycle of wetland deterioration. Increased saltwater intrusion causes increased land loss and vice versa.

[1]Fishery Biologist, Environmental Analysis Branch, New Orleans District

Levees, particularly those along the Mississippi River, have disrupted the natural processes of overbank flooding and distributary flow, depriving the adjacent wetlands of fresh water, nutrients, and sediments. Historically, the river meandered back and forth across coastal Louisiana creating numerous deltaic splays. With the levees in place, this no longer occurs, and the fresh water, nutrients, and sediments that once nourished the adjacent wetland areas are carried into the Gulf of Mexico.

Channelization has also contributed significantly to the demise of coastal wetlands. Virtually every hydrologic unit in coastal Louisiana has at least one major navigation channel for access to the gulf. The Gulf Intracoastal Waterway cuts across the entire coast. In addition, there are literally thousands of canals that have been dredged for petroleum exploration. Estimates of the proportion of land loss that can be attributed to canals range from 20 percent (Johnson and Gosselink, 1982) to 90 percent (Turner et al., 1982). Many factors contribute to the damage caused by these canals. The direct impact is the removal of marsh through dredging and the burial of marsh due to dredged material disposal. Indirect impacts stem from a variety of factors, particularly erosion and saltwater intrusion.

IMPACTS OF WETLAND DETERIORATION

Loss of wetlands and deterioration of habitat quality have serious implications for fish and wildlife productivity. Fishery experts generally agree that fishery production is related to the areal extent of wetlands. Studies point conclusively to marsh as being an ecologically limiting factor. Marshes produce large amounts of organic detritus and much of this detritus is transported into adjacent water bodies. Detritus is one of the most important components in the estuarine food web and is vital to maintaining the high level of fishery production in Louisiana. Darnell (1961) and Odum et al. (1973) have well documented the role and importance of detritus in the estuarine food web.

Marshes and associated water bodies are used by various life stages of many estuarine-dependent species that take advantage of protection from predators, warmer water temperatures, optimal salinity regimes, and the rich detrital food chain. Important sport and commercial species that use the shallow marsh habitat include the Atlantic croaker, menhaden, spot, sand seatrout, red drum, black drum, flounder, white and brown shrimp, blue crab, and the American oyster.

In coastal Louisiana, the most valuable fisheries include shrimp, menhaden, blue crabs, and oysters. Every year, Louisiana produces about 25 percent of the total United States fishery harvest. In 1982, Louisiana's fisheries harvest ranked first among the 50 states in total volume of landings with 1.7 billion pounds and third in value of landings at $240 million. In addition, estimates are that recreational fishing contributes about $150 million annually to the state economy (Aquanotes, 1981).

These valuable commercial and recreational species depend heavily on Louisiana's estuarine ecosystems. The U.S. Environmental Protection Agency (1971) stated that "it is currently assumed that none of the major commercial species would continue to exist in commercial quantities if estuaries were not available for development." Shrimp and menhaden yields have been directly correlated to the area of wetlands. Turner (1979) reported a link between the area in intertidal wetlands and shrimp production. Cavit (1979) established that yields of menhaden increase as the ratio of marsh to open water increases. Loss of the marsh and saltwater intrusion have had an adverse impact on fishery production and seriously threaten Louisiana's commercial and recreational fisheries.

Saltwater intrusion has narrowed the broad, brackish zones that are vital for the development of many species. The rising salinities have reduced the low-salinity nursery habitat important to white shrimp and blue crabs. The oyster, however, is the species most impacted by the rising salinities. Since oysters are immobile, they are unable to escape adverse conditions. The optimal salinity range for growth and survival of oysters is 5-15 ppt (Galtsoff, 1964; St. Amant, 1964; Loosanoff, 1965). Grave problems occur when salinities exceed 15 ppt. Above this level, oysters are vulnerable to considerable predation, parasitism, and disease. The most important enemies of oysters in higher salinities include a carnivorous conch, the southern oyster drill (Thais haemostoma), and the fungus Labyrinthomyxa marina. Other notable enemies include the black drum, boring sponges, polychaete worms, boring clams, and stone crabs.

Wildlife productivity in coastal Louisiana depends on the quantity and quality of the wetlands. The combined effects of land loss and saltwater intrusion have resulted in severe adverse impacts on valuable wildlife populations, including resident and migratory waterfowl, wading birds, shorebirds, furbearers, alligators, and a variety of small and big game animals. These losses have led to decreased harvests of furbearers and alligators and reduced opportunities for sport hunting.

Louisiana consistently leads the nation in furbearer production. Species harvested include nutria, muskrat, otter, mink, and raccoon. Over two-thirds of the state's fur harvest is derived from nutria, which exhibit highest productivity in low salinity marshes. During the period of 1978-1982, an average of 2.1 million furbearers were harvested each year. The pelts and meats were valued at about $13.8 million annually. Alligators also thrive in the fresh and intermediate marshes. Between 1979 and 1982, about 15,000 alligators, valued at $2.7 million, were harvested annually. Louisiana's vast wetlands provide wintering habitat for over two-thirds of the Mississippi Flyway waterfowl, as well as other migratory game birds, including rails, gallinules, and snipe (Bellrose, 1976). According to the Louisiana Department of Wildlife and Fisheries, over $25 million is spent on waterfowl hunting each year.

In addition to supporting fish and wildlife resources, the marshes provide numerous other benefits. The extensive marshes between open water and heavily populated inland areas serve to dampen storm surges from hurricanes and other severe storms. Marshes are also capable of removing organic and inorganic nutrients and toxic substances from the water that flows across them. Marshes also provide some unique esthetic values. In Louisiana, the marshes are the foundation for a unique cultural heritage.

PROPOSED SOLUTIONS

In order to address concerns related to land loss and saltwater intrusion, the New Orleans District has conducted studies investigating ways to ameliorate the problems. The study objectives included creation and restoration of coastal wetlands, enhancement of vegetative growth, maintenance of favorable salinity regimes, increased production of fishery resources, and increased production of wildlife resources. Measures investigated to satisfy one or more of these objectives included diversion of fresh water, construction of saltwater barriers, filling open water areas, establishing sanctuaries, and improved management of fish and wildlife resources.

Following extensive investigations, the New Orleans District concluded that freshwater diversion is the most attractive solution to the problems. Other measures have certain merit and are being investigated further in current studies. However, freshwater diversion would contribute significantly to satisfaction of many of the planning objectives. The concept is practical, feasible, and has widespread support. It has long been known that fresh water contributes significantly to the productivity of estuaries worldwide. In Louisiana, the value of freshwater input has been historically documented. Viosca (1938) reported that the 1937 opening of the Bonnet Carre' Spillway resulted in beneficial effects on oysters, finfishes, and penaeid shrimp. Gunter (1950) stated that the 1945 and 1950 openings of the spillway exerted overall beneficial effects on oysters and other organisms. The State of Louisiana and Plaquemines Parish constructed a freshwater diversion structure at Bayou Lamoque in 1957 and St. Bernard Parish installed a freshwater diversion structure at Violet in 1980. Several other freshwater siphons have been installed in the coastal area.

The two primary studies conducted by the Corps are the Louisiana Coastal Area (LCA) Study and the Mississippi and Louisiana Estuarine Areas (MLEA) Study. As a result of these studies, the New Orleans District has developed a comprehensive freshwater diversion plan as shown on Figure 1.

Louisiana Coastal Area Study

The LCA Study was authorized by resolutions of the Committees on Public Works of the U.S. Senate and House of Representatives and adopted on April 19, 1967. The study area covers about 2.3 million acres and encompasses the lower Mississippi River Delta Region in southeastern Louisiana. The area is bounded by the Mississippi River, Bayou La Loutre, and the Mississippi River-Gulf Outlet on the north and east, by Bayou Lafourche on

COMPREHENSIVE FRESHWATER DIVERSION PLAN

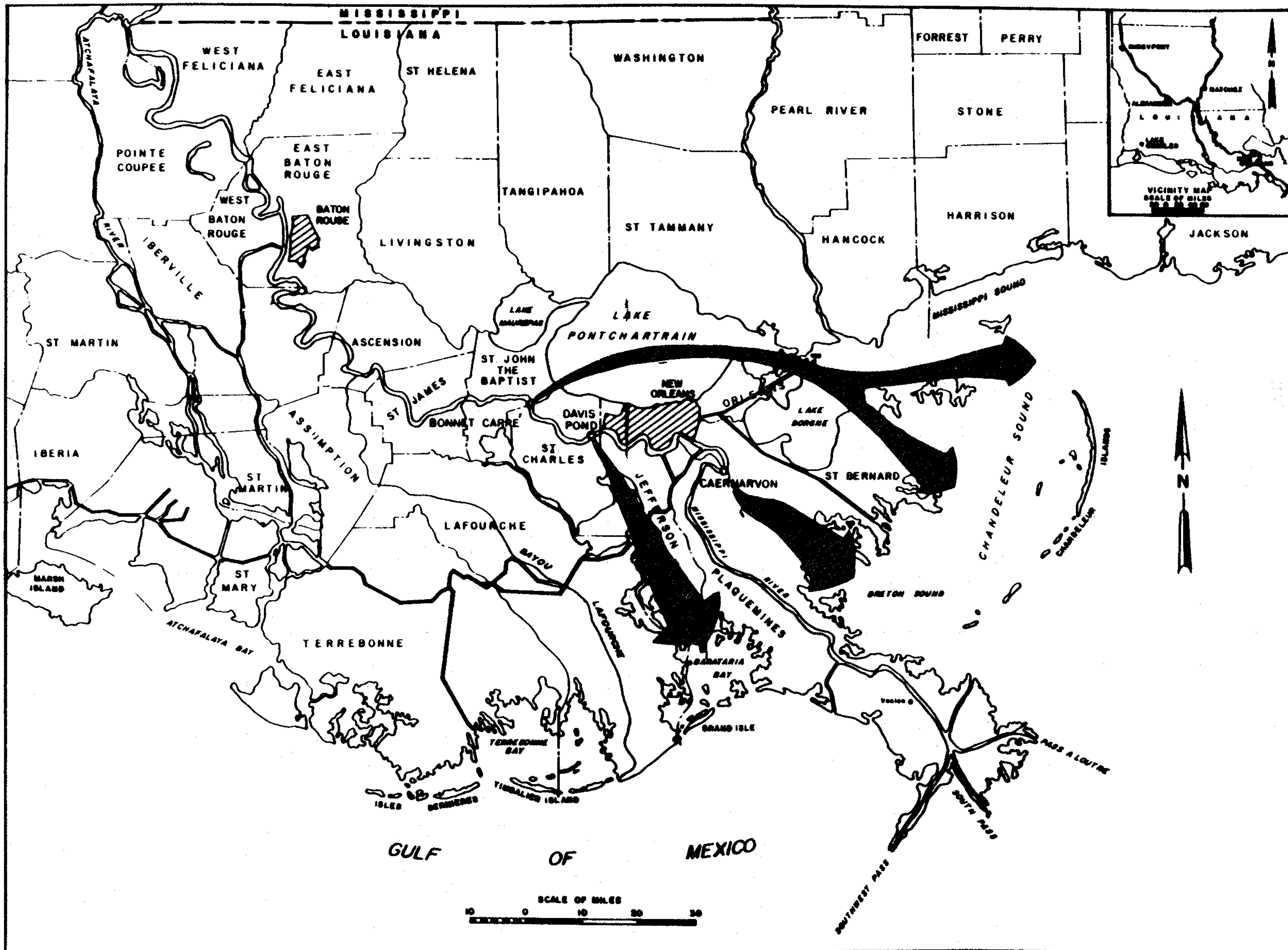

Figure 1. Locations of proposed freshwater diversion structures at Bonnet Carre', Davis Pond, and Caernarvon. Arrows indicate areas influenced by the diversions.

the west, and by the Gulf of Mexico on the south. The Mississippi River and its levees divide the area into two separate watersheds, the Barataria Bay estuary west of the river and the Breton Sound estuary east of the river. The Barataria Bay estuary is a triangular area about 40 miles wide at the gulf and extends inland about 90 miles. The Breton Sound estuary, also triangular, is about 20 miles wide at the gulf and extends inland about 50 miles to Caernarvon, Louisiana.

During the LCA Study, a total of 17 freshwater diversion sites were investigated. The analysis considered environmental, engineering, and socioeconomic factors in the screening process. Six sites were chosen for detailed analysis. Using these sites, a total of 16 plans were formulated for diversion of fresh water into the study area. The plans consisted of combinations of the six diversion sites and various magnitudes of flow. The recommended plan consists of a freshwater diversion site in both the Barataria and Breton Sound Basins. The site in the Barataria Basin is located at Davis Pond at river mile 118.4 Above Head of Passes (AHP). The site in Breton Sound is located at Caernarvon at river mile 81.0 AHP.

The Davis Pond structure would divert fresh water into an area of rapidly deteriorating marsh above the state-owned Salvador Wildlife Management Area. The structure would be constructed through the mainline Mississippi River levee and would consist of box culverts with electronically controlled liftgates. The structure would be capable of diverting up to 10,600 cubic feet per second (cfs) up to the 10-year drought condition. Structure operation would depend on whether fresh water is needed to supplement rainfall to maintain desired salinities in the Barataria Basin. In a normal 10-year rainfall cycle, supplemental water would be required in seven out of the ten years. In the 10-percent drought year, the peak flow of 10,650 cfs would be required. In the six moderate rainfall years, the flow requirements would vary. In the three heavy rainfall years, local precipitation would be sufficient to maintain the desired salinity conditions and the structure would remain closed. Daily operation of the structure would be guided by a comprehensive monitoring system. The overall objective is to achieve an optimal salinity regime in the basin. Over the 50-year life of the project, it is projected that about 83,000 acres of marsh and concomitant fish and wildlife productivity would be saved, primarily through reduction in saltwater intrusion.

The Caernarvon structure, located at the top of the Breton Sound Basin, would divert fresh water into an area that currently produces about 70 percent of Louisiana's oyster production. The structure would be capable of diverting up to 6,600 cfs and would be operated in a manner similar to the Davis Pond structure. The Breton Sound estuary has thousands of acres of formerly productive oyster reefs that are largely unproductive due to excessive salinities. The Caernarvon site was identified as a suitable diversion location many years ago and was authorized by the Mississippi Delta Region Project in 1965. However, at that time, land loss and saltwater intrusion were not as much of a source of concern as they are now and the project was not constructed due to lack of a non-Federal sponsor. The suitability of the site was reaffirmed under the LCA Study and the State of Louisiana has agreed to serve as the non-Federal sponsor. Over the 50-year life of the project, it is projected that about 16,000 acres of marsh could be saved in the Breton Sound estuary with implementation of this project. This project currently enjoys very strong support among Federal, state, and local agencies, as well as the general public.

Mississippi and Louisiana Estuarine Areas Study

The MLEA Study was conducted in response to a resolution adopted on September 23, 1976, by the U.S. House of Representatives Committee on Public Works and Transportation. The purpose of the study was to investigate the feasibility of introducing fresh water into the Lake Pontchartrain Basin and Mississippi Sound in the interest of improving habitat and productivity of fish and wildlife resources. The study area encompasses about 2.9 million acres. In Louisiana, the area includes the lower Mississippi River from Bayou Manchac to Bayou Terre Aux Boeufs, Lakes Maurepas, Pontchartrain, Catherine, and Borgne, Chandeleur Sound, and the swamps and marshes bordering the lakes. The study area in Mississippi embraces the Mississippi Sound and surrounding wetlands.

During the MLEA Study, a total of 13 freshwater diversion sites were investigated. The various plans were screened in a manner similar to that discussed for the LCA Study. The recommended plan calls for placement of a freshwater diversion structure just upriver from the Bonnet Carre' Spillway at river mile 129.0 AHP. The diversion channel would run through the Federally-owned spillway into Lake Pontchartrain. Modification of the existing spillway structure was investigated, but it was determined to be more expensive than building the new structure upriver. The sills on the existing structure are such that fresh water only passes over them at very high stages. Fresh water for environmental enhancement purposes is often needed when the river is at lower levels.

Saltwater intrusion into Lakes Maurepas and Pontchartrain has contributed substantially to major habitat changes in the last 25 years. Approximately 25,000 acres of formerly fresh habitats including fresh marsh and wooded swamp have been converted to nonfresh habitats. About 21,000 acres of baldcypress swamp have been converted to nonfresh marsh. Another 36,000 acres of swamp is under stress because of continued excessive salinities. Oyster reefs in the study area have also suffered. St. Bernard Parish historically had the most productive oyster harvesting areas in Louisiana, accounting for 70-75 percent of all oysters harvested. In recent years, saltwater intrusion has caused salinities suitable for oyster production to shift inland. As a result, thousands of acres of historically productive oyster bottoms lie dormant due to extensive predation, parasitism, and disease. With implementation of the proposed project, it is estimated that about 4,186 acres of marsh and 6,355 acres of wooded swamp would be saved over the 50-year life of the project. Thousands of acres of stressed swamp would be rejuvenated. In addition, it is projected that oyster production in the study area would approximately double.

MONITORING

Throughout the period of study leading to the recommendation of these freshwater diversion projects, there was extensive interagency and public involvement. During this period, numerous individuals and agencies recommended that the projects be carefully monitored. At first, the driving force behind these monitoring programs was concern over the relatively poor water quality of the Mississippi River and the potential for adverse impacts on organisms in the estuary. However, it soon became apparent that it would be wise to develop comprehensive monitoring programs to include biological, water quality, and hydrological data collection. These programs would provide information on prediversion conditions in the estuaries and allow us to assess the impacts of the diversions on these estuaries and their associated fish and wildlife resources. The programs would also provide information that could be used to guide structure operation including timing, magnitude, and duration of flow. The monitoring programs would be carried out in three distinct phases: an intensive, 3-year preconstruction program; an intensive, 4-year postconstruction program; and a long-term program which would continue for 46 years, the remainder of the 50-year project life. A draft report on the monitoring program for the Caernarvon diversion has been completed and will be finalized in the near future. The program was developed through an extensive interagency effort.

STATUS OF THE PROJECTS

The final main report and environmental impact statement (EIS) for the LCA Study, which covered both the Caernarvon and Davis Pond diversion sites, was completed in September 1984. It has been determined that the Caernarvon structure can be constructed under the authority of the Mississippi Delta Region Project, which was authorized in 1965. A General Design Memorandum for Caernarvon was completed in September 1985. A postauthorization change report (PAC) was forwarded to Washington in January 1985, recommending that the Davis Pond structure also be constructed under the authorization of the Mississippi Delta Region Project. No final decisions have been made at this time.

The final main report and EIS for the MLEA Study was completed in April 1984. Work is continuing on this study under Continuing Planning and Engineering authority.

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INDIANA HARBOR RESEARCH STUDIES

Jan A. Miller
U.S. Army Corps of Engineers
Chicago District
219 South Dearborn Street
Chicago, Illinois 60604-1797

INTRODUCTION

The Indiana Harbor and Canal is located in East Chicago, Indiana on the southern shore of Lake Michigan (plate 1). Indiana Harbor is the fourth busiest port on the Great Lakes, having a deep draft navigation channel maintained by the USACE. The Grand Calumet River, which is tributary to Lake Michigan via the Indiana Harbor and Canal, has a relatively small watershed which is entirely urban/industrial. The major industries along the canal are steel, petrochemical, lead, and gypsum. The Grand Calumet River/Indiana Harbor Canal has a long history of water quality problems and has been identified by the International Joint Commission of the Great Lakes (IJC) as a major area of concern.

The Chicago District, USACE has maintained the navigation channel at Indiana Harbor and Canal by periodic dredging until 1972. Prior to 1970, dredgings were disposed to the open waters of Lake Michigan. After 1970, federal environmental regulations prohibited the unconfined disposal of polluted dredgings. In 1972 maintenance dredgings were disposed to an enclosed lakefill on Inland Steel. Since 1972 the Corps has been unable to maintain the navigation channel because no acceptable disposal site was available. Despite several attempts, the Corps could not locate a site or local sponsor for almost ten years. In 1983 the Corps completed a Site Selection Study for potential dredged disposal sites. The Lake County Board of Commissioners offered to act as local sponsor for the construction of a confined disposal facility (CDF) in Lake Michigan at East Chicago. The Corps has prepared a Draft Environmental Impact Statement for the proposed project.

The dredging and disposal of polluted sediments from Indiana Harbor and Canal has received an unusually high amount of notoriety, including considerable media attention. A number of local citizens and environmental groups have expressed their opposition to the proposed project, fearing the dredging and disposal might endanger the quality of Lake Michigan. In November 1983, a few months after the release of the Site Selection Study, a meeting between the Corps, USEPA, State of Indiana officials, and representatives of citizens' groups was held at the IJC biennial conference in Indianapolis, Indiana. The citizens' groups described the Grand Calumet River/Indiana Harbor Canal as a valuable resource forgotten by the State and

USEPA and expressed doubt that the Corps would use the most up-to-date technologies in its dredging and disposal plans. At this meeting both the USEPA and Corps of Engineers, North Central Division pledged to take actions to address the concerns raised. The USEPA identified its intent to prepare a Master Plan for the Grand Calumet River/Indiana Harbor Canal, coordinating the regulatory and remedial actions necessary to improve water quality. The Corps stated it would explore innovative technologies for dredging and disposal of contaminated sediments.

USEPA MASTER PLAN

In 1984-5 the USEPA, Region V prepared a "Master Plan for Improving Water Quality in the Grand Calumet River/Indiana Harbor Canal." The Master Plan report included a discussion of existing environmental problems and pollutant sources, a presentation of existing water quality control programs, and recommendations for improving water quality and aquatic habitat conditions.

The summary of existing environmental problems in the Grand Calumet River/Indiana Harbor Canal (GCR/IHC) stated that there were "high concentrations of conventional, nonconventional and toxic pollutants in the sediments and overlying water column. Although improved point souce controls have resulted in significant improvements in ambient water quality conditions in recent years, the contaminated sediments continue to represent a major in-situ reservior of accumulated pollutants." The Master Plan report indicated that "the continued discharge of toxic and nonconventional pollutants (including contaminants leaching from sediments) are now the major limitation to the biological recovery of the GCR/IHC system."

The USEPA Master Plan formulated the following recommendations:

1) Continue the existing emphasis on pollutant controls.
2) Clarify the role of toxic pollutants in the river system.
3) Develop any additional toxic pollutant control programs that are necessary for restoration of the GCR/IHC.

The recommendations are to be implemented through a cooperative, interagency effort which is directed by USEPA. The Corps of Engineers participation is centered around the Environmental Impact Statement on Indiana Harbor maintenance dredging and its R&D study. The Corps "assessment of alternatives to dredging and spoils disposal from the Harbor and Ship Canal will contribute to public and agency perceptions of the feasibility of remedial actions proposed for upriver sediment contamination."

INDIANA HARBOR STUDIES

In 1984, the Chicago District contracted with the Waterways Experiment Station (WES) in Vicksburg, Mississippi to conduct a research and development study. The purposes of the study were threefold. First, to fulfill the pledge made at the November 1983 IJC meeting to investigate innovative dredging and disposal technologies. The second purpose of the R&D study by WES (which represents the major effort) was an evaluation of disposal alternatives for PCB contaminated sediments from Indiana Harbor Canal. Thirdly, the Chicago District asked WES to investigate what has become known as the "No Action" alternative.

