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RESERVOIR SITE PREPARATION: SUMMARY REPORT

by

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This report summarizes the results of Environmental and Water Quality Operational Studies (EWQOS) Work Unit IIF, Reservoir Site Preparation. The results of EWQOS and non-EWQOS studies pertinent to reservoir site preparation and initial filling are given in a summary of the literature, including discussions of clearing, soil stripping, initial filling, and reservoir aging. The procedures developed at the US Army Engineer Waterways Experiment Station and the application of laboratory study results to changes expected in water

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quality as a consequence of impoundment are given, and representative data are used to illustrate important trends. Existing regulations and specifications on reservoir site preparation and legislative requirements are discussed in an appendix.

PREFACE

This report synthesizes the results of the Environmental and Water Quality Operational Studies (EWQOS) Program, Work Unit IIF (CWIS No. 31603), Reservoir Site Preparation. EWQOS is sponsored by the Office, Chief of Engineers (OCE), US Army. The OCE Technical Monitors for EWQOS were Mr. Earl Eiker, Dr. John Bushman, and Mr. James L. Gottesman. Program Manager of EWQOS was Dr. Jerome L. Mahloch, EL.

The report was prepared by Drs. Douglas Gunnison, James M. Brannon, and Rex L. Chen, Ecosystem Research and Simulation Division (ERSD), Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). The study was conducted under the general supervision of Dr. John Harrison, Chief, EL, and Mr. Donald L. Robey, Chief, ERSD, and under the direct supervision of Dr. Thomas L. Hart, Chief, Aquatic Processes and Effects Group, ERSD. The report was edited by Ms. Jessica S. Ruff of the WES Publications and Graphic Arts Division.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres

RESERVOIR SITE PREPARATION: SUMMARY REPORT

PART I: INTRODUCTION

Background

1. After initial filling, a new reservoir undergoes several years of biological and chemical changes resulting from the decomposition of flooded organic material. Inundation of brush, debris, and standing timber is desirable because of the refuge and food these materials provide for fish. However, an undesirable aspect of inundation is that decay of these substances lowers dissolved oxygen, causes a release of objectionable materials, and makes achievement of water quality objectives difficult.

2. Regulations and specifications on reservoir site preparation involve removal of vegetation, debris, and man-made structures necessary to meet project construction, maintenance, and hazard-removal requirements. These guidelines provide details on horizontal and vertical limits of clearing for reservoir projects and describe areas that are to be included in these limits. Guidance on initial reservoir filling supplies methodologies for monitoring new projects for water control, dam performance, fisheries protection, safety, and public relations. There is no guidance for field offices in making cost-effective decisions concerning the amount and type of reservoir site preparation and the scheduling of initial filling necessary to meet water quality objectives. A work unit of the Environmental and Water Quality Operational Studies (EWQOS) Program was designed to produce such guidance. The chronology of the development of a methodology for reservoir site preparation to meet water quality objectives is given in Appendix A. The appendix describes the regulations, specifications, and legislative requirements for site preparation.

Purpose and Scope

3. The objectives of EWQOS Work Unit IIF were to determine the most environmentally compatible strategies for reservoir site preparation, clearing, and initial filling and to provide guidance for Corps field offices. Accomplishing these objectives involved two approaches: literature surveys and laboratory studies. This report was based primarily on reports of the tasks included in the work unit (identified by asterisks in the References section), as well as other technical literature cited in the text.

4. A majority of the information presented in this report is discussed in much greater detail elsewhere (e.g., sediment oxygen demand, nutrient release by decomposing vegetation, and nutrient and metal releases from flooded soil and sediment). For such subjects, summary discussions of the information specifically related to reservoir site preparation are provided, with reference to the appropriate article or report. Thus, this report provides general guidance on reservoir site preparation and filling assessment procedures and also serves as a reference to more exhaustive treatments in key literature sources.

PART II: LITERATURE SURVEY

5. Reservoir site preparation encompasses the operations that must be conducted at a site prior to filling to minimize the adverse impacts of vegetation decomposition and soil/water interactions on water quality. The potential impacts of vegetation and soil on water quality and the cost-effectiveness of remedial practices must be determined prior to reservoir filling. For example, it is important to know if removal of vegetation will result in a significant improvement in water quality compared to leaving vegetation in place. Will the improvement justify the expense required to clear the vegetation? Also, what are the effects on water quality that will result from the flooding of soils during reservoir filling? Is it better to remove or cover some soils that may contribute large levels of nutrients, metals, or contaminants to the water column? Or does the cost involved offset the benefits to be expected?

6. Reservoir filling involves the manner in which the water is first allowed to accumulate in the new reservoir. While not a part of the reservoir site preparation process, suitable reservoir filling practices can be applied prior to final filling to supplement or, in some cases, to replace some site preparation activities. For this reason, reservoir filling is considered along with site preparation.

7. This part of the report summarizes results from the literature pertinent to reservoir site preparation and filling. Only the most recent information is included. The results of earlier work were considered in literature reviews presented in other EWQOS reports and allied technical articles.

Clearing of Vegetation

8. Decomposition of brush, standing trees, and other aboveground organic matter in a new reservoir can release plant-growth stimulating nutrients and cause depletion of dissolved oxygen (Gunnison et al. 1980a,b; Gunnison, Chen, and Brannon 1983). Procedures such as clearing

and burning of vegetation have been used to improve water quality (Allen 1960, Sylvester and Seabloom 1965). Additional considerations for clearing include recreation, reservoir navigation (Dussart et al. 1972), aesthetics (Friedrich 1959), and concerns for fish and wildlife (Jenkins 1970a,b; Nelson, Horak, and Olson 1978).

Removal of vegetation

9. The references considered in the following paragraphs deal primarily with the removal of vegetation rather than with the effects of the decomposition of vegetation, which can severely impact reservoir water quality. The literature on effects of decomposition is discussed in the next section.

10. The following scenario describes what happens when a reservoir is not cleared. During filling, reservoirs are often extremely productive because nearly all the nutrients and detritus present during filling and the drowned terrestrial animals plus primary and secondary biological materials produced after filling are retained within the basin. These substances provide the substrate for a strong reservoir fishery (Ploskey 1981). Decomposing herbaceous plants and forest litter provide a food source for microorganisms, zooplankton, benthos, and some fish; herbs provide cover for young fish and spawning sites for adults; and woody vegetation provides cover for prey and young sport fish. The amount of cover influences the feeding efficiency and thus the movement of energy through predatory sport fish, improving the harvest (Ploskey 1981). Further, strong year classes of fish may be produced during years of increased precipitation that results in increased inflows of nutrients and detritus from the drainage basin and a raised lake level that floods additional woody vegetation, forest litter, and/or herbaceous plants (Ploskey 1981).

11. After filling, the new reservoir develops and retains a high capacity for fish production for the first 5 to 10 years. After this, the project normally experiences a progressive decline. This results from losses of nutrients and detritus to invertebrates and fish (Ploskey 1981) and from microbial formation of soluble and volatile decompositional products that then leave the reservoir system. The report by

Ploskey (1981) presents the results of retaining vegetation in the new impoundment, but it also gives consideration to the need for clearing with respect to water quality.

12. One approach to clearing involves the inclusion of a broad spectrum of considerations, such as clearing costs, aesthetics, safety, recreation, taste and odor problems, operation and maintenance problems, and vector control (e.g., mosquitoes), as well as fishing. An example of an approach to clearing is given in the discussion presented by Wurbs (1974) using several reservoirs in Texas. Toledo Bend Reservoir (Sabine River, Texas-Louisiana border) was cleared for safety in the vicinity of public-use areas, for aesthetics in the vicinity of highway crossings and public-use areas, and for recreation where boating access to open water was required. Further clearing by commercial interests was expected to take place at the lower end of the reservoir above elevation 157.0 ft NGVD. However, construction of the dam occurred rapidly, and clearing work was prevented because of delayed land acquisition and rising water levels. The results were residual boating safety hazards, floating debris hazards in recreation areas and power plant intakes, and several water quality problems including hydrogen sulfide odors in releases from the spillway or power plant and corrosion of anchors at navigational buoys. Whether water quality problems interfered with the reservoir's water supply purpose was not stated.