Equipment Demonstration

The purpose of this study was to demonstrate two pieces of innovative dredging/disposal equipment. The equipment are a "Matchbox" hydraulic suction head and a submerged diffuser. The "Matchbox" is a Dutch designed dredge head which had been used effectively in Rotterdam Harbor for the dredging of highly contaminated sediments with minimal resuspension. The submerged diffuser is a Corps designed "flange" to be placed at the discharge end of a hydraulic dredge pipeline for controlled placement of dredgings directly on the ocean/lake floor. The diffuser reduces exit velocities, reduces resuspension, and can be used to accurately place and cap contaminated sediments.

The equipment demonstration took place in October 1985 at Calumet Harbor in Chicago, Illinois (plate 1). The Corps hydraulic dredge "Dubuque" from the St. Paul District was used to demonstrate the equipment. The performance of the "Matchbox" was compared to a standard cutterhead. The submerged diffuser was demonstrated within the Chicago Area Confined Disposal Facility at Calumet Harbor. A report of the results of the demonstration should be available in June 1986.

Disposal Alternatives for PCB-Contaminated Sediments

The bottom sediments of the Indiana Harbor and Canal are heavily polluted with metals and organic contaminants such as PCB"s and Polynuclear Aromatic Hydrocarbons (PAH's). The levels of contamination present preclude any disposal of dredgings to the open water. Most of the sediments contain levels of contamination suitable for confined disposal in an upland or in-lake CDF. Two reaches of the canal contain levels of PCB's exceeding 50 parts per million (ppm). These sediments are subject to federal regulation under the Toxic Substances Control Act (TSCA), and the disposal alternatives are less clear. WES was asked by the Chicago District to evaluate the feasibility of three specific disposal alternatives for these PCB contaminated sediments and to analyze the control measures required under each alternative. These disposal alternatives are 1) upland confined disposal (CDF), 2) in-lake CDF, and 3) confined aquatic disposal (CAD).

In October 1984, twenty barrels of sediment from Indiana Harbor Canal and Lake Michigan were collected and transported to WES. A battery of chemical, engineering and biological tests were performed with these sediment samples, including:

1) Physical/engineering properties
2) Settling and consolidation tests
3) Solidification/stabilization tests
4) Bulk chemical analysis
5) Modified elutriate tests
6) Column capping tests - chemical/biological
7) Plant uptake
8) Animal uptake
9) Leachate tests
10) Run-off tests

The sediment collected from Indiana Harbor was a highly plastic clay, having a high concentration of oil and grease and 12.5% total organic carbon content. Metals were present in elevated levels, as expected given the industrialized area. Polynuclear armomatic hydrocarbons were present in high concentrations, including napthalene and benzo(a) pyrene. The mixed sediment sample also contained 33.4 ppm of PCB (Arclor 1248).

The tests performed by WES were used to evaluate the conditions expected during the three disposal alternatives. Modified elutriate tests were used to assess the quality of effluent from a CDF. Column capping tests were used to determine the thickness of cap required to isolate the contaminated sediments from the overlying water column. For these tests, aquatic organisms (fish, clams and crayfish) were placed in the column over capped and uncapped sediments. Plant (sedge) and animal (worm) uptake tests were used to determine the potential for bioaccumulation in an upland CDF.

In addition to the above testing procedures, WES scientists have been developing new methods to simulate the processes of leaching and run-off in confined dredged material disposal. This effort was necessary because there either was no standardized method available or the existing method was too costly or time consuming.

The preliminary results of the WES analysis of disposal alternatives for PCB-contaminated sediments from Indiana Harbor Canal are being reviewed by the Chicago District. It appears that with certain design and operational control measures, all three disposal alternatives would be feasible from an engineering and environmental basis. The specific control measures are beyond the scope of this paper. The final report should be available in June 1986. Following review of this report by the USEPA and the State of Indiana, the Chicago District intends to discuss the selection of a disposal alternative with these agencies.

No Action Alternative

The performance of maintenance dredging has long been viewed as a necessary evil by the public and environmental groups. A messy operation having no redeeming value except to navigation users. This preconception has been challenged only recently. If the USEPA can use dredging as a remedial action for a clean-up under SUPERFUND, how is maintenance dredging that different?

When the Corps prepares an Environmental Impact Statement for a planned maintenance dredging and disposal, no action is one of the alternatives evaluated. Typically this alternative is examined only for economic impacts. Yet if the proposed action is to remove polluted sediments from a river or harbor and place them in a confined environment, are there not some positive environmental impacts as well? Navigation channels are often located at the mouth of a river and act as a settling basin trapping sediments which would otherwise be transported out to the receiving waterbody. The maintenance of this sediment trap should be especially important if the sediments are heavily polluted and the quality of the receiving water is highly valued.

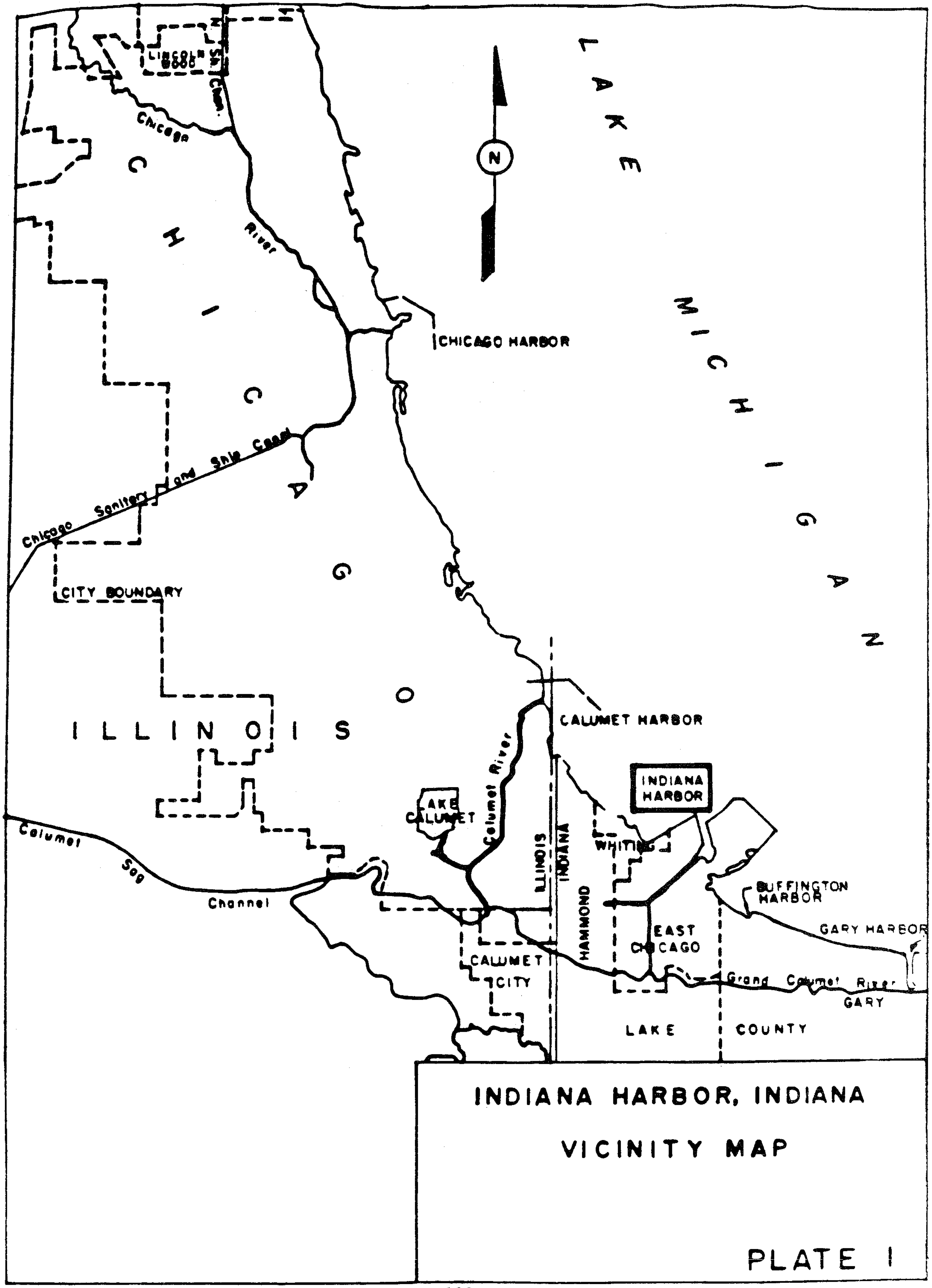
The Chicago District asked WES to evaluate the No Action alternative at Indiana Harbor. Since it was recognized that this was a large undertaking, WES agreed to do a "first-cut" investigation during 1985. This study was to examine the existing information on the GCR/IHC system, literature on the interaction between bottom sediment-water column, and sediment transport information.

The study would attempt to prioritize the mechanisms by which the polluted bottom sediments impact the water quality of the river and adjacent lake and identify laboratory or field investigations necessary to quantify these impacts. Preliminary findings indicate that sediment-bound contaminants represent the most important mechanism for water quality impacts and that field studies of the suspended sediment sources and transport are of highest priority. The conclusions and recommendations of the No Action alternative study will be available in June 1986.

SUMMARY

The experiences of the Chicago District at Indiana Harbor have shown the current perceptions of the public and regulatory agencies toward the environment, dredging, and the removal of in-place toxic pollutants. The public is becoming increasingly impatient with regulatory agencies tasked with restoring and maintaining environmental quality. Organizations such as the IJC have recognized that environmental problems are not solved by study alone. At their recent bienial conference in Kingston, Ontario, the Water Quality Board of the IJC expressed this in the theme of their presentation "Lets Get On With It."

At Indiana Harbor, the Corps and USEPA have opportunity to make significant improvements to the existing environmental conditions. The USEPA has formulated a Master Plan to coordinate regulatory and remedial measures. The Corps has proposed a plan for dredging most of the navigation channel and has completed studies on innovative dredging technologies, disposal alternatives for PCB-contaminated sediments, and the impacts of the no-action alternative. With this information in hand, the Corps should be able to remove and confine a portion of the in-place pollutants from Indiana Harbor under its navigation authority. The USEPA will be able to define the environmental benefits from the removal of in-place pollutants beyond the navigation channel and evaluate the feasibility for a remedial clean-up action using dredging/disposal alternatives developed by the Corps.


LAKE MICHIGAN
CHICAGO
ILLINOIS
INDIANA
CHICAGO HARBOR
CALUMET HARBOR
INDIANA HARBOR
BUFFINGTON HARBOR
GARY HARBOR
Chicago River
Chicago Sanitary and Ship Canal
CITY BOUNDARY
Calumet Sag Channel
Calumet River
LAKE CALUMET
WHITING
HAMMOND
EAST CHICAGO
CALUMET CITY
Grand Calumet River
GARY
LAKE COUNTY
LINCOLN PARK
N
INDIANA HARBOR, INDIANA
VICINITY MAP
PLATE I

ENVIRONMENTAL WINDOWS FOR BUCKET DREDGING

By

John D. Lunz,[1] Douglas G. Clarke,[2] and Thomas J. Fredette[3]

INTRODUCTION

Seasonal restrictions are often applied to certain Federal and permit dredging projects where environmental concerns are apparent. These restrictions are thought necessary to protect sensitive life history stages of significant biological resources from the physical and chemical alterations of aquatic habitats caused by dredging operations. These environmental concerns are related to various aspects of the ecology of target species in a given project area. For example, pelagic egg and larval stages of both fishes and shellfishes, due to their dependence on local hydrodynamic conditions for transport into and out of project areas and limited avoidance capabilities, have been asserted to be more susceptible to elevated concentrations of suspended sediments than motile juvenile or adult life history stages (2). Demersal eggs or life history stages which are sessile or non-motile are deemed particularly susceptible, either by virtue of longer exposures to elevated suspended sediment concentrations, or due to smothering as a result of increased sedimentation. Concerns for motile stages of fishes and shellfishes focus upon direct effects of suspended sediments on survival, and effects on movements or migration patterns. Actual causal factors for such effects are little understood, but have been summarized (6) to include mechanical abrasion of surficial membranes, reduction of available light in the water column, and sorption of contaminants carried by the sediments. In general, then, five categories of concern can be identified: (I) survival and development of egg and larval stages of fishes, (II) survival and development of egg and larval stages of shellfishes, (III) survival and movements of juvenile fishes and shellfishes, (IV) survival and movements of subadult and adult shellfishes, and (V) survival and movements of subadult and adult fishes.

There appears to be little consistency in patterns of seasonal restrictions applied among different US Army Corps of Engineer Districts inhabited by the same kinds of biological resources. For example, penaeid shrimps would certainly be classified as significant biological resources of the Wilmington, Charleston, Jacksonville, Mobile, New Orleans, and Galveston Districts. Among these Districts, the shrimp fisheries of Texas, Louisiana, Mississippi, Alabama, and Florida are larger than those of the Carolinas and yet a District

[1]Research Marine Biologist
[2]Oceanographer
[3]Marine Ecologist
Environmental Laboratory, US Army Engineers Waterways Experiment Station

survey suggests that seasonal dredging restrictions to protect penaeid shrimps occur only in the Mobile and Wilmington Districts.

Evidence indicates that all Districts desire a harmonious working relationship with other Federal and State resource management agencies. In order to maintain good interagency relationships, Districts tend to comply with seasonally restrictive dredging requests whenever possible. In some instances, however, these restrictions may complicate scheduling, funding, and contracting; increase project costs; increase the hazards of field operations; and may not result in any additional environmental protection or be supportable with technical data.

CRITIQUE OF AVAILABLE INFORMATION ON SUSPENDED SEDIMENT EFFECTS

The literature relevant to the effects of suspended sediments on aquatic organisms is very dispersed (6, 19, 20, 21, 28, 30, 32). Of the five categories of concern, only those dealing with direct effects on survival or development have received much attention. Table 1, modified from Priest (20), although far from comprehensive, provides a sample of results of laboratory examinations of physical effects of suspended sediments on estuarine and coastal marine species.

Summarization of the results of these studies is hindered by a lack of standardization in experimental protocol (e.g. selection of test concentrations, exposure durations, or suspensions of natural vs. processed sediments) or equipment used to maintain sediment in suspension. The most widely used approach incorporates basic bioassays (LC_{10} or LC_{50}). Other studies measure threshold concentrations of suspended sediments above which a given species is adversely effected. Several workers have employed histological preparations of gill tissues to demonstrate physical effects. Results have been somewhat conflicting. Ritchie (23) found no evidence of gill pathology in specimens of 11 estuarine fish species prior to and after exposure to dredging conditions. Sherk et al. (31), however, found disrupted gill tissue and increased mucus production in white perch exposed to sublethal suspended sediment concentrations.

A number of gaps in the knowledge of effects of suspended sediments are readily apparent. Very little is known of the importance, if any, of synergistic effects resulting from combinations of causal factors, or of physical features of the sediment particles such as size or angularity. Rogers (24) reported that processed sediments (highly angular incinerator residues) were much more toxic to experimental fishes than naturally weathered estuarine sediments. In addition, stresses of a chemical, physical, or biological nature may be manifested in chronic rather than acute effects (29). Indirect effects of elevated suspended sediments may be of consequence, for example via interference with feeding behavior of visually oriented larval stages, or delayed development resulting in asynchronous occurrences of larvae and their prey. Insufficient technical information exists upon which to establish the validity or significance of these issues.

Very few field studies have attempted to test the hypothesis that turbidity fields act as barriers to migratory patterns of sensitive species (e.g. anadromous herrings). Results have been largely inconclusive. An extensive sonic monitoring of fish

Table 1. Summary of Results of Experimental Determinations of Effects of Suspended Sediments on Fishes and Shellfishes (modified from Priest (21)).

Ref.	Species	Stage	Susp. Sed. Conc. (mg/l)	Exposure Duration	Type of Sediment	Degree of Effect
(28)	Yellow Perch	Eggs	50-500	Not Stated	Natural	No significant effect on hatching success; some delay in time to hatching noted in samples at > 100 mg/l (for all four species)
"	White Perch	"	"	"	"	
"	Striped Bass	"	"	"	"	
"	Alewife	"	"	"	"	"
(17)	White Perch	Eggs	50-5,000	"	"	No significant effect on hatching success; definite delay in development at > 1,500 mg/l
"	Striped Bass	"	20-2,300	"	"	No significant effect on hatching success; definite delay in development at > 1,300 mg/l
"	White Perch	Larvae	1,626-5,380	24-48 hrs	"	15-48 percent mortality
"	Striped Bass	"	1,557-5,210	"	"	20-57 percent mortality
(2)	Blueback Herring	Eggs	50-5,000	Not Stated	"	No significant effect on hatching success at all test concentrations
"	Alewife	"	"	"	"	
"	American Shad	"	"	"	"	"
"	Yellow Perch	"	"	"	"	"
"	White Perch	"	"	"	"	Significant effect on hatching success at 1,000 mg/l but not at lower concentrations
"	Striped Bass	"	"	"	"	
"	Yellow Perch	Larvae	50-1,000	4 days	Natural	Survival significantly reduced at > 500 mg/l
"	Striped Bass	"	"	2-3 days	"	Survival significantly reduced at > 500 mg/l
"	Alewife	"	"	4 days	"	Survival significantly reduced at > 100 mg/l
(32)	Spot	Adult	13,090	24 hrs	Processed	LC10
"	Spot	"	68,750	"	Natural	"
"	Striped Killifish	"	23,770	"	Processed	"
"	Striped Killifish	"	97,200	"	Natural	"
"	Mummichog	"	24,470	"	Processed	"
"	Atlantic Silverside	"	580	"	"	"
"	Bay Anchovy	"	2,300	"	"	"
"	White Perch	"	9,970	"	Natural	"
"	White Perch	"	3.050	"	Processed	"
(20)	Striped Bass	Subadult	4,000	21 days	Natural	"
(25)	Cunner	Adult	133,000	12 hrs	"	Median Tolerance Limit
"	Cunner	"	100,000	24 hrs	"	"
"	Cunner	"	72,000	48 hrs	"	"
"	Mummichog	"	300,000	24 hrs	"	No mortality
"	Sheepshead Minnow	"	300,000	"	"	< 30 percent mortality
"	Cunner	"	100,000	"	"	Median Tolerance Limit
"	Stickleback	"	52,000	"	"	"
(9)	American Oyster	Eggs	188	Not Stated	Natural	22 percent abnormal development
"	American Oyster	"	250	"	"	27 percent abnormal development
"	American Oyster	"	375	"	"	34 percent abnormal development
"	American Oyster	"	1,000	"	Processed	No significant effect
"	American Oyster	"	2,000	"	"	"
"	American Oyster	Larvae	750	12 days	Natural	31 percent mortality
"	American Oyster	"	2,000	"	Processed	20 percent mortality
"	American Oyster	"	500	Not Stated	"	78 percent mortality
(8)	Hard Clam	Eggs	750	"	Natural	8 percent abnormal development
"	Hard Clam	"	1,000	"	"	21 percent abnormal development
"	Hard Clam	"	1,500	"	"	35 percent abnormal development
"	Hard Clam	"	125	"	Processed	18 percent abnormal development
"	Hard Clam	"	125	"	"	25 percent abnormal development
(9)	Hard Clam	"	4,000	"	"	31 percent abnormal development
(8)	Hard Clam	Larvae	1,000	"	Natural	No significant effect
"	Hard Clam	"	500	12 days	Processed	50 percent mortality
(19)	Spot-tailed Shrimp	Adult	50,000	200 hrs	Processed	LC50
(20)	Black-tailed Shrimp	Subadult	21,500	21 days	Natural	20 percent mortality (contaminated seds.)
"	Dungeness Crab	Adult	3,500	"	"	LC10
(26)	American Lobster	"	50,000	Not Stated	Processed	No mortality
(34)	American Oyster	"	4,000-32,000	Extended	Not Stated	Detrimental effect
(14)	American Oyster	"	100-700	Not Stated	Mud	No effect
(13)	American Oyster	"	100-4,000	"	Silt	Reduced pumping
(19)	Blue Mussel	Subadult	100,000	5 days	Processed	10 percent mortality
"	Blue Mussel	Adult	100,000	11 days	"	10 percent mortality
"	Blue Mussel	"	96,000	200 hrs	"	LC50

distributions conducted in the Delaware River during dredging operations was unable to detect any dredge-induced changes in fish density or distribution (14). Variability in fish densities was just as great at sites far removed from the dredge as at the actual dredge site.

Recognizing the inconsistencies and shortcomings which characterize the current literature on effects of suspended sediments, we interpret the available data as evidence that most, if not all, life history stages of species adapted to naturally turbid estuarine conditions are moderately to extremely tolerant of elevated suspended sediment concentrations. In light of the inadequate comparative base of technical data, information gleaned from available references should be put into perspective with information on conditions generated by project specific dredging operations before any policies are implemented concerning seasonal dredging restrictions.

BUCKET DREDGING OPERATIONS

Suspended solid concentrations generated by a typical bucket dredge operation can be traced to four major sources: (a) sediment resuspension at bucket impact and (b) subsequent removal from the bottom, (c) sediment erosion from the open top and mud covered bucket surfaces as the bucket is hauled upward through the water column and (d) barge loading and draining (3). There is a great deal of variability in the amount of material resuspended by bucket dredges due to variations in bucket size, bucket type (open or closed), volume of sediment dredged per cycle, hoisting speed, sediment types and hydrodynamic conditions at the dredging site.

Suspended Sediments

A method to predict the combined effects of variables on the spatial and temporal changes in suspended sediment concentrations during a specific project does not exist at the present time. Enough field studies have been conducted, however, to suggest patterns in the spatial extent of sediment resuspension during bucket dredging operations.

Barnard (3) described a typical bucket dredge operation as producing a downstream turbidity plume extending 300 m (984.2 ft) at the surface and 500 m (1640.4 ft) near the bottom. In the immediate vicinity of the operation, maximum surface suspended sediment concentrations should be less than 500 mg/ℓ and rapidly decrease with distance. Average water-column concentrations should generally be less than 100 mg/ℓ. The near-bottom plume will probably have a higher solids concentration (4, 7, 10, 34). Within an estuary bucket-dredge-induced resuspension is primarily a near-field phenomenon and represents a relatively small-scale perturbation of the suspended sediment field (5). Sediment suspended by a dredge is similar to that produced by a small-scale storm that begins very suddenly, increases the concentrations, and modifies the quality of suspended sediment fields compared with undisturbed conditions. This turbidity plume appears to decay very rapidly following the reduction of energy required to suspend sediments and maintain sediment suspensions.

Dissolved Oxygen and Contaminant Mobilization

During dredging operations there is potential for significant reduction in the water-column concentration of dissolved oxygen (D.O.) and a detectable elevation in the dissolved concentration of any one of a variety of potentially toxic chemical contaminants if present in the sediments.

Information on changes in the concentrations of D.O. and dissolved contaminants has been thoroughly discussed in many published reviews of the environmental effects of dredging and dredged material disposal (1, 11, 15, 17, 20, 21). However, it is not yet possible to accurately predict whether a significant reduction in D.O. and/or an elevation in dissolved contaminants will occur during dredging or disposal operations using information on the characteristics of the waters and the sediments at the dredging and disposal sites.

Most studies deal with the questions of D.O. reduction and contaminant mobilization at the disposal site. Very few deal with these issues at the dredging site. Assuming similar suspended sediment-water interactions, the following qualitative conclusions are defensible: (a) these operations may increase oxygen demand and, depending on specific conditions, dissolved concentrations of ammonia, phosphate, sulfides, iron, and manganese; (b) the duration of the increased concentrations is a function of dilution by receiving waters; (c) the maintenance of at least partially oxidized conditions and rapid settlement of solids and, under special circumstances, the formation of highly concentrated density layers strongly influence the distribution and fate of sediment-associated chemical substances; (d) the sediment-associated chemical substances remain with the suspended solids where they are trapped by the large adsorptive capacity of the sediments and the oxygenated conditions of the overlying water; (e) the concentrations of most materials in the sediment have little relationship to the effects dredges have on water quality; and (f) bulk sediment analysis cannot be used as an accurate predictor of toxicity to aquatic organisms.