13. Wurbs (1974) reviewed the clearing practices used by the US Army Engineer District (USAED), Fort Worth. Nine reservoir projects constructed during the late 1940s and early 1950s were totally cleared to an elevation 3 or 5 ft* above the top of the conservation pool with one reservoir cleared to the top of the flood control pool. In the 1960s, the District used Engineer Manual (EM) 415-2-301 (Department of the Army 1959) to guide formulation of clearing plans for eight reservoirs. For these reservoirs, the largest areas of clearing were near public recreation areas and directly upstream of the dam embankments. Of the remainder, most of the clearing was done in the vicinity of

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

highway crossings, populated areas, boat lanes, seining areas, and sedimentation and degradation ranges. In several of these impoundments, minimization of clearing costs resulted in reservoir clearing less than that specified in Engineer Regulation (ER) 415-2-1 (Department of the Army 1969).

14. In general terms, after 1960, economics, aesthetics, and recreation appear to be the primary factors used to set clearing limits for reservoirs constructed in the USAED, Fort Worth. While several other factors received some consideration, clearing to prevent taste and odor problems appears to have been ruled out as economically unjustified. One factor responsible for this decision may have been that, in several projects, water-supply storage was not needed until several years after impoundment. Nonetheless, it is apparent that the general and arbitrary nature of clearing guidelines and criteria applied was the result of a lack of definitive procedures.

15. Specific items associated with clearing that require further investigation were listed by Wurbs (1974) and include:

- a. Procedures to measure benefits accrued due to improvement of appearance and recreation potential.
- b. Techniques to quantitatively predict effects on water quality of flooding specific areas of timber.
- c. Ways to assess fishing improvements resulting from leaving timber and brush in the reservoir (addressed by Ploskey 1981).
- d. Methods to determine the relationship of standing timber to shoreline erosion.
- e. Qualitative weighting techniques to compare benefits and detriments caused by clearing.
- f. Quantitative methods for determining benefits related to clearing objectives and comparing different benefits, detriments, and costs of clearing.

16. Limited additional guidance for reservoir clearing is given in a US Fish and Wildlife Service publication on reservoir and stream habitat improvement (Nelson, Horak, and Olson 1978). This handbook provides a series of criteria to assess habitat modifications as "successful," "marginally successful," or "unsuccessful." This guide

includes discussions of selective clearing for the purpose of preserving or producing habitats for fish and other wildlife rather than to improve water quality; the construction of artificial fish shelters is advised to compensate for inadequate cover or to replace decomposed vegetation.

Effects of decomposition

17. The US Army Engineer Cold Regions Research and Engineering Laboratory translated several Russian articles on the effects of soil and decomposing vegetation on reservoir water quality. One article by Maystrenko, Denisova, and Yenaki (1968) presented an evaluation of submersed forest vegetation as a source of biogenic and organic substances in natural inland waters. The decomposition products addressed in the report included organic and ammonium nitrogen, phosphorus, carbohydrates, and amino acids. The authors presented data relating the amount of materials released per gram of fresh wood into a litre of water. Using this information, it is possible to estimate the degree of impact of decomposition on water quality. This can then be extrapolated from the laboratory setting to the field situation.

18. The information from Maystrenko, Denisova, and Yenaki (1968) and the information contributed by others has been integrated into a mathematical model describing the effect of decomposition of flooded vegetation upon water quality in reservoirs (Therien and Spiller 1981). Although this model has not been adapted for general use on reservoir projects, it is perhaps the closest mechanism to a predictive tool presently available. The authors indicated that their model was being applied to reservoirs in the James Bay region (Canada) by incorporating hydrodynamic effects and the exchange of materials with the aquatic environment. Thus applied, the model would be useful in supplying an approximation of the actual impact of clearing or not clearing a reservoir basin on water quality of a new reservoir.