Based on what is known about the physical-chemical and temporal character of bucket dredging perturbations and the tolerance levels of estuarine organisms, we recommend that any determination of a requirement for seasonal restrictions be based on specific characteristics of the project location.

ARRIVING AT DECISIONS ABOUT THE NEED FOR SEASONAL RESTRICTIONS

Examination of the literature describing the effects of suspended sediments on sensitive life history stages of important biological resources suggests the utility of a standardized questionnaire for guiding discussions about the need for seasonal restrictions. The rationale for suggesting each of the questions, methods for obtaining answers, and standards that might be used for interpreting the answers are discussed below.

Question No. 1: Is the dredged material chemically contaminated?

Observations made primarily during controlled laboratory studies, and explanations offered by theories about an organism's physiological tolerance under natural and pollution-induced stresses

(26), lend support to the contention that animals exhibit greater sensitivity to contaminated suspended sediments than to uncontaminated ones. Testing of material to be dredged should not be required if there is "reason to believe" the material does not contain unacceptable levels of contaminants or if there is evidence to indicate that resident or transient biological resources inhabiting the system are adapted to elevated levels of suspended sediment-associated chemical contaminants.

Question No. 2: Is the material to be dredged composed of processed or unweathered natural angular particles?

These types of particles (e.g. incinerator residues, volcanic ash, etc.), in suspension, apparently effect an adverse response by fishes at concentrations which are lower than those required using natural weathered sediments (24). Most dredging projects will involve natural weathered sediments. In those rare instances where the answer to this question is not known, a simple microscopic examination of sediment particles from the dredging site supplemented by available information about the origin of the sediments would be adequate to perform this evaluation.

Question No. 3: What is the continuous open-water distance between the proposed dredging location and a mainland shoreline at mean low water?

Continuous open water may be defined by a line woven among a complex of islands situated between the proposed project and a mainland shoreline or by a straight line through uninterrupted aquatic habitat. Substantial evidence indicates that dredging operations produce a suspended sediment field that is contained within very limited spatial boundaries. This is a critical point relevant to this and to three of the four questions remaining to be discussed. For large bucket-dredging projects, an estimated distance of 500 m (1640.4 ft) or more would ensure the persistence of a safety corridor through which fishes can bypass the suspended sediment field if necessary. Of the three principal dredging plant types, i.e. bucket, cutterhead pipeline, and dragarm-hopper dredges, bucket dredges produce the largest suspended sediment fields (3, 22). Any standards developed therefore for bucket dredging would be conservative when applied to other types of dredging operations. We are unaware of any efforts to compile information about suspended sediment fields produced by small permit dredging operations or shore-based construction operations. These types of operations probably produce very small suspended sediment fields, but in the absence of field observation data, defensible standards cannot be suggested.

Question No. 4: Do local hydrodynamic conditions at the project location favor rapid sedimentation of material suspended by the dredge?

Certain important benthic biological resources are sensitive to increased rates of sedimentation. A significant acute impact potential exists when conditions favoring sedimentation occur in areas inhabited by these resources. In most instances a qualitative judgment about conditions favoring sedimentation or dispersion would be required for answering this question. Factors contributing to the determination should include water current and flow conditions, salinity, bathymetry, and ambient sediment texture patterns, whenever this information is available.

Question No. 5: Do important benthic or planktonic biological resources exist in the vicinity of the proposed project?

A very conservative position would be one that was concerned about important benthic biological resources occurring within 500 m (1640.4 ft) of a dredging project under conditions favoring rapid sedimentation. Reasonable standards intended to protect important planktonic biological resources such as fish or shellfish eggs and larvae are very difficult to define in instances where these resources are known to occur in the vicinity of the dredging project or when there is a chance they may be transported to the project location during the dredging activity. The position that dredging activities should be prohibited in bodies of water inhabited by important planktonic life stages such as striped bass eggs or larvae or hard clam or oyster eggs and larvae is a "safe" and conservative position to assume. But the literature about the responses of these life stages is neither consistent nor easily interpreted. There are strong scientific arguments for reduced restrictions based on the natural association of "sensitive" shellfish larvae with the sediment boundary layer while they search for suitable setting conditions. When these arguments are coupled with knowledge of suspended sediment concentrations representative of turbidity fields actually induced by dredging operations, the position favoring prohibition of dredging to protect these life stages seems unsubstantiated.

Question No. 6: Is there a natural or dredged channel in the vicinity of the proposed project?

A widely accepted professional opinion among fishery biologists is that some important fishes and shellfishes (e.g. anadromous fishes) immigrate to their upstream spawning grounds or emigrate to coastal waters via dredged or natural channel corridors. Occurrence of a dredging project within or adjacent to a channel is then assumed to potentially interfere with the upstream or downstream migrations of these organisms. We suggest that unless project-specific information is available, the expression "in the vicinity of the proposed project" should be defined as a distance equal to or less than 500 m (1640.4 ft). A channel is simply either present or absent. Technical information which describes the relationship between channel characteristics (e.g. configuration, cross-sectional profile, depth, etc.) and the channel's use as a fish or shellfish migration corridor is lacking.

Question No. 7: What are the natural seasonal suspended sediment maxima of the project area?

Cairns (6) stated, "Since aquatic organisms survive (or at least enough survive to perpetuate the species) temporary exposure to rather high concentrations of suspended solids, it seems best to relate suspended solids standards to the variations and conditions to which the aquatic species have become adjusted. This would of course mean that the standards would be based on stream conditions rather than fixed arbitrary standards." We suggest that the standards against which the answer to this question are compared should be based on ambient (background), seasonal suspended sediment concentration maxima (SSSCM) for the project area. The SSSCM value may have to be estimated rather than directly measured. The inclusion of this question in the list is based on our opinion that it is fundamental to any attempt to construct a method for arriving at socially responsible resource management decisions about seasonal restrictions on dredging projects.

If the dredge-induced suspended sediment concentration field substantially exceeds the SSSCM at the proposed dredging location and "sensitive life stages" of "significant biological resources" inhabit the area within the buffer zone, then imposition of a seasonal restriction would appear to be justified.

A standardized list of questions for assisting the determination of a need for seasonal restrictions on dredging operations would direct natural resource and dredging operations managers to the important issues. Rigid criteria against which to compare the responses to these questions are in most instances either inappropriate or technically unsupportable at the present time. The respective importance of site-specific social and political conditions on one hand and the inadequacy of readily available, quantitative impact data on the other, support this position.

In any specific region of the country, natural resource and dredging operations interests may repeatedly find themselves defending opposing positions. When the problems resulting from those opposing positions become sufficiently troublesome to those interests to stimulate a search for solutions, then science may offer additional help. The search should employ (a) an examination of existing, often unpublished technical information, along with (b) controlled laboratory observations which simulate dredging-induced conditions, and (c) field observations during actual dredging operations.

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MODEL APPLICATIONS TO WATER QUALITY IMPACT ANALYSIS FOR COASTAL PROJECTS

By

Susan Ivester Rees, Ph.D. [1]

INTRODUCTION

The Mobile District has responsibility for the operation and maintenance of civil works projects in Mississippi, Alabama, and the panhandle of Florida. At present there are 21 coastal navigation projects including six deep-draft channels and 340 miles of the Gulf Intracoastal Waterway with annual maintenance requirements ranging between 18 to 20 million cubic yards of dredged material. These projects are located in shallow estuaries and bays that are typical of the northern Gulf of Mexico and utilize a number of disposal alternatives including upland, island, ocean and open water adjacent to the channels. Continued maintenance and improvement of the channels has raised a number of questions concerning the availability of upland sites, the expense and impacts associated with island creation and ocean disposal, and the impacts of shallow open water disposal.

In 1977, the Mississippi Sound and Adjacent Areas Study was initiated, via Congressional Authority, in an effort to determine what changes, if any, should be made in the Districts' coastal dredging program in the interest of economic efficiency and environmental quality. In order to predict the impacts which might result from any changes, an evaluation methodology was developed which allowed: 1) the description of existing conditions; 2) the prediction of changes in the system which could result in the future from continuation or change in a dredging or disposal practice; and 3) the determination of changes in the system which may have been caused by construction of an existing project. This paper discusses the evaluation scheme and its applications to the Federal navigation project at Pascagoula, Mississippi.

EVALUATION METHODOLOGY

Numerical Models

The methodology utilizes a series of numerical models in the prediction of impacts of various planning activities associated with navigation projects. A telescoping approach was utilized starting with a model of the Gulf of Mexico and focusing down onto a model representative of a particular navigation project.

[1] Oceanographer, Environmental Branch, US Engineer District Mobile

The Gulf Tide Model (Reid and Whitaker, 1981) is a vertically integrated linear model with a constant cell size of 15 min X 15 min. The output of this model, components of the five major tidal constituents K , O , P , M , and S , serves as the boundary condition for a more refined geographic model. The Waterways Implicit Flooding Model or WIFM (Butler, 1980) approximates the hydrodynamics with an ADI explicit-implicit difference scheme from a grid system utilizing spatially varying cell widths. The minimum cell size in this grid is 3500 - 4000 feet (106,680 - 121,920 m). A flux corrected salinity transport algorithm was added to WIFM by Schmalz (1983). WIFMS, as it is now called, considers the influence of tides, wind stress, and tributary inflows and provides velocity vectors, salinity, and water surface elevation with respect to time for each grid cell.

The refined grid model (WIFMS) for Pascagoula is a nearshore model which extends from the west end of Horn Island to near the east end of Petit Bois Island in the east-west direction and from Pascagoula Harbor, in the north, to approximately three miles (4.8 km) south of Horn Island (Figure 1). The highest resolution of the grid is employed in the area of the navigation channels with a minimum cell width of approximately 300 feet (91.44 km). The boundary conditions for open water of the refined grid model were defined by results from the larger grid which includes the entire Mississippi Sound area.

Calibration and Verification

Because a model is only as reliable as the data used to construct the model, an extensive data set was collected in Mississippi Sound/Mobile Bay and the Gulf of Mexico. The model was then calibrated utilizing data from one time period and verified against data from a different time period. Based on these calibration/verification procedures, the model accurately reproduces the hydrodynamics of this estuarine system.

Base Conditions

In addition to their use in calibration/verification procedures, the data were analyzed to delineate boundary conditions which could be used to represent the system for extended periods of time. These conditions are:
1) low freshwater inflow and a 9 mph (14.5 km/hr) wind from the SSE;
2) high freshwater inflow and a 9 mph wind from the SSE;
and
3) low freshwater inflow and a 9 mph wind from the NNW.

Model runs were made for a 72-hour period (3 complete tidal cycles) at which time the model stabilized with respect to salinity.

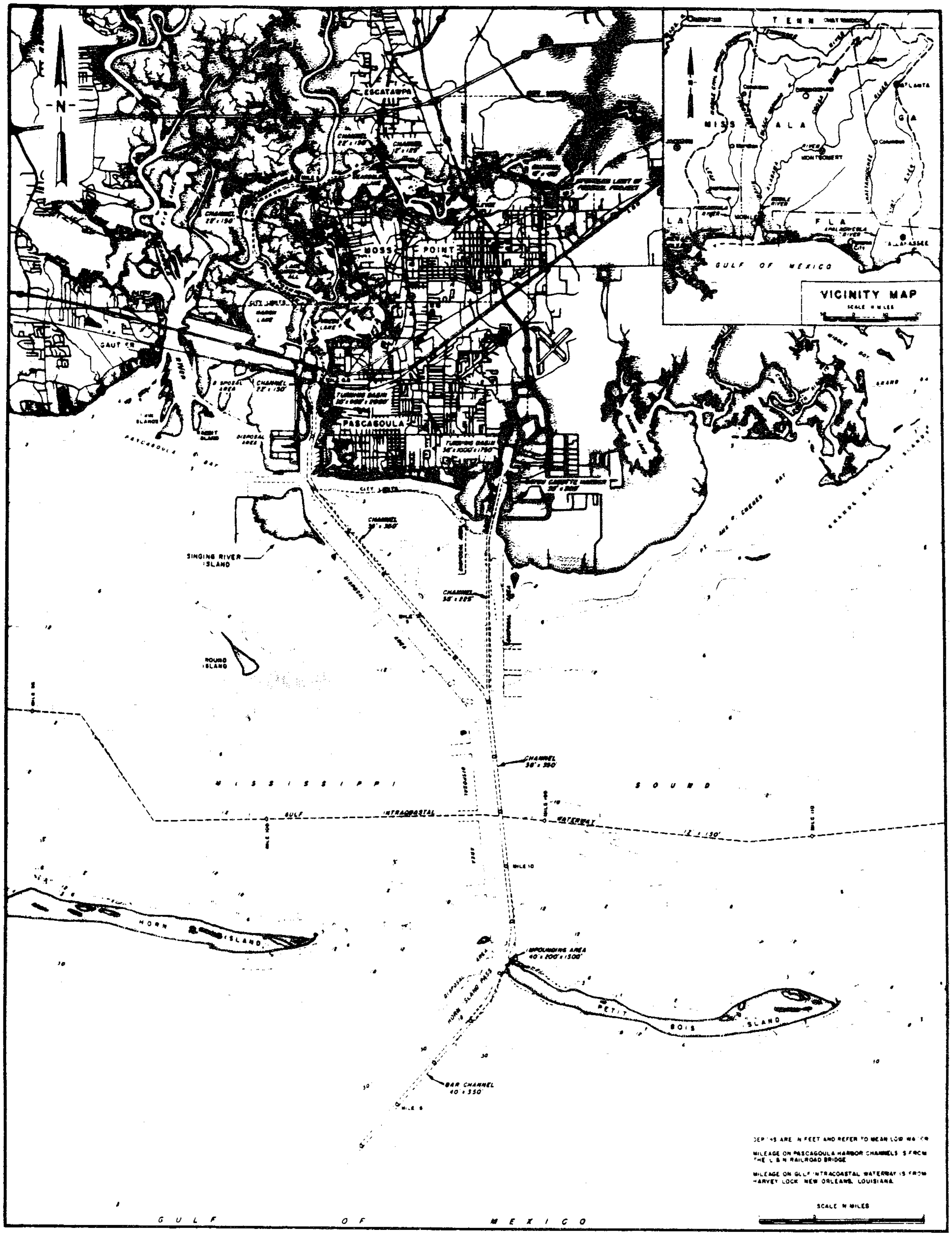

Figure 1. Pascagoula, Mississippi Navigation Project

SIMULATION RESULTS

Existing Conditions

Under existing conditions, circulation within the area is controlled by astronomical tides, winds and freshwater inflow. The average tidal range is 1.5 feet (0.46 m) with a predominant diurnal period of 24.8 hours. The tidal wave progresses from south to north, entering Mississippi Sound through Horn Island Pass, south of Pascagoula. The wave then splits, traveling both eastward and westward, causing as much as a 6 hour phase shift within Mississippi Sound. The effect of the wind is significant, causing a shift in this bifurcation area at Horn Island Pass either toward the east or west, depending on the magnitude of the east/west wind component and the phase of the tide. Freshwater inflows have a slight effect on the overall circulation pattern. Comparision of high inflow conditions to low inflow conditions shows the same general circulation pattern, with an increase in current velocity during high inflows (U. S. Army Corps of Engineers, Mobile District, 1984). Current velocities range between 0 to 3 feet per second (fps) (0 to 0.91 m/s) in the barrier island passes and between 0 to 0.8 fps (0 to 0.24 m/s) in Mississippi Sound. Salinities are highly variable, ranging from zero during high freshwater inflow to full Gulf salinities during late summer.

Alternative Evaluation

A number of alternatives were evaluated which involved the deepening of the navigation channels from their present 38-foot depth to 55 feet and a number of disposal alternatives including the creation of dry land adjacent to the harbor area, creation of islands in Mississippi Sound, the enlargement of Singing River Island, beach and barrier island nourishment, and continuation of existing open water disposal. For each of the alternatives, e.g., deepened channel without a disposal option, deepened channel with continuation of existing open water disposal, deepened channel with enlargement of Singing River Island, three model runs - one for each of the base conditions - of 72-hour duration were made. Each of these was compared to the appropriate base condition as modeled and the change in circulation and salinity structure was determined. For example, simulation of the deepened channel during typical summer low inflow conditions and SSE winds revealed a decrease in average water velocities in the region south of the river mouth for a distance of approximately 2 miles (3.2 km). The reduced velocities in this area could worsen the area's currently existing poor water quality condition. Also, higher concentrations of metals and hydrocarbons could accumulate in the surface sediments within this area. Furthermore, reduction in water velocity could cause increased sedimentation in this area resulting in the need for increased dredging. The model simulation also indicated that velocities within the Horn Island Pass channel would tend to increase gulfward with implementation of a deepened channel. In addition, a decrease in the net influx of water through the pass into the Sound on flood tides, and an increase in net flux of water through the Pass out of the Sound on ebb tide was indicated by the model.

Both these factors could have a deleterious effect on the migration of larval and post larval forms of fish and shellfish which utilize the tidal passes to enter the nursery grounds within Mississippi Sound.

The next simulation involved deepening of the channel and continuation of open water disposal. The State of Mississippi has imposed a restriction on open water disposal in Mississippi Sound such that disposal areas may not be made shallower than minus 4 feet MSL. In our simulation, the disposal areas in the northern half of the Sound were raised to this elevation and the base conditions run. As with the deepened channel simulation, this condition caused a decrease in average water velocities during the typical summer low inflow periods within the Bayou Casotte channel and southward in Mississippi Sound. In addition during the high inflow simulation waters from the East Pascagoula River were confined to the channels by the 'diking' effect of the open water disposal areas.

Since Singing River Island is a prime disposal and industrial area, a simulation was run which involved the deepened channel and enlargement of the island to approximately 1,790 acres. Approximately 36% of this area is currently above water. Much of the discussion of the impacts relating to deepening channels and open water disposal presented in the previous paragraphs also applies to this simulation. In addition, this design further resulted in reduction of velocities within the diagonal channel leading into the main harbor area. These reduced velocities would increase the area which could experience poor water quality conditions.

After stepping back and looking at the results of all the simulations, a common thread appeared in all the simulations. Singing River Island has been created over the past 40 years through the deposition of dredged material and appears to play a major role in the present circulation patterns and water quality within upper Mississippi Sound. To test this hypothesis, 'preproject' conditions were simulated in the model and compared to the existing conditions. The geographic boundaries of 1917 were assumed representative of the preproject. At this time the navigation improvements at Pascagoula consisted of a 17-foot channel and Singing River Island did not exist. The main differences between the 'preproject' and baseline conditions can be attributed to Singing River Island and open water disposal in upper Mississippi Sound. Singing River Island acts as a deflector which funnels freshwaters from the East Pascagoula River to the east and southeast. These waters would normally flow westward and southwest into Mississippi Sound. This deflection of waters has probably resulted in insufficient circulation in the area of the channels with resultant concentration of pollutants from river waters in the sediments of the channels. Open water disposal in the upper Sound has resulted in shallowing of the area and in some cases creation of emergent lands. This has tended to increase the funneling effect of the island. Subsequent testing of the sediments within this area of Mississippi Sound mirror these changes. Locations west and southwest of the island are remarkably clean compared to those in the channels and in the area east of the island.

In light of the evidence, Singing River Island is in the wrong place with respect to the mainland shoreline and the Pascagoula River system. Realistically we cannot change the location of Singing River Island, however we were able to modify our maintenance practices by deleting those open water disposal areas in the upper Sound area which, if used to the minus 4-foot MSL limit, would result in additional significant impacts to circulation patterns.

Models are only tools to be used in concert with an understanding of the system and existing conditions. Their application will not give instant answers, but only a piece or pieces to the puzzle. However, this example shows that models can be successfully applied in water impact analysis for coastal areas. Similar models are available for other coastal areas and these tools should receive greater utilization than has been afforded in the past.

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THE WATER QUALITY IMPACTS OF HARBOR AND COASTAL STRUCTURES

BY

Thomas H. Wakeman [1]

INTRODUCTION

The construction of onshore or nearshore structures and the subsequent effects of these structures have the potential of altering water quality in harbor and coastal environments. The Shore Protection Manual (Coastal Engineering Research Center, 1984) categorizes four general classifications of coastal engineering problems that may benefit from structural solutions: (1) shoreline stabilization; (2) backshore protection (from wave and surge); (3) inlet stabilization; and (4) harbor protection. These solutions involve the placement or removal of sediment, rock, wood or other material to create new structures, to modify existing structures, or to physically alter the shore.

During the process of construction of these structural solutions, several water quality impacts can occur. Most of these impacts are short-lived, including increases in turbidity, releases of toxicants, nutrients or petroleum products, and/or the reduction of dissolved oxygen. The most severe consequences of on and nearshore structures stem from the alteration of circulation patterns and flushing reductions that can occur following the construction. These changes in the hydrodynamic regime (circulation) and hydraulic and wave energy conditions (flushing) can be responsible for long-term water quality impacts.

STRUCTURES AND EFFECTS

Onshore and nearshore structures may be segregated into four categories: (1) groins, (2) bulkheads, revetments and seawalls, (3) jetties and (4) breakwaters. Each of these man-made structures has a slightly different purpose and impact in the coastal or harbor environment. Following is a brief description of each structure. The descriptions have been ranked so that each successive structure described has a greater potential for causing water quality impacts than those previously described.

a. Groins are structures that extend from the backshore into the littoral zone. They are generally constructed in series to modify the longshore movement of sand by accumulating or retarding sand loss. Because groins change local patterns of water circulation, some changes in specific water quality parameters may occur. Slight fluctuations in temperature, dissolved oxygen, and dissolved organics may be anticipated in the sheltered waters in the lee of groins. These impacts are minor, and long-term water quality problems should be insignificant from most groin projects.

[1] Model Director, San Francisco Bay - Delta Tidal Hydraulic Model, San Francisco District.

b. Bulkheads, seawalls and revetments are onshore structures that, although similar in design, provide slightly different protection to the upper shore whether beach or erodible bluffs. Bulkheads are chiefly soil-retaining structures that resist wave attack. On the other hand, seawalls are constructed to resist wave attack but also may retain some soil to aid in the process. A revetment differs from the first two by simply being an armoring of the existing slope face of a dune or embankment. Revetments are not soil-retaining structures but merely protect the shore from wave attack. The environmental effects of bulkheads and seawalls are similar in that both may promote erosion of the foreshore. This erosion is caused by an increase in scouring wave energy due to waves being reflected off the face of the structures. Foreshore erosion may be particularly severe during storms. These structures may also promote erosion of adjacent beaches. This increased erosion will increase the local levels of suspended solids and reduce light penetration. Often in conjunction with bulkheads and seawall construction an "improved" upland drainage system is incorporated into the design to protect the structure. Runoff concentrated by the drainage system will effect local water quality in some cases. Revetments, unlike bulkhead and seawalls, may improve water quality at the site by reducing turbulence. Wave energy tends to be dissipated by run-up on revetment faces instead of reflected as with the other structures. All three structures may modify circulation and flushing conditions thus influence local water quality. However, any changes in chemical parameters should be minor.

c. Jetties are structures extending offshore to direct or confine river or tidal flow into a channel and to prevent or reduce shoaling of the channel by littoral material. Training works located in estuaries and along rivers to guide currents and to assist in channel deepening are also commonly called jetties. The placement of jetties may not only alter circulation patterns and flushing conditions but also alter both river outflow and tidal conditions. These impacts are often of consequence well into the estuary and may have widespread effects. Temperature and salinity or other water chemistry changes may occur with increased water residence time caused by the change in water flow through the stabilized channel. The channel formed by jetties frequently migrates to one of the jetties from its original course, scouring the bottom and increasing turbidity levels in the project area. If a single jetty is installed, the opposite side of the inlet often erodes with concurrent shifts in circulation and impact on flushing action.

d. Breakwaters are wave energy barriers designed to protect landforms or harbor areas behind them. These offshore structures, by definition, influence circulation and flushing action in their lee. Furthermore, if the breakwater is constructed to form a semi-enclosed basin for use as a harbor or marina, the flushing conditions of the project area may be dramatically altered. Wave energy is greatly reduced inside the breakwater reducing mixing and decreasing or obstructing littoral drift. Furthermore, a fixed breakwater can cause piling-up of water behind it, decrease circulation and interfere with tides and currents. The ramifications of these changes in the area's hydrodynamics and hydraulics may include increased water temperature and salinity, increased toxicant and nutrient concentrations, increased light penetration with subsequent increases in algal biomass, and reduction of the dissolved oxygen concentration. Other water quality impacts may occur as a result of secondary effects stemming from the creation of a protected area. Shoreline construction and increased vessel traffic may introduce oxygen consuming materials and pathogenic organisms, release toxic wastes, or spill/dump petroleum products into the harbor. Any of these actions will further reduce water quality in the project area.

Assessment and evaluation of water quality impacts must begin in the planning stage and continue at least through the design stage. Post-construction monitoring is also recommended to provide feedback for future planning and design. To illustrate one method of incorporating water quality considerations into the planning and design process, a case study using numerical models to assess impacts following construction of a breakwater at San Francisco's Fishermans's Wharf Harbor will be presented.

CASE STUDY BACKGROUND

Fisherman's Wharf harbor is located in central San Francisco Bay approximately two miles east of the Golden Gate (Figure 1). The harbor is unprotected from surge and wave action. Periodically, the commercial fishing fleet, the piers and wharfs and the Golden Gate National Recreation Area's historic ships suffer extensive damage during winter storms and periods of high winds. To ameliorate harbor conditions, the San Francisco District of the U.S. Army Corps of Engineers was authorized by the U.S. Congress to construct a breakwater structure. Although a breakwater would reduce wave energy entering the harbor, there was also concern that the structure might adversely impact local water quality conditions. To assess the potential impacts and gain assistance in the design process, the District requested that the Hydrologic Engineering Center (HEC) evaluate potential changes in circulation and flushing action resulting from construction of two different breakwater configurations (one connected to Hyde Street Pier and the other detached).

STUDY APPROACH

The HEC elected to implement a combined program of field sampling and application of numerical models to analyze the hydrodynamics and water quality in the study area. Data from the monitoring and field sampling program were used to establish base-line information for the development of boundary conditions and to calibrate and confirm the hydrodynamic and water quality models. These models were used to quantify the differences between proposed alternatives in breakwater design, with special emphasis on circulation and water quality. They were originally developed by Resource Management Associates (RMA) of Lafayette, California. The hydrodynamic model is called RMA-2 and the water quality model is known as RMA-4.

MODEL PREPARATION

In order to be utilized in the Fisherman's Wharf Harbor area, RMA-2 and RMA-4 needed to be calibrated and confirmed using prototype data collected in the study area. These data were obtained using continuous monitoring and periodic field sampling between October 1982 and September 1983. Data collected included vertical profiles of current speed and direction at the study area boundaries, single and multiple depth current observations near harbor structures, long-term wave energy and surge measurements, long-term meteorogical observations and four water quality data field surveys (HEC, 1983).

Simultaneously, with the development of the prototype data base, the models were being prepared for application. These models are finite element models. A numerical network representing the existing harbor conditions was constructed containing 228 elements and 714 nodes. Existing bathymetric data were used to prepare a contour map of the bottom and this information was incorporated into the finite element network. Using this network, a series of simulations were computed for ebb and flood tides under both steady state and dynamic tidal conditions. These simulations included formulation to account for the frictional resistance to flow through the area's piers and other structures. Following the calibration process, RMA-2 was verified to be in good agreement with measured circulation data (HEC, 1984).

The next step in the process was to use the hydrodynamic results from RMA-2 as input to the water quality model, RMA-4. This model is a constituent transport model that computes multiple constituent concentrations as mixing occurs during advection and diffusion. Water quality data obtained during the field sampling program were used for model calibration and development of the water quality boundary conditions. The model was thereafter confirmed through a combination of individual parameter (DO, SS, BOD) comparisons of relative constituent concentrations and constituent gradients between the model and the prototype (HEC,1984). Results indicated that the model could successfully simulate existing water quality conditions in the harbor.

PRODUCTION RUNS

Following completion of model preparation, the next step was to develop numerical networks for the two proposed breakwater configurations. The networks were created, and the models were applied to assess the potential impact of each configuration on circulation, flushing and three water quality characteristics (DO, SS, BOD) in the harbor and adjacent areas.

The simulations suggested that both configurations would negatively influence water quality in the harbor because of changes in circulation and flushing. The configuration with the breakwater connected to Hyde Street Pier was predicted to reduce the flushing capacity by 54 percent on flood tide and 37 percent on ebb tide. The detached configuration appeared to have less impact on flushing with calculated reductions of 30 percent on flood tide and 17 percent of ebb tide. Simulations of dissolved oxygen concentration indicated that in low energy areas concentrations would be degraded between 0.3-0.5 mg/l, with the detached breakwater having slightly less impact. Likewise, suspended solids concentrations and biological oxygen demand levels were elevated by the breakwaters, 0.5 mg/l and 1.0 mg/l respectively.

Subsequent physical model evaluations of these two configurations indicated that neither of the two designs provided adequate interior wave height protection for the harbor (Bottin et al., 1985). Recognizing the superiority of the detached design, this configuration was modified and refined during additional physical model tests until a final configuration was identified that satisfied interior and entrance channel wave height criteria. This new configuration was also modeled by HEC and tested to determine its effects on harbor circulation and water quality.

Unlike the prior configurations, the new configuration only slightly modified overall circulation and flushing. In fact, the simulations suggested that net flushing would improve approximately 8 percent during flood tide and about 4 percent during ebb. Hydrodynamic simulations indicated that the breakwater would redirect portions of the ebbing tide through the harbor that presently are deflected around the harbor by Pier 45 as well as capture a greater portion of the incoming flood tide. Maximum predicted changes from existing conditions for dissolved oxygen, suspended solids and biological oxygen demand were 2, 3 and 6 percent, respectively. These changes were found only to occur during the slack water after ebb tidal period. During all other phases of the tidal cycle, constituent concentrations were simulated to change 2 percent or less. Thus, the new breakwater configuration appears to cause only minor impact on existing flushing and water quality conditions based on the RMA-2 and RMA-4 numerical results.

SUMMARY AND CONCLUSION

Structural solutions to coastal engineering problems have the potential of adversely impacting water quality. Their impacts may occur during the initial construction phase as well as thereafter. Long-term impacts on water quality result from changes in circulation patterns and reduction of flushing action. Each of the four basic categories of onshore and nearshore structures has a slightly different potential for water quality impacts. Generally, groins have the least potential and breakwaters the greatest potential for creating long-term negative impacts on water quality.

If during the planning and design process, the potential for adverse water quality impacts is considered and assessed, then methods, such as numerical and physical models, etc., can be applied to assist in designing structures that minimize future water quality problems. As illustrated by the Fisherman's Wharf Harbor breakwater case, the original configurations, if built, may have caused a major problem in a highly sensitive area. Fortunately, water quality issues were examined. It is important that post-construction monitoring be performed to provide feedback to the planner and designer as to the success of the selected method for incorporating water quality considerations.

ACKNOWLEDGEMENT

The author wishes to acknowledge the Hydrologic Engineering Center, Bill S. Eichert, Director; Robert C. MacArthur of Simons, Li & Associates, principal investigator on the Fisherman's Wharf Harbor project; and William R. Norton of Resource Management Associates, the modeler on the project. Without the support and assistance of each, the findings presented with regard to potential water quality impacts caused by breakwater construction at Fisherman's Wharf Harbor would not have been available. Furthermore, I want to thank Jerry Willey, HEC, and Robert Engler, WES, for the opportunity to participate in the Committee on Water Quality's sixth seminar.

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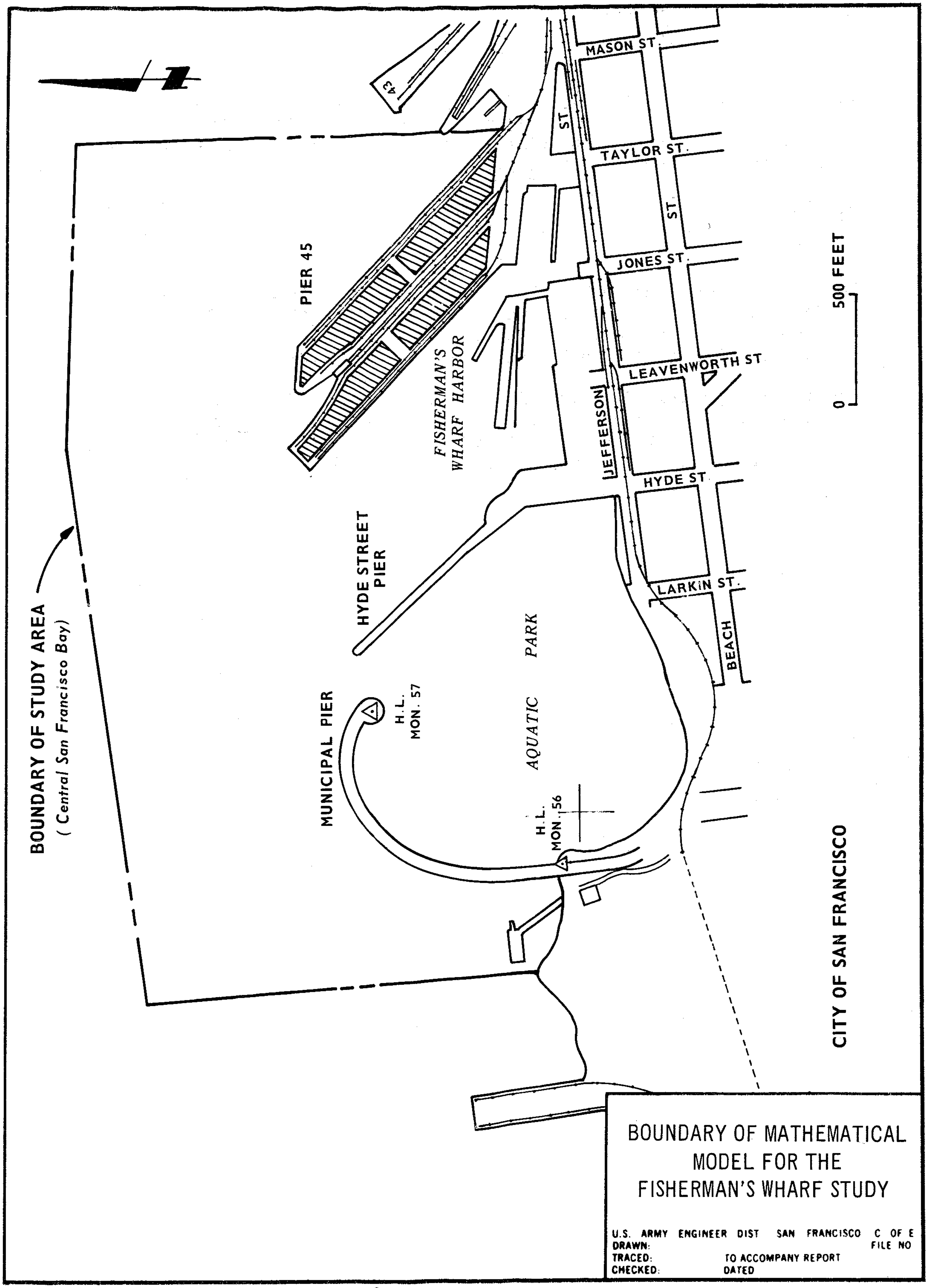

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FIGURE 1

TAMPA HARBOR OCEAN DISPOSAL LITIGATION

BY

LLOYD H. SAUNDERS, PH.D.

A study of Tampa Harbor at the request of the Port Authority in the late 1960's, found that harbor deepening was economically feasible. The survey report was submitted to Congress and resulted in project authorization in 1970. The project provides a 43-foot main channel from the Gulf of Mexico into East Bay and branches to Sparkman and Ybor Channels and to Port Tampa. The authorization specified that project-related environmental studies be conducted during the preconstruction planning and construction stages to determine the design and construction practices that would have the minimum adverse effect on the ecology of Tampa Bay and that would enhance existing conditions.

When preconstruction planning commenced on the project, the major problems involved the details of engineering and environmental considerations incident to the excavation and open-water disposal of approximately 73 million cubic yards of material. Of this quantity, about 63 million cubic yards were removed from the main channels, and about 10 million cubic yards will be removed from the branch channels. The project has required intensive study, data collection, and coordination between parties with special knowledge. Practical considerations, limitations imposed by technological or natural constraints, and financial resources, are all factors. It is this process of study, design, and coordination which the Corps of Engineers has endeavored to follow from the beginning.

When preconstruction planning had advanced to the stage where a plan had been developed, the Jacksonville District, in early 1973, requested participation of an Interagency Group to monitor progress of environmental studies on Tampa Harbor. Several meetings were held and the Group's assistance was very helpful to the District staff in producing the Draft Environmental Impact Statement. That draft was coordinated with all interested parties in February 1974 and The Final Statement was filed with CEQ in July 1975 (Figure 1).

1 Chief, Environmental Resources Branch, Planning Division, Jacksonville District

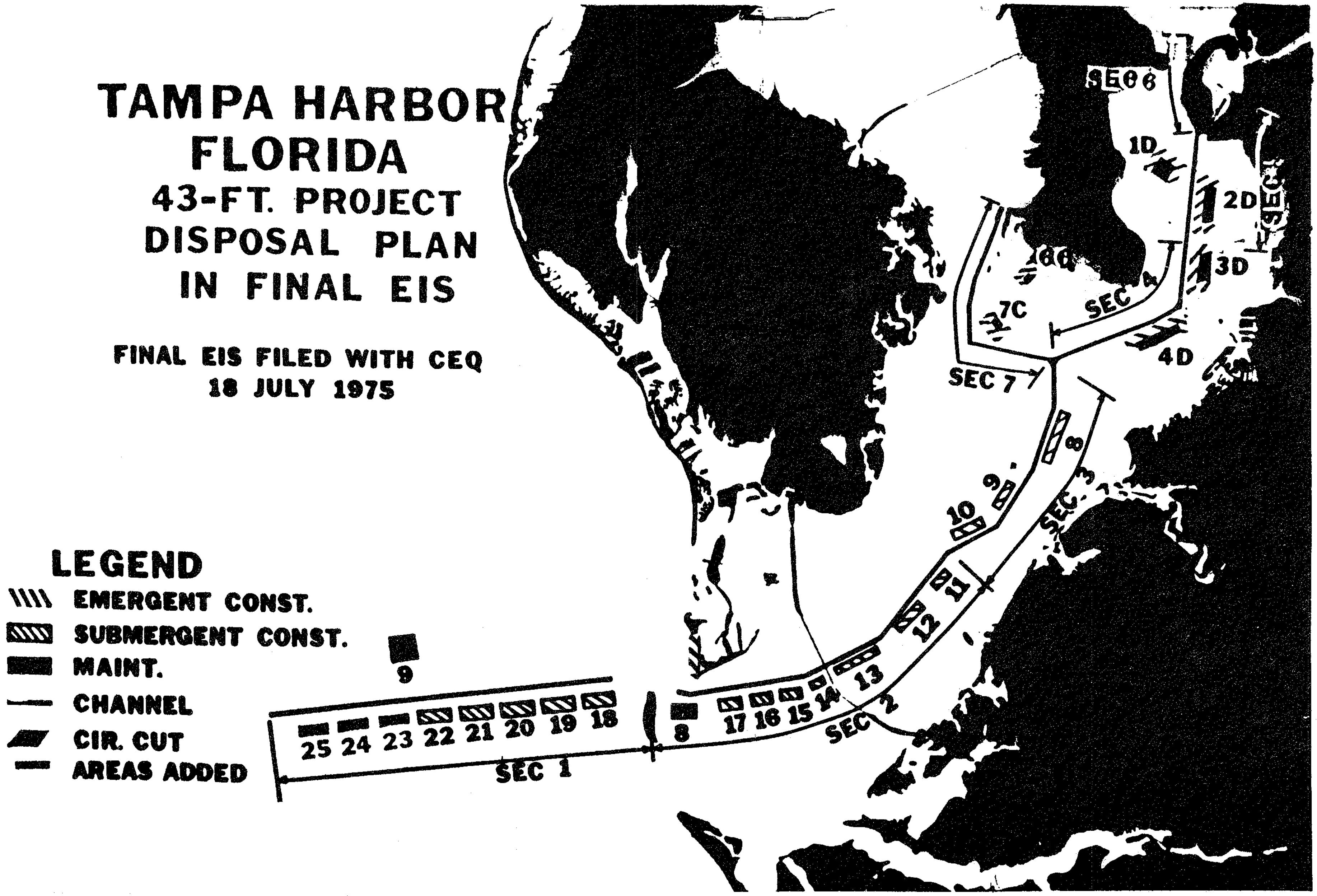
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FIGURE 1

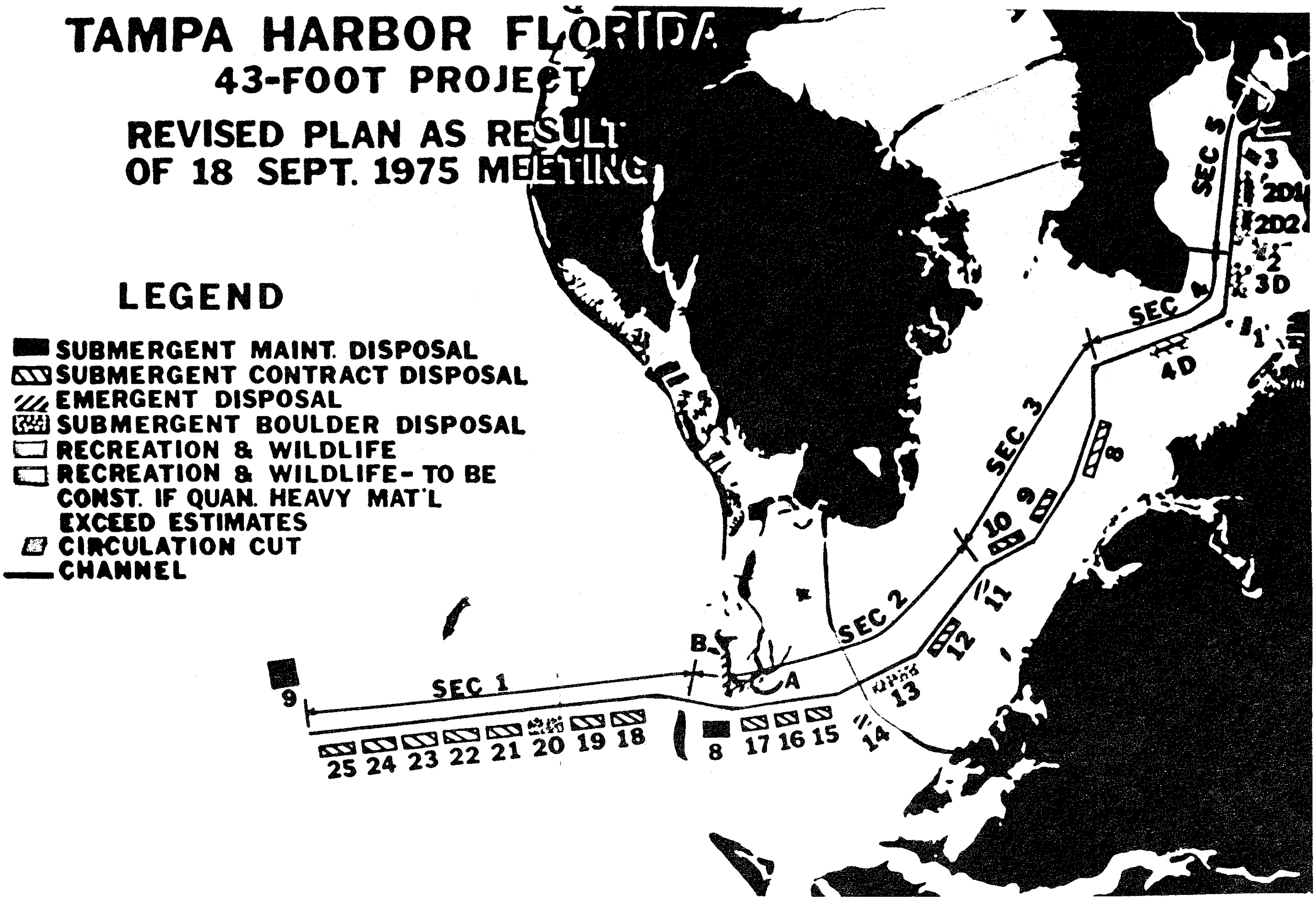
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FIGURE 2

A public meeting was held in Tampa in 1974 to discuss the project. As a result of comments received at the meeting, a special Ad Hoc Committee was formed to pinpoint environmental issues associated with the project and to offer assistance to their solution. Several meetings have been held in the years since, and a number of suggestions have been explored at those meetings and in correspondence between District staff and members of the committee. The end result of the suggestions and our investigations was the adopted plan for Tampa Harbor. This plan was sufficiently different from that presented in the final environmental statement that a supplement was prepared and filed with CEQ in 1977 (Figure 2).

There were significant differences in the open-water disposal plans prepared in 1975 and 1977. By 1977 the disposal areas in Hillsborough Bay had become completely diked to contain future maintenance material. An historic ocean disposal area, Site B, was relocated seaward five nautical miles and renamed MD/A-9. This site was subsequently called Site A and was the subject of litigation in 1982.

Construction began on the deepening project in 1976. With each construction contract there was an environmental monitoring contract. The environmental monitoring was designed with the assistance of the Ad Hoc Committee and generally reflected the level of environmental concern in different areas of Tampa Bay. For instance, the intensity of monitoring was lower in the open Gulf than in the Bay. In the Bay, it included physical, chemical, benthic and sensitive areas monitoring. As a result of the monitoring, we had accurate documentation of the environmental impact of the construction as it was occurring. This information was provided to the design engineers, and the construction was modified to reduce adverse impact.

During 1979, Corps hopper dredges were scheduled to construct part of the project with disposal in the Gulf at Site A. A diver survey was performed at Site A and no marine communities of any significance were observed. Bioassays were performed on the dredged material and it met the criteria for ocean disposal. EPA approved the use of the site, and about 665,000 cubic yards of material were placed in Site A in 1980.