Soil Stripping and Initial Filling

19. The impact of flooded soil on water quality of a new reservoir has not received a great deal of attention from the scientific

community, although organic loading releases from flooded soil have been examined (Ponnamperuma 1972; Gunnison, Engler, and Patrick 1985). This lack of attention may be the result of the opinion that, in comparison to the organic loading contributed to water by flooded vegetation, the contribution made by flooded soils would be limited. However, such releases from flooded soil into the overlying water column can be a problem and have been investigated to some extent, as have various ways of dealing with these releases. A considerable amount of literature exists on the use of various cationic or anionic treatments of soils. However, the application of this methodology to reservoir site preparation activities has limited utility for several reasons. Use of low-concentration chemical treatments is not cost-effective for any soil area larger than a small farm pond. In addition, if soil organic matter is not removed, any positive gains made with soil treatment will be nullified by the activities of the sediment microflora. Finally, anaerobiosis rapidly becomes established in newly flooded soils; this completely negates any prevention or reduction of organic or inorganic exchanges or conversions and removal of readily soluble ions that would initially be obtained by chemical treatment.

Filling and flushing

20. Sylvester and Seabloom (1965) considered both vegetation and soil in the area to be flooded by Hanson Reservoir in the Pacific Northwest. Because one of the major concerns with the project was its impact on the quality of the water supply for the city of Tacoma, Wash., the area in the conservation pool was stripped of all structures, debris, trees, logs, and material more than 4 in. in diameter. A swamp having deposits of organic matter ranging from 2 to 14 ft in depth was also cleared of standing timber. However, it was not possible to cover or remove the organic soil in the swamp due to the high costs of soil stripping. Instead, a series of fillings and flushings was used. Use of these procedures resulted in water of acceptable quality when the reservoir was filled for the final time.

21. As a result of their work, Sylvester and Seabloom (1965) made

several recommendations with regard to future impoundment site selection and/or site preparation.

a. Remove all standing timber, brush, stumps, logs, structures, and man-made debris from the reservoir site.

b. Mow/remove grass and other forms of herbage on river bottoms or former pasturelands immediately prior to inundation.

c. Conduct soil/water contact studies to assess the impact per unit area of soil surface on the overlying water. If the soil/water contact studies indicate that a soil would have an undesirable effect, after considering the soil area involved and the rate of water exchange, either the site should not be used or a mineral soil should be used to cover the undesirable soil to a depth of 6 in.

d. Flush impoundment areas several times before filling to collect wood debris and remove readily soluble mineral constituents and fine soil particles.

e. Conduct complete water quality analyses under various flow conditions for evaluation of possible future water quality conditions in the reservoir relative to the underlying soil and biological productivity.

Soil stripping/flushing

22. Another soil treatment approach was examined by Campbell et al. (1976) for the Victoriaville Reservoir on the Bulstrode River in Quebec, Canada. Through laboratory studies and tests simulating natural terrain and climate, these scientists assessed the effects of soil stripping on water quality. Stripping the soil surface was found to reduce or, in some cases, nearly eliminate the negative effects associated with topsoil submergence on quality of the overlying water.

23. This analysis resulted in the development of a number of recommendations on selection of a reservoir site and a general method for analysis of limnological problems created by the operation of these types of impoundments. Recommendations were also made for both water-supply and multiple-purpose reservoir projects.

24. In the case of Victoriaville Reservoir, the southeastern portion of the reservoir was found to constitute a dead zone, i.e., an area with no circulation. To eliminate this situation, several alternatives were recommended. These recommendations, given below, are also

applicable to other reservoirs having a dead zone.

a. Construct a dike to prevent the area from being flooded.

b. Ensure circulation within this zone by introducing river water into the extreme southeast portion of the reservoir using channelization.

c. In the case of a multiple-purpose reservoir, strip down to a depth established by soil profile analysis and cover the area with sand and gravel.