At the request of the City of St. Petersburg, maintenance of St. Petersburg Harbor was scheduled in 1980. An examination of the material revealed that it was predominantly silt, but it met the criteria for ocean disposal. For whatever reason, the disposal of this material became an environmental issue. The issue was kept alive by local scientists, public servants, politicians, and above all, the media. The major opponents of ocean disposal were entities within Manatee County on the southwest shore of Tampa Bay. The major fear was "some of the gunk would float to the surface and be washed ashore on Manatee County beaches, notably Anna Maria Island". This fear was never overcome and the issue became generalized to opposition to ocean disposal. To support this broad opposition to ocean disposal many arguments have been developed by the opponents. St. Petersburg Harbor was dredged in 1980 and 383,000 cubic yards of silt were placed in Site A. The opponents in Manatee County were furious. They retained a very capable law firm in Miami and commenced legal proceedings against the Corps and EPA.

The results of environmental monitoring indicated that the impact of construction within Tampa Bay was as we had anticipated in the environmental statement. Sensitive areas along the shore were not impacted; and physical, chemical, and biological parameters returned to normal quickly after construction. The most noticeable impact during construction was turbidity from open water disposal in Tampa Bay. The combination of silt, clay, and limestone in some reaches of the project generated large and visible turbidity plumes. Although the biological and chemical monitoring demonstrated no adverse impact, the perception of turbidity as an unacceptable impact prevailed. This perception was given broad and frequent exposure by the media. The environmental monitoring results and reports were ignored by the critics and the media.

In order to reduce the impact of open water disposal in the Bay, the decision was made to dispose of about 7 million cubic yards of material at Site A. This decision was environmental enhancement. The material was a combination of silt, clay, and limestone. Disposal in the Bay would generate an extensive turbidity plume for the duration of the construction. The fines would continue to be suspended by surface currents for some time after construction. The Bay is more productive and sensitive than Site A. Disposal in Site A would not create a visible plume, and the fines would not be resuspended by surface currents. The environmental benefits of Gulf disposal of this material outweighed the additional costs of transporting it to Site A. In 1981-82 about 3.3 million cubic yards of dredged material from the Tampa Harbor Deepening Project were placed in Site A.

Site A has never received final designation as an ocean disposal site. It was an interim designated site while the Jacksonville District was using it in 1980. At the request of the Jacksonville District, EPA was conducting field studies to permanently designate a Gulf disposal site in the Tampa area. This was a lengthy process-study, EIS, and formal rulemaking for final designation. In the meantime the plantiffs were preparing their case against the Corps and EPA.

Manatee County brought suit in March 1982, and the case was tried in Tampa in late 1982. The court ruled that the Corps had not adequately complied with NEPA and the Marine Protection, Research and Sanctuaries Act in using Site A and enjoined further use until EPA completed designation of a permanent site. The court also concluded that the permanent site would be available for use on 1 February 1983. The "permanent" site, Site 4, was finally designated in November 1983. It cost the government $4,886,956 to terminate and rebid the completion of the deepening project. The injunction delayed completion of the project one year.

EPA conditioned the designation of Site 4. The site was designated for only 3 years and only construction material (no maintenance material) could be placed in the site. The site would also be monitored; and if significant adverse effects were observed outside the site, disposal would cease. The annual budget for monitoring was $100,000, but local pressure on EPA resulted in an actual cost of $142,000 in 1984 and $528,000 in 1985. Construction of the main channel of the Tampa Harbor Deepening Project was completed in 1985. There is still no ocean disposal site for maintenance dredged material.

TESTING BIOAVAILABILITY OF POLYCHLORINATED BIPHENYLS FROM SEDIMENTS USING A TWO-LEVEL APPROACH

by

Victor A. McFarland[1] and Joan U. Clarke[2]

INTRODUCTION

Public laws (Section 404 of the Clean Water Act and 103 of the Ocean Dumping Act) regulating dredged material disposal require ecological evaluation prior to permitting of operations. Assessment of bioaccumulation potential of chemical contaminants in sediment may be required as a part of the evaluation process. Current methodology (USEPA-CE 1977) involves exposure of aquatic organisms for a period of ten days to sediments deposited in aquaria. Analysis of tissues of surviving organisms at the end of this period indicates whether detectable bioaccumulation has occurred, and thus, whether there exist in the sediments specific chemicals of interest in bioavailable forms. The current approach is applied empirically on a case-by-case basis and is limited to simply demonstrating bioavailability under the conditions of exposure. This procedure yields no information concerning residues of chemicals that could result in organisms given prolonged exposure to the sediments. Neither is there included any means of relating gross chemical contamination of sediments to concentrations that could result in exposed organisms, i.e., a measure of the potential for bioaccumulation.

Methods capable of indicating probable residues in organisms given prolonged exposure to chemically contaminated sediments would offer substantial advantages over current practice. Tissue residues may be more accurate predictors of toxicity of certain organic chemicals than exposure concentrations (Friant and Henry 1985). This is suggested by the fact that tissue residues reflect only that portion of sediment-associated chemical that is actually available to the organism. Many factors operate in the field to influence the bioavailability of such chemicals. Examples include water solubility of organic chemicals, organic

[1]Aquatic Biologist and [2]Research Scientist, Environmental Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

carbon content of sediments and their particle size distributions, dissolved organic carbon, suspended particulate and microparticulate concentrations, temperature, hydraulic retention time of the aquatic habitat, and life style and stage of development of aquatic organisms.

McFarland (1984) suggested a two-level approach for evaluating organic chemical contaminants in sediments. Level-I evaluation would be based on chemical phase distribution relationships and would use the results of sediment chemical analysis to estimate a theoretical maximum tissue residue resulting in an exposed organism if all the chemical of interest in the sediment were bioavailable. Level-II evaluation would follow if the maximum calculated in Level-I were judged unacceptable, and this level could involve exposures of aquatic biota to the sediment as is done presently.

Level-II evaluation would use the resultant tissue residue data after ten days exposure to project steady state residues by application of a kinetic model. Comparison of the potential in Level-I with the projected achievable in Level-II results in a semi-quantitative estimation of bioavailability of chemicals in the sediments under investigation.

As originally described, Level-II evaluation could be accomplished using single time-point observations of tissue residue, such as would result from the current ten day sediment bioassay, provided elimination rate constants for the chemicals under consideration were known or could be estimated (McFarland et al. 1984). We now feel that it is unlikely that accurate results can be obtained in this way. Estimation equations for calculating elimination rate constants rely on water solubility or octanol:water partition coefficients (Neely 1979, 1984; Spacie and Hamelink 1982). These methods are inaccurate for highly hydrophobic chemicals, e.g., high molecular weight polynuclear aromatic hydrocarbons, or PCBs having three or more chlorine substitutions per molecule. Elimination rate constants are reported in the literature for some of the chemicals of concern as sediment contaminants. However, the utility of these is limited by the lack of consistency in the methods by which the rate constants were obtained. For these reasons, we have continued to employ methods using time-sequenced sampling and empirical determination of steady-state residues in tissue.

In this paper, we further describe the two-level approach and report some results of an experiment involving exposures of freshwater fish and bivalve molluscs to contaminated sediments. These results illustrate the magnitude of the differences between Level-I potential and Level-II projected achievable contaminant bioaccumulation from sediments.

LEVEL-I EVALUATION

Partition coefficients relate concentration of a chemical in one phase of a two-phase system to concentration in the second phase when the system is in equilibrium. Examples of partition coefficients that are useful in describing the behavior of chemicals in the environment are:

a. Kow -- octanol:water
b. Koc -- soil or sediment organic carbon:water
c. S -- pure chemical:water (aqueous solubility)
d. BCF -- organism:water (bioconcentration factor)
e. H -- air:water (Henry's Law constant)

Water is the second phase in all of the partition coefficients listed above; however, water is not a phase of interest in a Level-I evaluation. At this level, we wish to know the equilibrium phase distribution of a chemical between the two environmental compartments: sediment and organism. By normalizing chemical concentration data on the appropriate bases for phase activity, it is possible to estimate the difference in "preference" of a chemical for either sediment or organism using free-energy relationships. Knowing such a "preference factor" (pf) permits calculating equilibrium concentrations of chemicals in organisms using data from sediment chemical analysis.

For neutral organic chemicals, the appropriate normalizing bases are lipid in organisms (Konemann and van Leeuwen 1980, Geyer et al. 1982, Mackay 1982) and organic carbon in sediment (Karickhoff 1981). Two equations that have been reported in which experimental data was used to relate either lipid-normalized equilibrium concentrations of neutral organic chemicals in fish or organic carbon-normalized equilibrium concentrations in sediments to the octanol:water partition coefficients of the chemicals are:

a. Karickhoff (1981),

$$\log Koc = 0.989 \log Kow - 0.346, \ r^2 = 0.987 \quad (1)$$

b. Konemann and van Leeuwen (1980),

$$\log BCF = 0.980 \log Kow - 0.063, \ r^2 = 0.982 \quad (2)$$

In both equations the slopes are very near unity, indicating that the normalizing bases do indeed account for most of the phase activity of the chemicals and are appropriate for the systems chosen. The chief difference between the two equations lies in the magnitude of the y-intercepts, and since the regressions are nearly parallel, this difference is a close approximation of the difference in phase-activity of neutral organic chemicals in the phases lipid and organic carbon, i.e., can be taken as a "pf". Using this approach, McFarland (1984) calculated a sediment-organic carbon:organism-lipid pf of 1/0.52 (or 1.92). At equilibrium then, the maximum chemical residue that could be reached in an organism's lipids from sediment as the only source of contamination would be about double the organic carbon-normalized concentration in the sediment. We have since recalculated pf by taking the difference in geometric mean log Kow of the original data sets of Karickhoff (1981) and of Konemann and van Leeuwen (1980) between the regression lines in which they generated the equations shown above as (1) and (2), and this calculation results in a slightly different value:

$$pf = \text{antilog } 0.239 = 1.72 \quad (3)$$

This is in close agreement with a ratio for equilibrium concentrations of chemical in biota and sediment determined by Mackay[1] using fugacity calculations and an evaluative model ecosystem (personal communication, 1984):

$$\frac{C_B}{C_S} = 1.56 \qquad (4)$$

in which: C_B = concentration in biota
C_S = concentration in sediment

The ratio of equation (4) resulted from example calculations using default and estimation values in an evaluative model. The model uses fugacity calculations to describe the fate of a chemical in an ecosystem. In its simplest form, processes affecting chemical distribution such as advection, biotransformation or degradation are not considered, and equilibrium distributions of the chemical in environmental compartments are calculated. Mackay's ratio for equilibrium distribution of a chemical between biota and sediment (equation 4) could have varied somewhat from the value shown had different default values been used. However, the ratio of equation (4) is in principle exactly like the pf of equation (3), only arrived at by a different series of calculations. Mackay used a one-constant equation (Mackay 1982) to estimate bioconcentration factor and this equation entered into the fugacity calculations referred to above:

$$\log K_B = \log Kow - 1.32 \qquad (5)$$

or:

$$K_B = 0.048\ Kow \qquad (6)$$

in which K_B is the bioconcentration factor.

Equations (5),(6) resulted from re-evaluation of previously reported work in which bioconcentration factors had been determined on a whole-organism basis, mainly in several species of fish. We chose to use the slightly different equation of Konemann and van Leeuwen (equation 2) that resulted from their laboratory experiments and was normalized on a lipid basis. Lipid normalization enables application to specific organisms differing in lipid content. The very close agreement between our calculated pf and Mackay's ratio, arrived at independently and by a different series of calculations, argues strongly for the accuracy of these estimates of phase-activity difference. This leads to a usable Level-I sediment evaluation: a thermodynamically defined bioaccumulation potential (TBP).

TBP is calculated using the pf value of Equation 3:

$$TBP = 1.72(Cs/OC) \qquad (7)$$

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[1]Dr. Donald Mackay, Department of Chemical Engineering and Applied Chemistry, University of Toronto, Toronto, Ontario, M5S 1A4 Canada.

In which: Cs = concentration of chemical in sediment
OC = organic carbon content of sediment
TBP = equivalent concentration in organism lipid in the same units as Cs.

In application, sediment would be analyzed for the concentration of a neutral organic chemical of interest and for organic carbon content. TBP, calculated using equation (7), expresses equilibrium concentration in lipid equivalents. The maximum that could be bioaccumulated by an exposed organism is estimated by multiplying TBP by the decimal fraction of that organism's lipid content. Implicit in these calculations are two important idealizations: (1) the assumption of no metabolic degradation or biotransformation of the chemical, and (2) total bioavailability of sediment-associated chemical to the organism. Estimations involving TBP, then, are inherently conservative. The model is "thermodynamic" in the sense that a closed system is conceived in which net exchange of chemical between the phases or compartments of the system is zero, i.e., true equilibrium exists and time is not a factor.

Since lipid analyses are ordinarily done on fresh tissue, the concentration would be expressed on a fresh weight basis. If the tissue residue that is calculated is acceptable by whatever criteria are applied, then the sediment evaluation need go no further. If the calculated levels are not acceptable then further evaluation could involve biological testing in Level-II.

LEVEL-II EVALUATION

In this evaluation, it is necessary to expose aquatic organisms to contaminated sediment under unvarying conditions for a sufficient period of time for bioaccumulation to occur, although not necessarily to steady state (Css). In practice it is not likely that Css will be reached in any period of time short enough for economical laboratory testing. By taking samples sequentially over a short period of constant exposure, a simple model can be used to project Css (Blau et al. 1975). The model considers an organism to be a single compartment for uptake and elimination, and calculates rate constants for each of these processes.

Uptake and elimination occur simultaneously. If exposure is held constant, uptake is negatively exponential and the time course of the process is solely a function of the rate of elimination. For very slowly eliminated chemicals, such as most of the neutral organic chemicals, which are not easily metabolized and are highly hydrophobic/lipophilic, steady state between exposure concentration and tissue residue may not be achieved for months or years. A series of samplings over a relatively short period can provide the data necessary to determine rate constants and project Css. A computational form of the model integrated for constant exposure is:

$$C_T = C_W \frac{k_1}{k_2} (1 - e^{-k_2 t}) \qquad (8)$$

in which: C_T = concentration of chemical in organism
C_W = concentration of chemical in exposure medium
k_1 = uptake rate constant
k_2 = elimination rate constant
t = time.

As duration of exposure increases, the term $e^{-k_2 t}$ approaches zero, and:

$$C_T = \frac{k_1 C_W}{k_2} = Css \tag{9}$$

in which Css is the concentration of chemical in tissue at steady state, and for the purposes of this evaluation is expressed on a lipid basis.

The projected achievable lipid-normalized Css can then be compared with the potential maximum (TBP) estimated from sediment chemistry in Level-I and is expressed as the proportion (p) of TBP projected at steady state:

$$p = \frac{Css}{TBP} \tag{10}$$

If all of the chemical of interest in the sediment to which an organism is exposed is bioavailable, then $p = 1.0$. Any value of $p < 1.0$ indicates less than complete bioavailability of the chemical of interest in a sediment under investigation. The magnitude of p is a numerical expression of bioavailability, which could be of assistance in decisionmaking regarding the suitability of open water disposal as opposed to other alternatives. Application of this parameter in ecological assessments will be dependent on development of a reference database.

APPLICATION TO PCB CONTAMINATED SEDIMENTS

Three species of freshwater fish and two species of freshwater bivalve molluscs were exposed to sediments dredged from Sheboygan Harbor, Wisconsin (McFarland et al. in preparation). Sediments were deposited in aquaria under constantly recirculating water that also was replaced at a constant rate. Exposures were conducted at constant temperatures of either 4°C or 20°C representing seasonal extremes. Sheboygan Harbor sediments were analyzed for PCB after collection at several sites and depths. Based on the analytical results, individual lots were mixed to provide homogeneous batches having concentrations of total PCB and other characteristics as shown in Table 1. Lipid content of the five species of organisms ranged from 0.26% in mussels to 6.75% in killifish.

Analysis of PCB was by glass capillary column gas chromatography and electron capture detection (GC/ECD). Quantitation was by total PCB in isomer groups di- through decachlorobiphenyls, total PCB as the sum of all isomer groups and as

Aroclor 1242, 1254 or 1260 whenever chromatographic patterns adequately matched Aroclor standard mixtures.

Steady state residues of total PCB projected by the kinetic model were highest in the most lipoidal organisms in all exposures and at the high temperature. The highest residue of total PCB bioaccumulated was 130 ppm on a lipid basis or 8.8 ppm on a fresh weight basis in killifish exposed to sediment H at 20°C. The bioaccumulation potential (TBP) calculated for sediment H using equation (7) was about 4700 ppm, and on a fresh weight basis in the killifish this is equal to a maximum total PCB residue of about 300 ppm, giving a p of 0.064 (equation 10).

TABLE 1

Characteristics of Sediment Mixtures: Means and (S.D.)

Sediment	Total PCB ppm,dry	Moisture %	Organic Carbon, %	Sand:Silt:Clay %
Reference R	0.45 (0.23)	24 (0.77)	1.5 (0.21)	62:19:19 (2.9):(2.6):(1.3)
Low PCB L	4.0 (0.89)	28 (0.20)	1.6 (0.18)	62:18:20 (0.0):(0.0):(0.0)
Medium PCB M	33.0 (4.3)	48 (0.12)	1.6 (0.18)	43:21:46 (1.4):(1.4):(1.4)
High PCB H	44.0 (10.0)	46 (0.22)	1.6 (0.21)	37:28:35 (0.0):(0.0):(0.0)

Proportion (p) of bioaccumulation potential (TBP) to bioaccumulation projected (Css) was calculated using equation (10) for each analysis in which the kinetic model successfully fitted the measured tissue residues for the isomer groups di- through hexachlorobiphenyls, total PCB and Aroclor 1242. These proportions are plotted on log-log scales against PCB concentration in sediment in Figure 1 for the exposures at each temperature and for each of the four sediment treatments (R,L,M and H).

DISCUSSION AND CONCLUSIONS

Figure 1 shows that the percentage of PCB that is bioavailable decreases with increasing concentration of PCB in the sediments. The pattern is clearly visible for both temperature treatments. Bioavailability was also obviously greater at the higher temperature than at the lower, although the difference is not as pronounced for the least PCB-contaminated sediment (R) as it is for the three more highly contaminated sediments. The sediment containing 4.0

ppm total PCB (L) was intermediate in PCB bioavailability between the sediment having an order of magnitude lower PCB concentration and the two sediments that approached or reached an order of magnitude greater PCB concentration (M and H). These two most highly PCB-contaminated sediments (having 33 and 44 ppm total PCB) clustered together in degree of bioavailability at both temperatures. The relationship (as indicated by p) of bioavailability to concentration of PCB in sediment is clearly exponential.

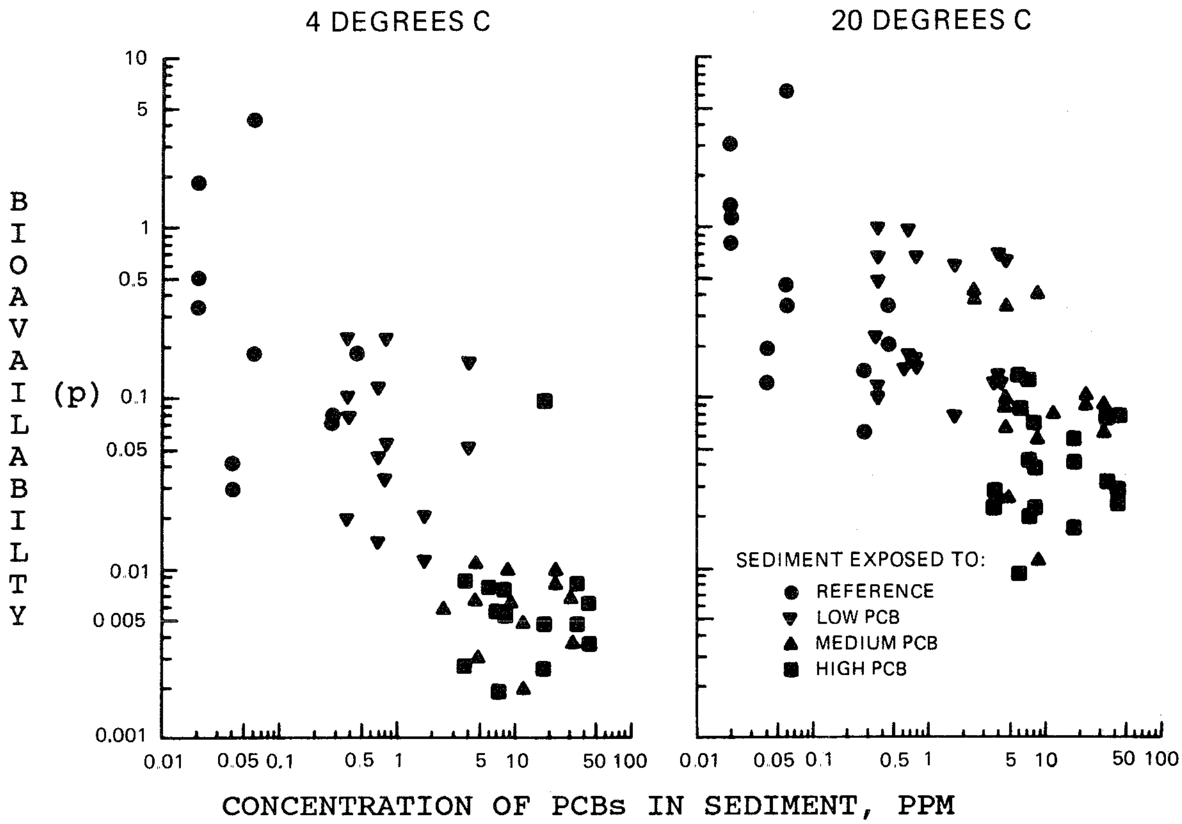

Figure 1. Comparison of PCB bioavailability, measured as the proportion p = Css/TBP, with PCB concentrations in sediments to which the organisms were exposed (R,L,M and H in Table 1.)

In this investigation we observed that although there are increases in the tissue residues of PCB in organisms exposed to contaminated sediments that relate to increased concentration of PCB in the sediment, the increase is far less than the potential represented by the concentration of the chemicals in the sediments. Water solubility may be a primary limiting factor influencing bioavailability of these chemicals.

Other factors undoubtedly interact to affect bioavailability in complex ways. Suspension of contaminated sediments in the water column, for example, would increase the surface area for desorption and could be expected to increase concentrations of desorbing chemicals available to fish and filter-feeding bivalves. In these investigations, every effort was made to eliminate suspension of particulate material arising from the deposited sediments, and the generally low levels of PCBs bioaccumulated (relative to TBP) reflect bioavailability in essentially clear water exposures.

Research in this laboratory is being conducted to elucidate the roles of these and other environmental variables in determining the bioavailability to aquatic biota of chemicals associated with channel sediments that must be dredged. From these findings methods for evaluating the ecological impact of dredging and disposal operations are being developed that will have improved utility and more interpretable meaning than present methods.

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PUGET SOUND DREDGED DISPOSAL ANALYSIS
BY
FRANK J. URABECK[1]

INTRODUCTION

The Puget Sound Dredged Disposal Analysis is a 3-year study with primary focus on unconfined, open-water disposal of material dredged from Federal and non-Federal navigation projects. It is a joint study by the Seattle District Corps of Engineers, The Environmental Protection Agency's (EPA) Region X and the Washington Departments of Natural Resources and Ecology. The study began in April of 1985.

OVERVIEW OF PUGET SOUND AREA

Well over one-half of the State's population is located in the Puget Sound area and about 2.2 million reside in the metropolitan corridor of Tacoma, Seattle, and Everett. The Sound is treasured because of its environmental resources, including its beaches and popular boating waters used for sailing, power cruising, and fishing. Also, the Sound is very important to the economic well-being of the region because of foreign and domestic trade made possible by its deep harbors.

WATER QUALITY ISSUES

Three main areas of concern have focused public attention on the Sound's water quality and resulted in public demand for action.

First, high levels of potentially harmful chemicals have been found in marine sediments and organisms, especially in the urban bays near Tacoma, Seattle and Everett. Many see these chemicals as a causal factor of tumors and other biological abnormalities found in fish and shellfish in these areas. Secondly, oceanographers estimate 60-80 percent of the water flowing out of the central and south Sound on outgoing tides is recycled back into the system. Most contaminants released into the Sound appear to never leave and end up bound to the bottom sediments. And thirdly, in light of limited knowledge on the cumulative effects of pollutant discharges from human activities, there are uncertainties about the long-term health of the Sound. There are several examples of public and agency reaction to these concerns.

In the fall of 1984, a citizen appealing to the Washington State Shoreline Hearing Board protested a disposal site-use permit, previously issued to the Washington Department of Natural Resources (WDNR). This resulted in the closure of Fourmile Rock, a major long-term, open-water disposal site in Seattle's Elliott Bay.

1/Director, Puget Sound Dredged Disposal Analysis, Engineering Division, Seattle District, U.S. Army Corps of Engineers

Conditions imposed through a shoreline permit on the Port Gardner Disposal Site in Everett Harbor have resulted in a closure of that site also.

In early February 1985, Governor Booth Gardner, Senator Dan Evans, and Congressman Norm Dicks sponsored an all day conference on Puget Sound water quality concerns which focused on sources of pollution and urban hotspot areas. A number of references were made to the dredged disposal issue.

What has been the Federal response to public and agency demands for action?

PUGET SOUND INITIATIVE

Region X of EPA developed a program known as the Puget Sound Initiative, administered by EPA and the Washington Department of Ecology (WDE). This program has two primary purposes: (1) identification of water quality problems, and (2) promotion of cleanup actions through EPA/WDE programs, as well as efforts by others.

Under the Puget Sound Initiative which had its name changed in September 1985 to the Puget Sound Estuary Program, local governments and other State and Federal agencies, including Seattle District, Corps of Engineers, are involved in ongoing studies leading to cleanup actions. Key initiative study activities can be divided into two groups: (1) problem identification and (2) problem solving. The problem identification category includes these research studies:

o Pollutant loading from point and nonpoint sources involves determining the amount of contaminants entering the Sound and through what pathways, such as outfall pipes, surface runoff, and dredged material disposal.

o Tidal transport of contaminants involves studies of how water currents move contaminants from one place to another.

o Sediment problem identification deals with the bottom of the Sound and areas of concern where the bottom sediments have unusually high levels of potentially harmful chemicals.

Problem solving activities include:

o Improving point source monitoring and testing to reduce the level of contaminants entering the Sound.

o Correcting nonpoint sources of contaminants which have caused commercial shellfish area closures.

o Preparing contaminated sediment cleanup plans for Elliott Bay, Everett Harbor, Commencement Bay, and other areas where contaminated sediments have been identified as being a major concern. Source control, that is reducing or eliminating the release of harmful chemicals into the Sound, is a key feature of all cleanup plans. Prevention should be cheaper and easier than cleanup after the fact, and is an essential prerequisite to cleanup actions, which can be very costly.

o The last problem solving activity is PSDDA, the subject of this paper.

THE STATE PLAN

The State's response under Governor Gardner has been new legislation. This legislation will have the reconstituted Puget Sound Water Quality Authority undertake preparation of a comprehensive plan by January 1, 1987.

The initial plan is expected to be a state policy and priority setting and coordinating effort rather than a detailed blueprint for pollution abatement activities.

PSDDA AND THE CORPS OF ENGINEERS

In August 1984, Ernesta Barnes, EPA Region X Administrator, asked the Corps to undertake the lead in a Soundwide, programmatic environmental impact statement (EIS) on dredged material disposal. Her request was supported by then Governor Spellman, the directors of the Washington Departments of Natural Resources and Ecology, and many others, including the Puget Sound Water Quality Authority, in the form of letters and personal contacts.

In December 1985, the Corps of Engineers, EPA, and the Washington State Departments of Ecology and Natural Resources began a period of intensive technical negotiations to develop a jointly acceptable study strategy. The culmination of these negotiations is the plan of study for the Puget Sound Dredged Disposal Analysis, agreed to by the agencies in March 1985 as the basis for the cooperative effort. The study has three key objectives: (1) acceptable unconfined open-water disposal sites; (2) acceptable dredged sediment testing and test interpretation procedures; and (3) formal unconfined open-water disposal site management plans.

Acceptable unconfined, open-water disposal sites are needed to handle maintenance dredging and new project construction for Federal and local navigation projects. Over the past decade, an estimated 50 percent of all dredged materials have been placed in designated Puget Sound disposal sites. Most of the balance of the material has been used as economic fill for shoreline development. Acceptable dredged sediment testing procedures and a basis for interpretation of test results are also needed for use of these sites. EPA and the State of Washington will be using the results of the study in subsequent implementing actions. And finally, disposal site use will need to be regulated through formal site management plans. This will primarily be a function of the Washington Department of Natural Resources. However, other agencies and local governments will participate in controlling use of these sites.

METHODS OF DREDGED MATERIAL DISPOSAL

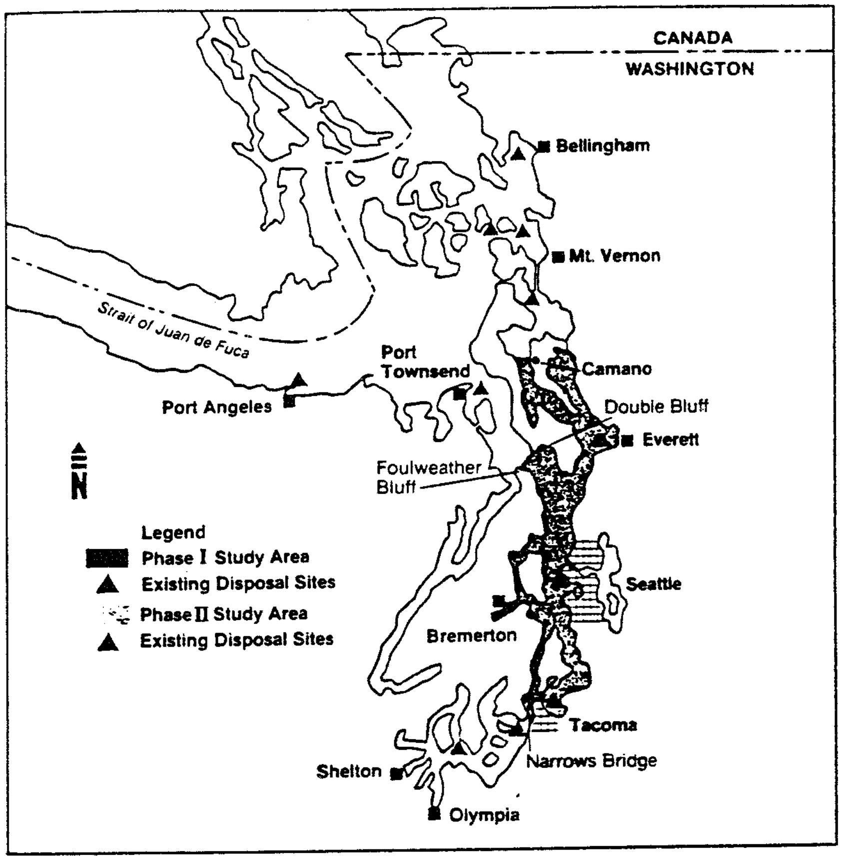
The study primarily covers unconfined, open-water disposal of dredged material. However, other means of dredged disposal are being addressed on a generic or nonsite-specific basis, including confined disposal options, such as upland, nearshore confined and aquatic capped. Design criteria will be developed for these options including appropriate sediment tests such as leachate mobility, a consideration for the nearshore and upland options.

One method of confined, open-water disposal involves placement of a cap of material, 2 feet to 6 feet thick, that prevents the contaminants from reaching the water and adversely affecting marine organisms. Capping has been shown to be a successful way of dealing with contaminated sediments in New York Harbor and even in Seattle's West Waterway where the Corps of Engineers has a small prototype program underway. This may be the solution for the portion of contaminated sediment to be dredged as part of the Naval Task Force Project in Everett Harbor. Other confined disposal options include near shore and upland containments. A nearshore disposal site is being planned by the Port of Seattle at its Pier 90-91 facility. A confined upland site may be near a water body or located some miles inland, resulting in a costly truckhaul operation.

TWO-PHASE APPROACH

The dredged disposal analysis is a Soundwide effort that is estimated to take 3 years. Two phases, each about 2 years in length, overlap - the second phase started a year after the first. Each phase covers a different area of the Sound.

The figure below shows the geographic coverage of Phase I and Phase II. The Phase I effort covers the critical central Puget Sound industrial core where several major navigation projects lie and where major Federal and State permit decisions are pending, such as the proposed Navy homeport site at Everett. Phase II of the study covers the remaining dredged disposal areas in Puget Sound including north and south Sound. While Hood Canal falls in the Phase II area, no disposal sites are expected to be located there.



The phasing is an attempt to expedite efforts on the most critical disposal sites first.

Each phase includes an EIS to support subsequent implementing actions by EPA and the State. These implementing actions include disposal criteria that define the appropriate tests for dredged sediments. The draft EIS and final EIS for Phase I are to be published in February 1987 and July 1987, respectively. The draft and final statements for Phase II are expected to be out for public review in November 1987 and April 1988, respectively.

ALTERNATIVES

The study is addressing a variety of alternatives; however, the prime focus in the environmental impact statements will be on three categories of alternatives dealing with the main issue of the study: unconfined, open-water dredged material disposal.

The first category covers the no unconfined open-water disposal option which could be achieved by stopping all dredging or requiring that all dredged material be placed in a confined disposal environment.

The second category would allow varying levels of contaminated sediments into unconfined, open-water sites, depending on the alternative selected. What can not go into an unconfined, open-water disposal site would have to be placed in a confined disposal area, such as one of the options mentioned above.

The third category deals with alternative locations that would be designated for unconfined open-water disposal. These may include existing disposal sites such as Fourmile Rock in Elliott Bay, depending on the initial screening process which employs 19 site location factors. These factors, encompassing human activities, natural resources, and physical characteristics are: navigation, recreation, historical sites, aquaculture facilities, foodfish and shellfish harvest areas, pipelines and cables, natural preserves and sanctuaries, outfalls, sediment characteristics, currents, threatened and endangered species, foodfish and shellfish habitat, wetlands, saltwater intakes, shoreline master programs, aesthetics, noise, bathymetry, and beneficial effects.

ORGANIZATION AND MANAGEMENT

To manage this study effectively, a relatively simple organization structure has been established, consisting of four key control elements: a policy review committee, a technical steering committee, technical work groups, and a study director.

The policy review committee is chaired by the Corps of Engineers, and includes the Commander of the Seattle District, the Regional Administrator of EPA, and the Directors of the Washington Departments of Natural Resources and Ecology. This committee periodically reviews study progress, and deals with major policy issues regarding PSDDA findings.

The technical steering committee provides oversight of the study, giving close review of progress and products. It also acts as a liaison with the Puget Sound Estuary Program Implementation Committee.

There are three technical work groups corresponding to each of the three study objectives: disposal site, evaluation procedures, and management plan. All four agencies serve on these groups where the basic work of the study is accomplished. Other agencies and interests are being encouraged to participate on an ex-officio basis. The Corps chairs the Disposal Site and the Evaluation Procedures Work Groups. The Department of Natural Resources chairs the Management Plan Work Group.

The fourth key management element in the study organization is the study director who interfaces with the policy review and technical steering committees and the work groups. The study director, a Corps employee, has been assigned the responsibility for carrying out the program with guidance and advice from the committees. He and the work groups perform as a study team.

The Corps shares with the Department of Natural Resources, the responsibility for preparing the environmental impact statements to ensure compliance with both Federal and State EIS regulations. EPA will be a cooperating Federal agency and WDE a cooperating State agency for the statements.

STUDY COSTS

The study's total estimated cost is about $3.7 million, of which about $2.5 million is being funded by the Corps. Funding covers staff time, contracts, and overhead of all four agencies. EPA and WDNR are sharing in the cost of consultants.

STUDY STATUS AND FUTURE OUTLOOK

As of February 1986, technical studies were well underway in support of the disposal site selection process. Preferred and alternative sites have been identified for the Phase I area. Also sediment testing and test evaluation procedures are being developed that will become guidelines for disposal site use. A preliminary findings report is scheduled to be distributed for public review in May 1986.

The Corps sees the following as expected accomplishments of the study and impacts of future dredging:

- open-water unconfined disposal sites acceptable to the public, resource agencies and those performing dredging in Puget Sound.

- reasonable guidelines for use of these disposal areas that will protect the environment and give the public confidence that Puget Sound water quality will not be impaired by dredged material disposal.

- management plans covering site use that will promote predictability and consistency for the regulatory agencies as well as the dredger.

The Seattle District Corps of Engineers views this effort as being very important to its ability to carry out its navigation mission and meet the Corps' responsibility for maintaining the many Puget Sound Federal deep and shallow draft harbor projects. Much of Federal project maintenance dredging, averaging about 250,000 cubic yards per year, will continue to be placed in open-water sites, in part due to the coarse-grained, cleaner sediments that are generally removed. Without these sites, maintenance dredging disposal costs would increase by several orders of magnitude such that funding for some projects may become difficult to continue due to budget constraints.

For navigation improvement projects, a substantial amount of the sediments are not expected to be found suitable for unconfined open-water disposal as contaminated materials have built up over time in those portions of harbors not subject to periodic maintenance dredging.

There is no question that in the future, more controls will be imposed on the dredging and dredged material disposal process. This will be necessary to achieve a more consistent and accountable program. These controls are likely to include specialized dredging equipment to reduce contaminant release during sediment removal, navigation positioning at dump sites to ensure material is placed where it should be, and environmental monitoring during and following the use of a dump site to verify study predictions of impacts on marine resources. The bottom line is that the total cost of dredging is expected to go up, perhaps significantly, until the extent of contaminated sediments has been reduced. This could also be reflected in higher state disposal fees. The long-term solution is to reduce the source of toxic chemicals, which is what the State of Washington and EPA are now pursuing, through the Puget Sound Estuary Program.

INNOVATIVE STRATEGIES FOR GROUND-WATER PROTECTION AT UPLAND DISPOSAL SITES

by

Tommy E. Myers[1]

INTRODUCTION

Heavy metals, polychlorinated biphenyls, polyaromatic hydrocarbons, and other toxic substances are present in sediments of many urban waterways. The potential for adverse environmental impacts during dredging and disposal of contaminated sediment varies on a project-to-project basis. Hence, the appropriate method of disposal will vary from project to project.

Disposal alternatives are divided into four general classes: open water, open water with restrictions, confined, and confined with restrictions (Francingues 1985). Approximately 10 per cent of the total volume of sediment dredged in the United States each year is not suitable for unrestricted disposal (Francingues 1985). This paper discusses two innovative strategies for ground-water protection at upland disposal sites (confined disposal with restrictions): solidification/stabilization and codisposal.

When contaminated dredged material with a potential for leaching is disposed in an upland site, the site must be planned to prevent ground water pollution. Current strategies for minimizing ground-water pollution include proper site selection, dewatering to minimize leachate production, lining of bottom and sides to prevent leakage and seepage, capping to minimize infiltration and thereby leachate production, and leachate collection and treatment. Economic considerations and tough environmental constraints for disposal are providing initiative for developing innovative approaches to upland disposal of contaminated dredged material. With proper development, new strategies such as solidification/stabilization of dredged material to prevent or retard leaching and codisposal--the use of clean dredged material to adsorb contaminants in leachate draining from contaminated dredged material--could provide the disposal technology needed to contain and immobilize contaminants in an upland site.

[1]Ecologist, Environmental Laboratory, USAE Waterways Experiment Station

SOLIDIFICATION/STABILIZATION

Solidification is the process of eliminating the free water in a semisolid by hydration of a setting agent(s). In the process, structure is developed that microencapsulates or entraps contaminants in a hardened mass. Typical setting agents include portland cement, lime, fly ash, kiln dust, slag, and combinations of these materials. Coadditives such as bentonite, soluble silicates, and other materials are sometimes used with the setting agents to give special properties to the final products.

Technical Basis

Stabilization can be both physical and chemical. Physical stabilization refers to improved engineering properties such as bearing capacity and handling characteristics. Chemical stabilization is the alteration of the chemical form of the contaminants to make them less soluble and/or less leachable. Solidification is a physical stabilization process that usually, but not always, provides some chemical stabilization. In this paper, physical stabilization and chemical stabilization are discussed together as solidification/stabilization technology.

Specific studies of solidification/stabilization technology applied to contaminated dredged material are limited to the Japanese work in this area. Japanese research has been oriented to physical stabilization, with minor emphasis on chemical stabilization (Kita 1983, Nakamura 1983, Murakami 1977, Otsuki 1984). Application of the technology to industrial wastes in the United States has emphasized chemical stabilization (Pojasek 1979, Malone 1980). Experiences in Japan with dredged material and in the U.S. with industrial waste indicate that solidification/stabilization is a promising contaminant immobilization technology for materials that show a potential for leaching.

Physical Stabilization. The development of structure immobilizes contaminated solids (i.e., the solid mass is dimensionally stable), and the solids do not move. Since most of the contaminants in dredged material are tightly bound to the sediment solids, solidification can be an important immobilizing mechanism (Kita 1983). Solidification technology has the flexibility to meet specifications for physical stability ranging from primarily immobilizing solids in a low-strength product to producing a material suitable for end-uses typical of soft concrete.

Permeability is an important parameter because it partly determines the rate at which contaminants will be released. Solidification does not necessarily reduce the permeability of dredged material, although experience with industrial waste indicates that some solidification/stabilization processes do reduce the permeability of some wastes (Bartos 1977). The accessibility of water to the contaminated solids is important parameter related to permeability. Solidification/stabilization can reduce the assessibility of water to contaminated solids by embedding discrete grains in a silicate matrix. Thus, the accessibility of water to the contaminated solids within a cemented matrix and hence the surface area across which transfer or loss of contaminants can occur is less in solidified/stabilized material than in untreated material.

Chemical Stabilization. Solidification/stabilization processes are usually formulated to minimize the solubility of metals by controlling pH and alkalinity. Additional metal immobilization can be obtained by modifying the process to include chemisorption (Myers 1985). Because anions are typically more difficult to bind in insoluble compounds, most solidification/stabilization processes rely on microencapsulation to immobilize anions.

Some vendors of solidification/stabilization processes claim to be able to immobilize organic contaminants. There is as yet, however, no scientific evidence that stabilization of organic contaminants against aqueous leaching occurs when cement- and pozzolan-based systems are used (Tittlebaum 1985). Practically no published information exists on the aqueous leaching of organic contaminants from solidified/stabilized materials.

Because the state-of-the-art for process design is primarily empirical, a process formulation cannot be developed soley on the basis of chemical characterization of the material to be solidified/stabilized. It is, therefore, necessary to conduct laboratory leach tests in order to evaluate the effectiveness of chemical stabilization. Although chemical stabilization has to be evaluated on a case-by-case basis, isolation of contaminated dredged material solids in a cemented matrix appears to be a promising technology for significantly reducing or eliminating the release of contaminants, particularly metals, from dredged material.

Potential Implementation Scenarios

Solidification/stabilization of contaminated dredged material could be implemented in a variety of ways, depending on the design of the disposal facility and the manner in which the setting agents are added to and mixed with the dredged material (Francingues 1984). Two design concepts for disposal of contaminated dredged material in an upland site are illustrated in Figures 1 and 2. Other designs and mixing concepts or modifications of those presented below may also be feasible.

Disposal Area Design. The layered concept shown in Figure 1 involves alternating layers of clean fine-grained dredged material with contaminated dredged material that has been solidified/stabilized. The initial lift of clean dredged material would be dewatered to promote densification and consolidation to provide a foundation with low permeability. Once this layer achieved the desired degree of consolidation, a layer of solidified/stabilized contaminated dredged material would be placed on top. Conventional earthmoving equipment would be used for shaping the solidified/stabilized material before it hardened.

The secure disposal concept shown in Figure 2 provides the highest degree of environmental protection. A soil or a flexible membrane liner, or both, are used to line the bottom and sides of the disposal site. A coarse-grained layer is used for leachate collection. Contaminated dredged material that has been solidified/stabilized is then placed into the prepared site so that a monolithic block develops as the material cures.

An alternative to the secure facility is to delete the liner and coarse-grained layer from the disposal site design, if the permeability and leachability of the solidified/stabilized dredged material are sufficiently low. Laboratory permeabilities in the range of 10^{-11} to 10^{-5} cm/sec have been achieved with solidification/stabilization of industrial waste (Bartos 1977). Soils with laboratory permeabilities of 10^{-7} cm/sec or less are often considered for liner construction.

Addition and Mixing Methods. Three basic methods of setting agent addition and mixing are considered feasible (Francingues 1984): in situ mixing, plant mixing, and area wide mixing.

In situ mixing is suitable for dredged slurries that have been dewatered. In situ mixing is most applicable for the addition of large volumes of low reactivity setting agents. This method incorporates the use of conventional construction machinery, such as a backhoe, to accomplish the mixing process. Where large containment areas are being treated, clamshells and/or draglines may be used. An alternative to using construction equipment is mixing by injection. Specially designed equipment is commercially available that injects and mixes setting agents with the material to be solidified/stabilized. The system moves laterally along the perimeter of a facility, solidifying the material within reach of the injection boom. As soon as one pass is completed, and the material has set long enough to support the injection carrier, the process is repeated. The equipment advances in this manner until the job is complete.

Plant mixing is most suitable for sites with relatively large quantities of contaminated material to be treated. In the plant mixing process, the dredged material is mechanically mixed with the setting agent(s) in a processing facility prior to disposal. If the volume of material to be processed does not justify the expense of a mixing plant and if the dredged material is to be barged to a take-out point, an alternative is to mix the setting agent(s) with the dredged material in a scow before it is unloaded. Mixing may be accomplished in route to a docking site (Figure 3) by using a specially designed system mounted on the scow for this purpose or by using a shore-based injection system (Figure 4). In the shore-based injection system, track-mounted injection equipment moves along the dock and is articulated to reach all parts of the scow. The solidifying agent(s) is in a dry state and is piped directly from a tank truck to the injector. Since the setting process takes several days before freshly prepared solidified/stabilized dredged material hardens and cannot be rehandled, the risk of having the material set-up before it can be removed from the scow is minimal.

Area wide mixing is applicable to those confined disposal sites where slurries with high solids content must be treated. Area wide mixing involves the use of agricultural-type spreaders and tillers to add and mix setting agent(s) with dredged material. Area-wide mixing is land area intensive and presents the greatest possibility for fugitive dust, organic vapor, and odor generation. Implementation of the area wide mixing concept requires that the dredged material be sufficiently dewatered to support construction equipment.

Limitations

Careful process selection involving laboratory tests is needed to maximize physical and chemical stabilization because some constituents in contaminated dredged material may interfer with the setting reactions responsible for the development of a hardened mass (Jones 1985). The performance expected from solidified/ stabilized dredged material can be evaluated using laboratory tests to provide information on strength development versus cure time, ultimate strength, leachability, and resistance to freeze-thaw. Information on several important aspects of field application, however, is not readily available. Field testing and evaluation are needed to address mixing efficiency and scale-up factors, long-term stability of solidified/stabilized dredged material, and construction procedures and quality control.

Cost

Actual project cost data for solidification/stabilization of dredged material are not available. Application of the technology to industrial waste is estimated to cost $30 to $50 per ton (Cullinane 1985). Actual cost will vary with the amount of setting agents(s) required. The amount of setting agent(s) required depends on the implementation strategy and the performance criteria that are selected. Cost estimates must also take into consideration the volume increase due to the addition of setting agent(s) and future expenditures needed for end-uses anticipated at the site. The cost effectiveness of solidification/stabilization as an alternative to liners and leachate collection and treatment systems or other ground-water pollution control strategies for upland disposal sites depends on the site-specific environmental constraints that are placed on disposal.

CODISPOSAL

Codisposal is the disposal of clean and contaminated dredged material in a site designed to utilize the adsorptive capacity of the clean material. An upland disposal site designed for codisposal may be similar to Figure 1, except that the contaminated dredged material is not solidified and an envelope or blanket of clean dredged material surrounds the contaminated material. It should be realized that the codisposal concept appropriately applied involves an engineered site. It does not include disposal of clean and contaminated dredged material in a site that has not been specifically designed to use the adsorptive capacity of the clean material.

Technical Basis

Codisposal is primarily applicable to organic contaminants. The technical basis for codisposal is contaminant attenuation by adsorption (i.e., organic contaminants in leachate draining from the contaminated dredged material are adsorbed by the sediment particles in the clean dredged material). The adsorption process is well understood and is widely used to remove organic contaminants (Metcalf 1972; Weber 1972).

The basic principle of adsorption and, hence, the codisposal concept is thermodynamic partitioning of contaminant between dredged material solids and dredged material pore-water. Organic contaminants are distributed between solids and pore-water according to a partitioning coefficient, K_d, defined as follows (Thibodeaux 1979):

$$K_d = X_s / X_w = q / C \qquad (1)$$

where X_s is the contaminant mass fraction in the solid phase; X_w is the contaminant mass fraction in the aqueous phase; q is the contaminant concentration in the dredged material solids (mg/kg); and C is the contaminant concentration in the pore-water (mg/l).

The partitioning coefficient is probably the single most important parameter governing the fate and transport of many organic contaminants (Jaffe 1984). Thus, the pore-water contaminant concentration in contaminated dredged material is dependent on the partitioning coefficient and the sediment contaminant concentration. Partitioning coefficients can either be estimated (Karickhoff 1979) or determined by laboratory tests.

For hydrophobic organics (polychlorinated biphenyls, for example) the partitioning coefficient is on the order of 10^5 l/kg. When the partitioning coefficient is this high, the pore-water contaminant concentration will be very low. Most of the contaminant will remain tightly bound to sediment solids, and total removal of the contaminant by leaching can be shown to require hundreds, even thousands, of years.

Adsorption is usually modeled with either the Freundlich or Langmuir equations (Weber 1972), equations 2 and 3, respectively.

$$q = K\ C^x \qquad (2)$$

$$q = Q\ b\ C\ /\ (1 + b\ C) \qquad (3)$$

where q and C are as previously defined; K and x are empirical constants for the Freundlich equation; b is the Langmuir constant related to the energy of adsorption; and Q is the mass of contaminant adsorbed per unit weight of solids in forming a complete monolayer on the surface of the solids. Freundlich and Langmuir constants can be determined for clean dredged material using laboratory batch adsorption tests. Data from adsorption tests partly provide the information needed to determine the required thickness of clean dredged material.

Design Concepts

The information needed for design of an upland site for use in a codisposal strategy includes adsorption properties of the clean dredged material, the volume of contaminated sediment to be dredged, bulk sediment contaminant concentrations, partitioning coefficients for each contaminant of interest, permeabilities of each dredged material, and hydrostatic head. From these data, the mass flux from the contaminanted material is calculated. Adsorption in the clean layer is then modeled with a mass transport equation so that breakthrough curves for various thicknesses can be computed.

Contaminated sediments are usually fine-grained materials. Since the permeability of fine-grained dredged material is low, the loading rate on the clean dredged material will be low, and the movement of leachate through the clean dredged material will be slow. The time required for contaminants to reach the boundaries of the site may extend into hundreds of years. In this case, biodegradation is significant. Depending on contaminant-specific biokinetics for the contaminated dredged material and the site design, the biodegradation rate may exceed the rate of penetration into the clean layer. Theoretically, at least, an upland disposal site could be designed using the codisposal strategy to contain the contaminants until they have been biologically degraded.

Limitations

As with any engineered facility, the designer should use safety factors. Since codisposal is only a concept, there are no applicable standards of practice. Further, contaminant-specific biodegradation rates for dredged material are not available. This type of information is needed to fully evaluate the technical feasibility of the codisposal strategy.

The availability (volume and cost) of clean dredged material with adequate adsorption properties will probably be a limiting factor in some locations. Construction techniques for the codisposal strategy may also be a problem. Acceptance by the regulatory community may limit implementation of codisposal. These issues would have to be addressed before the technical and economic feasibility of the codisposal strategy could be fully evaluated.

Cost

The codisposal strategy is probably easier to implement and less expensive than the solidification/stabilization strategy and the current ground-water protection strategies that involve liners and leachate collection and treatment. One important cost that should not be overlooked is the research and development needed to verify the technical feasibility of codisposal.

SUMMARY

Solidification/stabilization and codisposal are innovative strategies proposed for controlling ground-water pollution at upland disposal sites. The use of solidification/stabilization technology to prevent or retard leaching, is probably more applicable to dredged material with a potential for leaching metals than to dredged material with a potential for leaching organic contaminants. Codisposal is primarily applicable to dredged material with a potential for leaching organic contaminants.

While the technical basis and the concepts for implementing each strategy indicate feasibility, significant research and development must be accomplished before either strategy is applied full scale.

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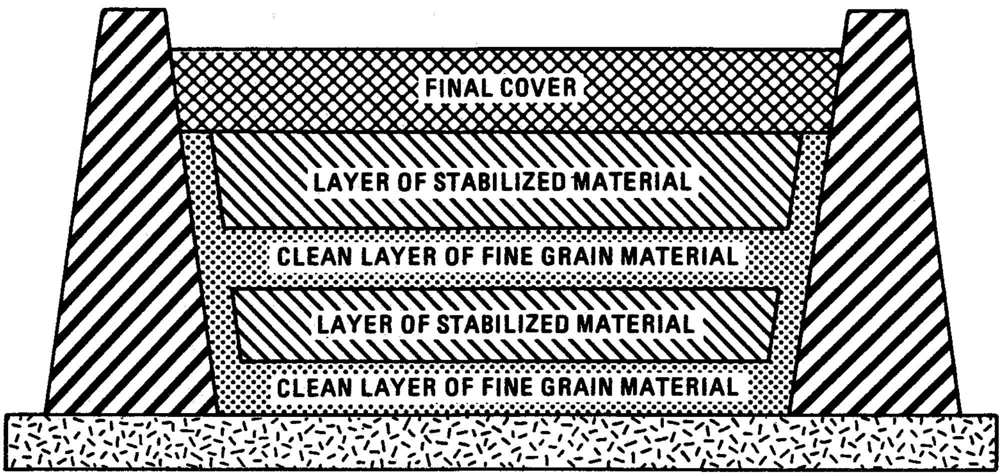

Figure 1. Disposal concept for alternating layers of solidified/stabilized contaminated dredged material with layers of clean fine-grained dredged material

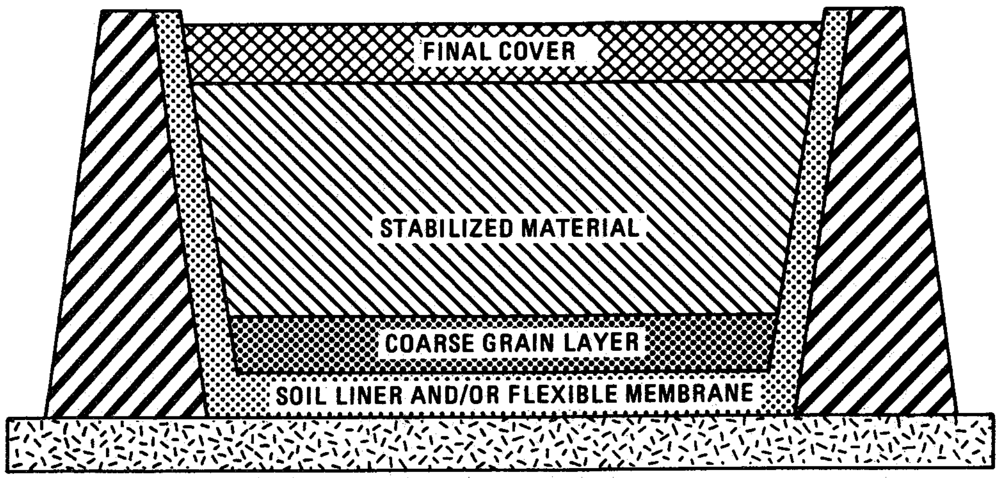

Figure 2. Disposal concept for solidification/stabilization of contaminated dredged material in a secure facility

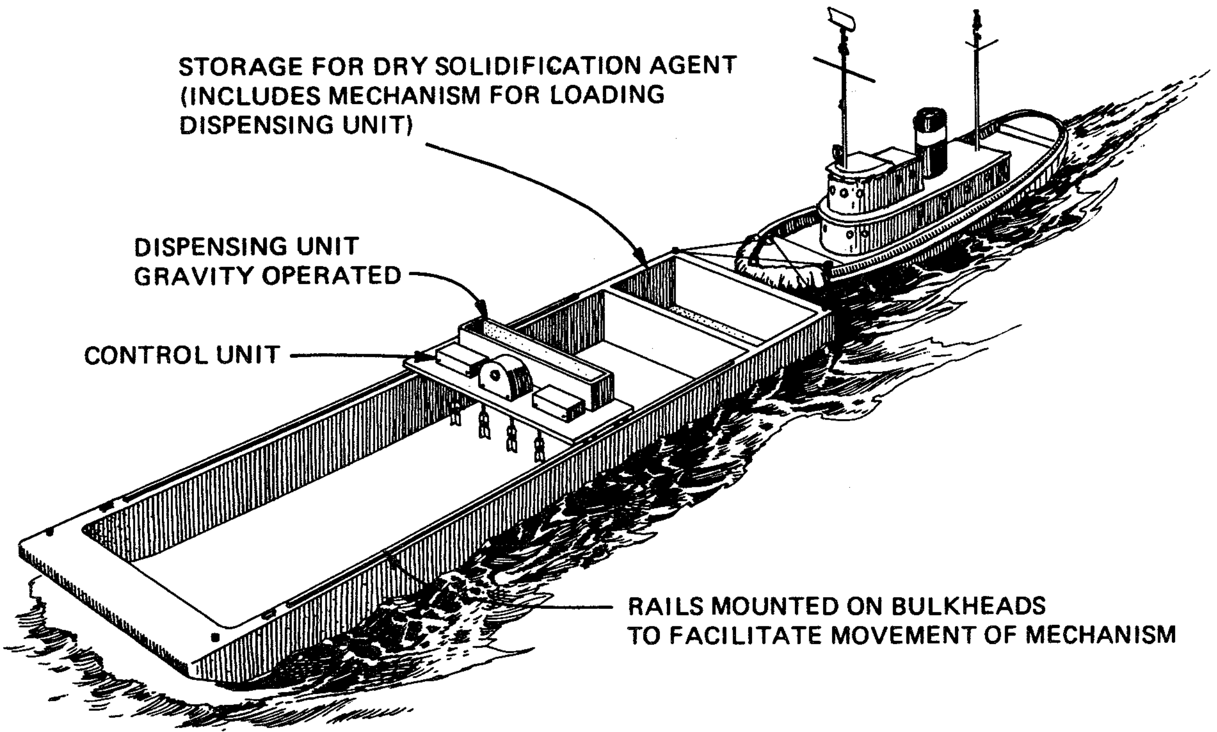

Figure 3. Scow fitted with mechanism for adding and mixing setting agents with dredged material

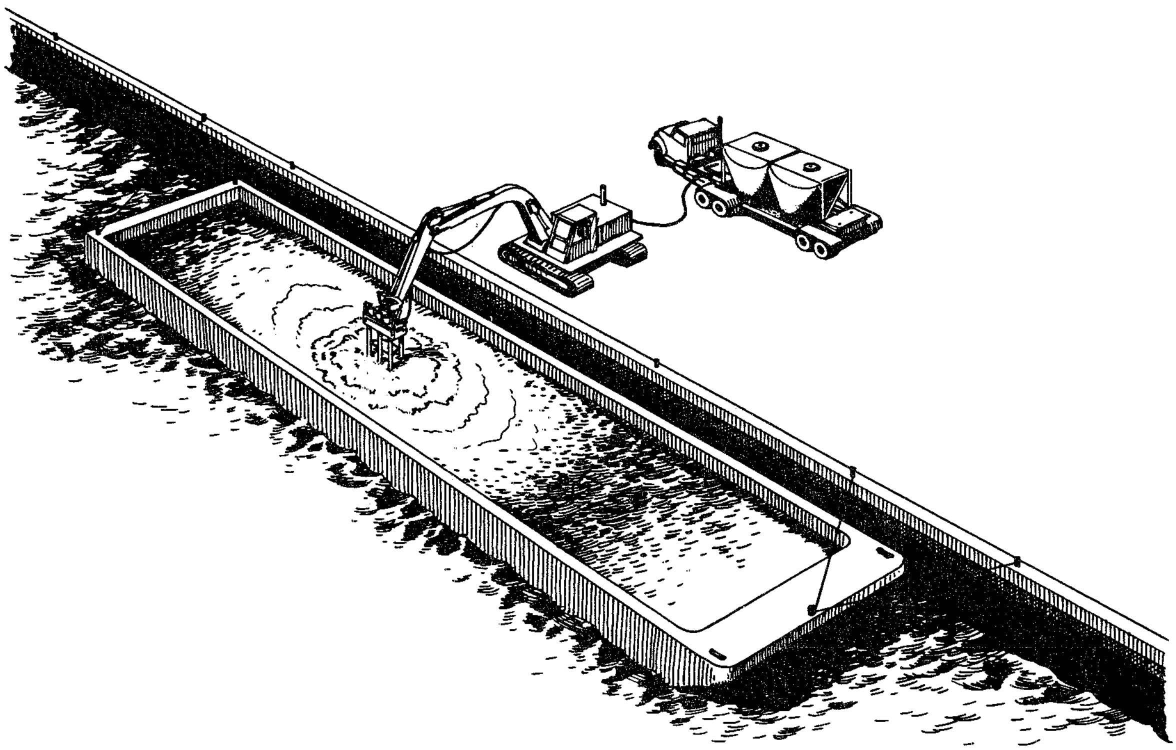

Figure 4. Shore-based injection and mixing equipment

WATER QUALITY ASPECTS OF DREDGES

by

E. C. McNAIR, Jr.[1]

INTRODUCTION

Turbidity is a term normally associated with dredging operations to denote the deterioration of water quality due to dredging. However, according to Barnard (1976), "dredging activities probably contribute only a small percentage of the total turbidity found in the nation's waterways and harbors when compared to that created by natural erosion; resuspension by waves, currents, and ship traffic; land runoff and drainage outfalls; and industrial and municipal discharges. In addition, turbidity measurements made around dredging operations indicate that high levels of turbidity are often restricted to the immediate vicinity of the operation and tend to dissipate rapidly."

Turbidity represents a complex composite of several variables that individually and collectively interfere with transmission of light through a liquid. A number of terms are used more or less interchangeably with turbidity and a variety of methods are available for quantifying turbidity levels. Color, transparency, visibility, clarity, opacity, and suspended solids content are terms that are often used and sometimes confused with turbidity (Herbich and Brahme, "Literature Review and Technical Evaluation of Sediment Resuspension During Dredging," in publication).

The Jackson candle turbidimeter was first used as a quantifiable and somewhat consistent method for determining the turbidity of a sample. The Jackson Turbidity Units (TBU) scale was eventually replaced with the Formazin Turbidity Units (FTU) scale. Both of these scales make use of the measure of the amount of light from a standard source that is transmitted through a sample (Barnard 1978).

The most widely used turbidity index today is the Nephelometric Turbidity Unit (NTU) that is a measure of the light-scattering properties of a sample and is measured at 90 degrees to the sample axis.

Some work has been done relating optical measurements of turbidity to absolute properties of the sample such as suspended solids concentrations (Barnard 1978). Basically, the studies have shown that variations in optical characteristics from one sediment type and character to another make it virtually impossible to establish a consistent relationship with other

[1]Research Hydraulic Engineer, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 39180-0631.

characteristics of the sample. It is possible and in practice is usually done to correlate optical characteristics and suspended sediment characteristics for a given site with more or less uniform sediment characteristics.

Dredging impacts water quality by entraining bottom sediments into the water column (this is also known as resuspension). When the sediments are fine-grained, the very low fall velocities of the particles cause them to stay in suspension for relatively long periods of time. Local currents may transport the resuspended sediments to other locations where they are not wanted.

Impacts of turbidity can be short- or long-term in three distinct areas: physical impacts, chemical impacts, and biological impacts (Herbich and Brahme, in publication). Physically, resuspension is aesthetically displeasing, may decrease the availability of nutrients and thereby encourage migration of local species away from the site, and may affect local hydrodynamics by generation of density-driven currents. Chemical impacts include changes in oxygen concentration, the uptake and release of nutrients, and the uptake and release of toxins. Biological impacts include destruction of spawning areas, smothering and suffocation of organisms, and sorption of toxins.

GENERATION OF TURBIDITY BY DREDGES AND DREDGING OPERATIONS

The nature, degree, and extent of sediment resuspension and transport at a dredging operation are functions of the characteristics of the dredged material, the nature of the dredging operation (dredge type and size, discharge/cutter configuration, pumping/production rates, operational procedures being used, etc.), and the hydrologic regime in the vicinity of the dredging operation (salinities, waves, currents, etc.). Detailed discussion of all these factors is beyond the scope of this paper. However, in general, dredged materials with a high percentage of clays, particularly organic clays, tend to produce the greatest levels of suspended solids (turbidity); the presence of salinity up to about 5 ppt tends to suppress suspended sediments concentrations while the higher turbulence levels associated with waves and currents tend to accentuate and increase suspended sediment concentrations and to keep sediment particles in suspension for longer periods of time.

Studies have been performed of the resuspension tendencies of various dredge types. Some of these studies are summarized in the following paragraphs.

Cutterhead dredges. The cutterhead dredge is the most common, the most versatile, and probably the most efficient dredge type in the United States today. It is in a class of dredges called the hydraulic pipeline dredge group and is called a cutterhead because of the special treatment given to the suction pipe. The basket cutter has a number of vanes that may have serrated edges or teeth for special cutting applications. As the cutter rotates, bottom materials are loosened by mechanical shearing action and are brought into the high-velocity flow field near the dredge suction.

Field observations show that the highest levels of suspended sediment generated by a cutterhead dredge are within a few meters of the cutterhead itself. Within 3 meters of the cutter, suspended solids concentrations are highly variable but may be as high as tens of grams per liter (Barnard 1978). A few hundred meters from the cutter, suspended sediment concentrations may be only a few milligrams per liter higher than background levels.

Studies of operational procedures have shown that rotational speed of the cutter has a decided bearing on sediment suspended by the cutterhead dredge. The guidance seems to be that dredging efficiency and production can be maintained by matching swing speed, cutter rpm, and cut thickness to material characteristics and at the same time minimize resuspension of bottom sediments.

Trailing suction hopper dredges. Trailing suction hopper dredges are primarily used in entrance channels where rough water, heavy traffic, or absence of suitable, close by disposal sites occur. The draft of most hopper dredges makes them unsuitable for the shallower draft inland waterway channels so they work primarily in coastal or estuarine settings or in the Great Lakes.

Most resuspension of fine-grained sediments by hopper dredges takes place in two ways: (1) the drag heads resuspend materials near the bottom as they are pulled along by the dredge; and (2) overflow of turbid waters introduces sediments into the upper layers of the water column. There is also some minor resuspension by turbulence generated by the vessel's propellers and other ship-generated turbulence (Sustar et al. 1976).

Observations of hopper dredge operations have shown that when dredging to overflow, the overflow introduces more suspended sediment into the aquatic environment than is generated at the drag head. Field data are available to show that suspended sediment concentrations on the order of 200 grams per liter can be present in the immediate vicinity of the dredge when pumping to overflow (Barnard 1978).

Sidecast dredges. Sidecast dredges are special cases of hopper dredges except that the dredged materials are disposed of by pumping directly through a "boom" to the side of the dredging project. Sidecast dredges are normally assigned to coastal projects where littoral processes are at work to convey the dredged materials away from the navigation channel. Because these dredges normally work in free-flowing granular materials, the resuspension potential of sidecast dredges is relatively small.

Dustpan dredges. The dustpan dredge is a hydraulic pipeline dredge with a special attachment on the suction that gives the dredge its name. The suction head resembles a large vacuum cleaner that is about as wide as the hull of the dredge. The dredge head, the "dustpan," has water jets that loosen and agitate the bottom materials to make them easier to be brought into the dredge suction. The dustpan dredge is best suited for free-flowing granular sediments but some adaptions for fine-grained, consolidated materials have been made (Klein 1983). However, tests of the specially adapted dustpan that were performed in the James River in 1982 indicated that there was no clear advantage of the dustpan dredge over a cutterhead dredge for dredging fine-grained materials (Raymond 1983).

Clamshell dredges. The clamshell dredge consists of a bucket, or clamshell, operated from a crane or derrick mounted on a barge or on land. It is primarily used for removing maintenance materials in restricted areas but in some cases is used for new work dredging. Although the bottom materials are removed in nearly in situ density, production rates are relatively low in comparison to hydraulic pipeline dredges. Dredging with clamshells is essentially unlimited by water depth.

Sediment resuspension by clamshell dredging takes place in four major ways (Barnard 1978):

a. Sediment is resuspended when the bucket impacts and is pulled off the bottom.

b. Material at the surface of the bucket load is eroded as the bucket is pulled up through the water column.

c. A decided erosive action occurs as the bucket breaks the water surface.

d. Turbid water leaks through openings between the jaws.

Field data taken from clamshell dredging operations indicate that suspended sediments are generally distributed throughout the water column. The data further showed that maximum suspended sediment concentrations in the immediate vicinity of the dredging operation were only about 500 mg/l above background concentrations (Barnard 1978).

RECENT DEVELOPMENTS TO MINIMIZE RESUSPENSION BY DREDGES

There have been a number of techniques and equipment types developed in recent years directed to minimizing or eliminating resuspension of bottom sediments during dredging operations. A brief description of some of the equipment is presented in the following paragraphs.

Watertight buckets. A watertight bucket with edges that seal during clamshell operations has been developed. In addition, the top of the watertight bucket is covered so that the dredged material is totally enclosed within the bucket (Barnard 1978).

Hopper dredge submerged overflow system. To minimize the dispersion of the discharged overflow from a hopper dredge, a relatively simple submerged discharge system for hopper dredge overflow has been developed. The overflow collection system in the dredge was streamlined to minimize the incorporation of air bubbles and the overflow discharge ports were moved from the sides to the bottom of the dredge's hull (Barnard 1978).

Clean up system. The Clean Up Head, a Japanese development, consists of a shielded auger that collects sediment as the dredge swings back and forth and guides it toward the suction of a submerged centrifugal pump. To minimize sediment resuspension, the auger is shielded and a movable wing covers the sediment as it is being collected by the auger. Any gas that is released from the sediment is trapped by a shroud and vented to the surface where it is collected (Barnard 1978).

Pneuma pump. The Pneuma pump is an air-actuated device developed in Italy that has the advertised capability of producing high solids content dredged mixtures with minimal bottom sediment resuspension. Field tests performed by Richardson et al. (1982) tend to support the advertised claims but report that the system had a very low power efficiency compared with a conventional centrifugal pump.

CONCLUSION

Dredges, in performing the functions for which they were designed, resuspend bottom sediments and thus generate turbidity. However, different dredge types resuspend sediments in different amounts, and operational procedures have a pronounced effect on the resuspensional aspects of any given dredge.

Some work is ongoing to devise equipment and techniques to minimize resuspension of bottom sediments by dredges during dredging operations in fine-grained materials.

ACKNOWLEDGMENTS

Permission of the Chief of Engineers to publish this paper is acknowledged.

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APPENDIX:

Poster Abstracts

The Committee on Water Quality: Sixth Seminar
New Orleans, Louisiana
25 - 27 February 1986

This appendix contains the abstracts for the posters displayed at the sixth seminar on water quality. The committee on water quality decided to attempt this forum at the New Orleans seminar to provide an opportunity for displays on general subjects of interest to attendees and ones on related topics not specifically covered in the technical sessions. The response was excellent from participants and viewers for this first trial at a poster session. The committee has decided to continue with a poster session at the next seminar scheduled for early 1988.

J. L. Mahloch
Chair, Poster Session

TITLE: OVERVIEW OF TABS-2, TWO-DIMENSIONAL HYDRAULIC MODELLING SYSTEM

CONTACT: Joseph V. Letter, Jr., U. S. Army Engineer Waterways Experiment Station, Telephone FTS 542-2845

TABS-2 is a generalized numerical modeling system used for hydraulic engineering studies in rivers, reservoirs, estuaries and bays. TABS-2 consists of three generalized computer programs used to model two-dimensional hydrodynamics, constituent transport, and sedimentation, plus numerous utility programs to form a complete numerical modeling system. The major programs are RMA-2V, RMA-4, and STUDH.

The equations solved for the flow model RMA-2V are the depth-integrated equations of momentum and continuity. The transport model RMA-4 solves the depth-integrated convection-diffusion equations with sources and sinks. STUDH, the sediment transport model solves the depth-integrated transport of sands, silts, and clays with deposition and erosion, along with wave induced transport and bed consolidation. The solution technique is a fully implicit finite element solution.

The system provides a complete set of tools, from mesh generation of modeling to graphical displays and output analysis. Automatic mesh generation and interactive mesh editing are provided. Interactive creation of computer jobs removes the user from the need for learning extensive job control. Companion data management and file management systems with error checking are included. Metric or English units may be chosen. Summary or detailed tabular output, variety of graphical output, including contours, factor maps, vector plots, and drougue plots are available. The models have wetting and drying capability of shallows. Critical and supercritical flows are not permitted.

Previous applications include: Lower Granite Reservoir, Columbia River Entrance, Cape Fear River, North Carolina, Atchafalaya Bay, Louisiana, Norfolk Harbor, Virginia, Chesapeake Bay, Mississippi River, Greenville Reach, New York Harbor, Mississippi River, Lock and Dam 26, Kings Bay, Georgia, Arkansas River, Lock and Dam 3, Mississippi River at Wabasha, Minnesota, Yazoo Backwater area, Mississippi, Terrebonne Marshes, Louisiana, Arkansas River at Little Rock, Arkansas, Atchafalaya River at Morgan City, Louisiana, Portsmouth Harbor, Maine, Corpus Christi Harbor, Texas, Lock and Dam 2, Red River, Charleston Harbor, South Carolina, Mississippi River Passes, Louisiana, Dredged Material Containment Area Design, Lock and Dam 3, Red River and applications of some components by Hydrologic Engineering Center, universities, and private companies.

The TABS-2 System is documented in the manual: Thomas, W. A. and McAnally, W. H., "User's Manual for the Generalized Computer Program System: Open-Channel Flow and Sedimentation, TABS-2," Department of the Army, Waterways Experiment Station, Vicksburg, Ms, July, 1985. A three-dimensional companion modeling system is under development that will be compatable with the TABS-2 system. The component models of TABS-3 are being applied to several production field sites.

TITLE: SUPERFUND, TOXIC WASTE CLEANUP AND THE CORPS OF ENGINEERS

CONTACT: Richard Winnike, U. S. Army Engineer Division, Missouri River, Telephone FTS 864-7317

Superfund is a program managed by the Environmental Protection Agency (EPA) to cleanup hazardous and toxic waste sites throughout the nation.

EPA identifies and surveys toxic waste sites, attempts to locate the parties responsible for the generation, transportation or uncontrolled disposal of the material and then seeks to have them pay for the cleanup.

If such attempts fail, the Federal Government works with state and local government agencies and other private organizations. The Comprehensive Environmental Response, Compensation and Liability Act of 1980 initially provided $1.6 billion in Federal funds to help finance the cleanup of sites.

The bulk of the money for Superfund is provided by taxes levied on industrial and petrochemical production. State and local governments as well as other segments of private industry are contributing millions of dollars and services.

Once the Environmental Protection Agency selects a priority site for Federal cleanup, it requests the US Army Corps of Engineers to conduct contracting and management support for design and construction.

The Missouri River Division in Omaha, Nebraska, has been designated as the National Design Center for all Superfund projects assigned to the Corps.

All actual design and construction work is performed by professional architect/engineer firms under contract with the government.

The Corps is responsible for advertisement of work, selection of proposal, award of contract and monitoring the work provided by the private firms. The completed cleanup site is then turned over to the Regional EPA Office.

TITLE: NUMERICAL MODELING OF RESERVOIRS BY THE U. S. ARMY CORPS OF ENGINEERS

CONTACT: Michael Schneider, U. S. Army Engineer Waterways Experiment Station, Telephone FTS 542-3424

The capabilities of numerically modeling reservoirs by the Corps of Engineers was displayed in a poster session at the biannual Water Quality Conference held in New Orleans. The major features of both one and two-dimensional reservoir models were presented. The temporal and spacial variability of physical, chemical, and biological parameters differentiate the family of numerical reservoir models. The following table lists numerical reservoir models and associated features.

	SPACIAL VARIABILITY	TEMPORAL VARIABILITY	WATER QUALITY CONSTITUENTS
SELECT	1	NO	NO
CE-RES-OPT	1	YES	NO
CE-THERM	1	YES	NO
CE-QUAL-R1	1	YES	YES
GLVHT	2	YES	NO
CE QUAL-W2	2	YES	YES
WESSEL	2	YES	NO

TITLE: MENDOTA POOL SEDIMENT QUALITY STUDY

CONTACT: George Nichol, U. S. Army Engineer District, Sacramento, Telephone FTS 460-2510

The Sacramento District is preparing to remove 150,000 cubic yards of sediments from the Mendota Pool near Firebaugh, California, to aid in flood control along the San Joaquin River. Because of potential contamination of river water from substances adsorbed or otherwise associated with the sediments, the District shall conduct a water quality testing program for heavy metals and pesticides. Background river quality will be tested to determine base conditions. Standard elutriate tests shall be conducted to determine the contamination potential of any plume of suspended solids that is caused to occur in the river. Modified elutriate tests shall be conducted to determine the detention time required in a contained dredged spoil pond such that re-adsorption of any dislodged contaminants onto colloidal particles and subsequent settling allow effluent criteria to be achieved.

Bulk analysis of heavy metals of undisturbed pool sediments shall be conducted to determine the dry weight fraction of contaminants, for comparison to similar studies done in the nearby contaminated Kesterson area. Bulk analysis of heavy metals and pesticides of settled solids remaining after the modified elutriate tests shall be conducted to determine the dry weight fraction of contaminants in the dredge spoil that will remain in the pond after the dredging project is completed. This is needed information because the dredge spoil may be used for cover material elsewhere, and vegetation growth will occur in the material. By comparing this data to previous studies done by others to determine the uptake of heavy metals and other toxic materials from urban sludge or contaminated dredged material into crops, it can be determined whether contamination of vegetative leaf tissue will occur from this dredge spoil.

A column settling test shall be conducted to determine the fraction of suspended solids (and therefore the mass of adsorbed contaminants) that can be removed during various detention times, so that the detention time needed for the spoil pond can be selected.

The procedures for running the modified elutriate and column settling tests, and the calculations to be used in taking laboratory results from which detention time required in a contained dredged spoil pond is determined, are those specified by Palermo (Waterways Experiment Station, Environmental Effects of Dredging Technical Notes, 1985).

TITLE: MAPPING SURFACE WATER QUALITY PATTERNS OF LAKE HAVASU, ARIZONA - CALIFORNIA WITH THEMATIC MAPPER IMAGERY

CONTACT: James P. Verdin and Richard A. Roline, U. S. Bureau of Reclamation, Telephone FTS 776-6005

In August 1984, surface water quality data, including temperature, Secchi depth, and chlorophyll a concentration were collected at 36 stations on Lake Havasu during the same time that the TM (Thematic Mapper) multispectral scanner on board the Landsat 5 satellite acquired digital imagery of the lake. Spectral bands of the TM multispectral scanner are as follows:

Band	Wavelength (μm)	Color/Spectrum
1	0.45-0.52	blue-green
2	0.52-0.60	green
3	0.63-0.69	red
4	0.76-0.90	near infrared
5	1.55-1.75	middle infrared
6	10.40-12.50	thermal infrared
7	2.08-2.35	middle infrared

Computer-compatible tapes of the TM imagery were purchased from NOAA through the EROS Data Center. A scene subset of Lake Havasu made up of 1500 lines of 1700 pixels, each pixel representing a 30 meter square on the earth's surface, was selected for processing. Surface sampling sites based on USGS 7.5 minute quadrangle maps were identified in the imagery and digital counts at these locations were recorded. Using MINITAB software, stepwise linear regression procedures were used to identify water quality predictor equations having digital image counts as independent variables for all three measured parameters. The best predictor for Secchi transparency was found to be:

$$\frac{1}{SD} = 0.172 + 0.0262\ TM4 + 0.0396\ TM3 - 0.0110\ TM1$$

where SD is Secchi transparency in meters, and TM4, TM3, and TM1 are image counts in bands 4, 3 and 1, respectively. This equation was obtained with values for 33 stations and has a coefficient of determination (r^2) of 0.89 and a standard deviation about the mean of 0.44 meter.

The best predictor equation obtained for chlorophyll a concentration was:

$$CHLA = 25.5 + 0.518\ TM4 - 0.325\ TM1$$

where CHLA is chlorophyll a concentration in mg/m^3, and TM4 and TM1 are image counts in bands 4 and 1, respectively. This equation has a coefficient of determination (r^2) of 0.92 and a standard deviation about the mean of 1.28 mg/m^3. It was derived with values for the same 33 points as were used to obtain the equation for Secchi depth transparency.

Although pixels in TM band 6 are stored as 30 meter squares to be consistent with the spatial resolution for the other bands, the IFOV (instantaneous field of view) for this thermal band is actually 120 meters square. For this reason, greater care had to be exercised in selecting stations with a pure water signal in this band. In narrow parts of the reservoir and in small inlets, a 120 meter square takes in both water and land. Eleven stations from the main channel were selected, for this reason, to derive the surface temperature predictor equation. The equation found by linear regression was:

$$T = -56.6 + 0.584 \text{ TM6}$$

where T is surface temperature in degrees Centigrade and TM6 is a digital count in band 6. The coefficient of determination (r^2) is 0.82, and the standard deviation about the mean is 1.25° C.

Once equations had been obtained, color-coded image maps were prepared for Secchi depth, chlorophyll a, and temperature. Results obtained with TM data on Lake Havasu showed high correlations between the remote sensing data and water quality variables, with a significant improvement over those seen in earlier studies with coarser resolution Landsat MSS data.

TITLE: BIOLOGICAL CONTROL OF WEEDS IN WESTERN IRRIGATION SYSTEMS

CONTACT: Fred L. Nibling, Jr., and Joan S. Thullen, U. S. Bureau of Reclamation, Telephone FTS 776-6005

Scientists from the Bureau of Reclamation are adapting aquatic weed control techniques using grass carp to conditions found in western United States water systems. Questions being addressed concern the feasibility of using grass carp in flowing water and in the cooler temperatures typical of the region. Development of safe and efficient methods for grass carp use could save the high costs of mechanical cleaning methods and reduce environmental contamination and expense from use of herbicides.

Objectives of the program include: (a) document weed control using grass carp; (b) determine stocking levels needed to provide weed control in an operating system; (c) study the movement behavior of the fish in irrigation canals and reservoirs; (d) evaluate growth, survival and feeding habits of herbivorous fish; and (e) develop effective barriers and guidance and handling techniques.

A 2-year study in the South Platte Supply Canal in northern Colorado demonstrated that grass carp were effective in controlling aquatic weeds in cold, flowing water. The maximum biomass controlled by the fish was 257 grams of dry weight macrophytes per square meter within two months. At maximum water temperatures of 20 °C, diploid grass carp increased in weight by an average of 44 percent in the first season, and an additional increase of 70 percent the second season. Overall percentage weight increase during the combined two-season period was 22 percent. Grass carp overwintered well in the South Platte Supply Canal in 0 °C water with high dissolved oxygen and under a maximum ice depth of 300 millimeters. The average grass carp lost only 4 percent of its body weight from October 1984 and May 1985. Although grass carp show a great deal of promise as an effective tool to control aquatic weeds in western irrigation canal systems, additional research is being conducted to evaluate their movement behavior and to develop effective fish screens.

TITLE: RESERVOIR WATER QUALITY MANAGEMENT -- TENNESSEE VALLEY AUTHORITY

CONTACT: Donald W. Anderson and Richard J. Ruane, Tennessee Valley Authority, Telephone FTS 858-7323

The Tennessee Valley Authority (TVA) is the developer and manager of an extensive system of reservoirs in the southeastern United States. The evolution of reservoir uses far beyond those envisioned in the 1930's presents a variety of management challenges and opportunities--challenges to resolve conflicts among competing uses, and opportunities to maximize the benefits obtained from the public's $5 billion water resources investment. Increasingly, water quality is a key factor in achieving maximum benefits.

TVA is currently implementing a water quality management planning program for selected reservoirs. The program has five phases: problem identification, data collection, data analysis and interpretation, plan formulation, and plan implementation. Plans have been completed for five reservoirs and work is underway on two more. 2-D water quality models have been developed for the five reservoirs and are being used by regulatory agencies for allocating point source wasteloads. Remote sensing techniques are being used to identify and prioritize nonpoint source problems. The plans are developed in cooperation with various State and Federal agencies, local governments, and the public. Where existing programs or techniques are not adequate to address a problem, TVA undertakes demonstrations or experiments to identify feasible new approaches.

TVA is implementing improvements for reservoir releases, as well. The water uses of many rivers below dams are significantly impacted. Such waters marginally support fish and aquatic life and have a reduced capacity to assimilate wastewater. Intermittent flows, low dissolved oxygen (DO) concentrations, and high concentrations of materials such as dissolved iron, dissolved manganese, and sulfides are responsible.

TVA views reservoir release improvements as an opportunity to increase the usefullness of rivers below dams. In 1981, a program to improve releases was begun. The first objective was to develop technology for increasing DO in the releases, including aeration using hydropower turbines and aeration of the reservoir itself. Subsequently, research and development efforts were directed toward maintaining minimum streamflows and providing additional flow at times of critical water quality conditions. Examples include a reregulation dam, a small hydroturbine, and modification of hydrogeneration schedules. Improvement measures are underway at six projects and are being considered for fourteen others.

TVA is also developing reservoir system operation refinements that enhance the overall benefits of TVA projects. Changes in reservoir operations are being considered to increase DO concentrations at Fort Loudoun Reservoir and to assist in managing toxic spills as they may occur in the Holston River.

TITLE: THE CORPS' ENVIRONMENTAL EFFECTS OF DREDGING PROGRAMS

CONTACT: R. L. Lazor, U. S. Army Engineer Waterways Experiment Station, Telephone FTS 542-2935

Before the early 1970's, little was known of the environmental effects of dredging and dredged material disposal. Consequently, there was no sound technical or scientific basis for regulating the disposal of dredged material, and often regulations were excessive and counterproductive. This problem was recognized by the Congress of the United States, and the Corps of Engineers (Corps) was directed to conduct a comprehensive research program. The Dredged Material Research Program (DMRP) was to develop procedures for determining the environmental consequences of dredged material disposal and to develop new or improved methods for minimizing any adverse effects.

The Corps was given the lead responsibility for conducting the research since, in the United States, the Corps is responsible for maintaining over 25,000 miles (40,000 km) of waterways and 1,000 harbors involving the annual disposal of 250 to 300 million cubic yards (191 to 229 million cubic meters) of dredged material. In addition, the Corps regulates the disposal of dredged material in water of the United States. In 1981, over 10,000 dredging-related permit applications were processed by the Corps. In 1982 and 1983, 16,000 and 13,000 permits were processed, respectively. Although the Corps regulates disposal, the regulations are based on criteria developed jointly by the Corps and the U.S. Environmental Protection Agency (EPA). Therefore, results of the DMRP and other program described in this paper are the major technical base from which regulations are developed.

The major programs addressing environmental effects of dredging and disposal that have been or are being conducted by the Corps since 1973 are:

- o Dredged Material Research Program,
- o Dredging Operations Technical Support Program (DOTS),
- o Long-term Effects of Dredging Operations Program (LEDO),
- o Field Verification Program (FVP)
- o Dredging Contaminated Sediment Work of the IOMT (Improvement of Operations and Maintenance) Program.

All of these programs have been or are being conducted by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, Mississippi, using contractual and in-house research and development capabilities. WES has evolved into an internationally recognized center of excellence for studies related to the environmental effects of dredging and dredged material disposal. All current research and programs are under the centralized management of EL's Environmental Effects of Dredging Programs (EEDP).

TITLE: THE COMPUTERIZED ENVIRONMENTAL RESOURCES DATA SYSTEM (CERDS): A GEOGRAPHIC INFORMATION SYSTEM FOR ENVIRONMENTAL DATA ON THE LEVEED FLOODPLAIN OF THE LOWER MISSISSIPPI RIVER

CONTACT: S. P. Cobb, U. S. Army Engineer Division, Lower Mississippi Valley, Telephone, FTS 542-5854, A. N. Williamson, U. S. Army Engineer Waterways Experiment Station, Telephone FTS 542-2468

The Mississippi River Commission (MRC) of the U. S. Army Corps of Engineers is conducting the Lower Mississippi River Environmental Program (LMREP), an extensive series of physical, limnological, and ecological investigations of the leveed floodplain of the lower river from Cairo, Illinois to Head of Passes, Louisiana. The objectives of the LMREP are to collect and synthesize basic environmental resources inventory data for the river channel and leveed floodplain and to develop environmental design considerations for levees and channel improvement works (dikes and revetments) associated with the main stem feature of the Mississippi River and Tributaries Project for flood control and navigation.

A key task in the LMREP is development of a geographic information system called the Computerized Environmental Resources Data System (CERDS) to meet the environmental inventory objectives of the program. Such a system will facilitate integration of LMREP component investigations and will allow for assessment and characterization of basic land and water resources in the leveed portion of the Lower Mississippi Valley, an area of about 2,500,000 acres. In addition, CERDS will be available for a variety of uses in planning, engineering and design, and operation activities for Corps water resources projects.

CERDS will contain data on five basic environmental and cultural features: alluvial soil deposits; land use and vegetation types; aquatic habitats in the main channel and on the floodplain; terrain elevations and bathymetry; and transportation works and navigation and flood control structures.

Data for system variables is being collected and quantified using 1:24,000 scale color IR photography, detailed hydrographic surveys, USGS topographic maps, controlled mosaic black and white photography, and extensive ground truthing. The base map for the system is the 1:20,000 scale 1973-1975 Comprehensive Hydrographic Survey of the Lower Mississippi River prepared by the MRC.

The computerized geographic information data base will be configured using a 12.5 x 12.5m (.04 ac) grid cell (picel) size. However, CERDS will allow for spatial analyses at other resolution scales, e.g., 100m resolution. The spatial analyses can be made of areas ranging in size from the entire study area to one picel. Output can be in the form of various types of color-coded maps of environmental features at specified scales and tabulations of quantitative spatial analysis results.

TITLE: MULTIDIMENSIONAL WATER QUALITY MODELING

CONTACT: Sanda Bird, Ron Hall and James Martin, U. S. Army Engineer Waterways Experiment Station, Telephone FTS 542-3286

Many waterbodies, particularly estuaries and coastal embayments, exhibit variability in factors affecting water quality in two or three dimensions. A system of models were developed to address multidimensional problems using two different approaches: (1) directly linking hydrodynamic and water quality codes and (2) indirectly linking with a coarse grid multiple box type water quality model overlaid on a finer grid used for generating hydrodynamics.

Using the first approach, a two-dimensional, laterally averaged, water quality model (CE-QUAL-W2) has been developed and applied to DeGray Lake, Arkansas, and the Savannah River Estuary, Georgia. The model allowed relatively long term (such as seasonal) variations in water quality to be economically addressed. Two-dimensional, vertically averaged, and three dimensional hydrodynamic codes are also available for linking with water quality models for short term (days to weeks) simulations of water quality.

The box modeling approach was applied to the Savannah River Estuary and Mississippi Sound and compared to predictions from directly linked two-dimensional models (both laterally and vertically averaged). The applications produced closely comparable predictions of averaged concentrations at greatly reduced computational costs. Where lower resolution is acceptable, this approach makes long term multidimensional water quality modeling practical.

TITLE: ENVIRONMENTAL WATER QUALITY OPERATIONS STUDIES AND WATER OPERATIONS TECHNICAL SUPPORT PROGRAMS

CONTACT: J. L. Mahloch, U. S. Army Engineer Waterways Experiment Station, Telephone FTS 542-3635

The Environmental Water Quality Operations Studies (EWQOS) Program involved extensive research over eight years on reservoirs and waterways and on the mathematical modeling of various aspects of the water quality of the two types of waterbodies. Engineering, operations and management techniques were investigated to develop the technologies required to improve the environmental quality compatible with authorized reservoir project purposes. Specific subjects investigated were reservoir limnology, releases, improvements, shoreline erosion and filling/clearing. Extensive sampling, data analysis, laboratory and field studies were conducted to define the environmental impacts of river training structures on the ecosystem. Design/construction guidance was developed to enhance the environmental quality of these structures. Specific studies involved bendways, dike fields, revetted banks, design/construction procedures, and the impacts of navigation traffic on the ecosystem.

The Water Operations Technical Support program is service oriented, designed to facilitate the transfer of EWQOS technology to Corps of Engineers field offices. Assistance is available in the following technical areas:

Water Quality Models
Algae Control
Reservoir Fisheries
Reservoir Contaminants
Reservoir Regulation
Reservoir Shoreline Erosion
Reservoir Filling/Clearing
Reservoir Outlet Works
Reservoir Pool Water Quality
Project Impacts
Navigation Traffic Impacts
Project environmental design/construction guidance

Types of spatial analyses possible include quantifications of areas by variable type, proximity analysis, and association analysis. In addition, quantification of areas inundated by selected flood events can be accomplished.

A prototype of the data base containing all system variables for a small river reach is used to demonstrate CERDS capability and output. Graphic or tabular displays illustrate (1) quantification of vegetation types, aquatic habitat types and alluvial soil deposits; (2) association analyses using land use, soil deposits and terrain elevations; and (3) quantification of land areas inundated by simulated flood events. The applicability of these types of analyses to water resources projects are discussed.