25. Recommendations made by Campbell et al. (1976) for both water-supply and multiple-purpose projects include the following;

a. In order to reduce biochemical oxygen demand (BOD) and to minimize development of localized anaerobic conditions, all vegetation in the reservoir basin should be burned.

b. Marshy deposits that would be flooded should be removed.

c. A minimum water depth of 6 ft should be maintained throughout the reservoir to prevent transformation of the reservoir into a swamp.

d. To ensure good water quality, initial filling should be done with spring runoff to permit flushing and draining. At least two additional flushings of approximately 50 days duration should be carried out in order to prepare for the first winter storage.

e. The need to modify existing water treatment procedures to meet unexpected changes in quality of raw water must be anticipated.

f. A control policy should be established for agricultural wastes in the watershed upstream from the reservoir.

g. A strategy should be developed to fight occurrences of nuisance algal blooms.

Farm pond construction

26. It is common practice in farm pond construction to remove all vegetation and strip the surface soil layer (A horizon) to the next soil layer (B horizon). However, this practice is as much a function of the need to obtain material to form the pond sides and/or dam as it is to ensure desirable water quality.

Reservoir Aging

Aging process

27. Aging, the principal process that causes the gradual improvement of reservoir water quality over initial filling conditions, has been described in detail by others (Gunnison, Engler, and Patrick 1985). In summary, during the first 6 to 10 years after filling (transition phase), the readily available organic matter and easily solubilized minerals are removed from the reservoir by biological and physicochemical processes. Unless additional nutrients are brought into the reservoir by inflows and/or meteorologic inputs, the available organic matter and minerals within the system are removed through respiration, denitrification, sulfide formation, and/or being washed from the system either in dissolved or particulate form. As a consequence, the biological productivity of the system tends to decline once the transition phase is completed. At this time, the reservoir may shift from a eutrophic to a mesotrophic state. For a reservoir sport fishery, the results can be negative (Ploskey 1981), although the effect is desirable for reservoir water quality.

28. Several other authors have discussed factors and effects related to the reservoir aging process (Stearns 1890, 1916; Saville 1925; Wilroy and Ingols 1964; Ploskey 1981; Gunnison, Chen, and Brannon 1983), while Sylvester and Seabloom (1965) provided a detailed description of the aging process. Among the factors Sylvester and Seabloom enumerated were:

a. Ion exchange through the clay and humic colloids under water-saturated conditions.

b. Microbiologic degradation of organic materials, which releases dissolved materials and carbon dioxide.

c. Leaching of organic and mineral substances from soil or vegetation, which could support algal growth and production of additional organic matter and result in additional formation of decompositional products.

d. Microbiological activity at the soil/water interface that depletes dissolved oxygen (DO), possibly resulting in anerobic conditions and a release of reduced substances.

Management techniques

29. There is no known management technique that can substitute for the natural aging process of reservoirs. Burning may hasten the process by reducing organic matter to its inorganic constituents, thereby allowing those constituents to be removed from the reservoir during the filling process. However, the effect of burning is restricted to the vegetation and litter present and has little or no impact on soil organic matter. Controlled filling and emptying can be used to flush readily soluble materials and easily suspended particulates. For the duration of the transition phase, selective withdrawal can be used to allow only surface releases during warm summer periods when decomposition rates are maximal in the bottom layers. Use of this procedure requires that any downstream impact as a result of warmwater releases is acceptable.

30. A combination of burning, filling and emptying, and selective withdrawal can be used to reduce the impacts of the transition phase. However, since these procedures have been applied to only a limited number of reservoirs, it is not possible to predict the influence these methods have on the transition phase. To obtain this information, it is appropriate to run predictive soil/water and vegetation/water interaction tests to gain perspective on the nature, rate, and magnitude of products released so that an attempt can be made at accurately predicting the impact of the reservoir filling process. After a review of the data from these tests, it may be apparent that one or more of the above procedures should be used after construction to remove readily soluble and decomposable materials.

31. Additional measures such as air or oxygen injection into the forebay area or the penstock can be used to increase the DO of release waters. However, these measures may only treat the symptom (low DO) and not the problem (presence of oxygen-demanding substances). Thus, the DO may meet standards in the water leaving the reservoir, but a pronounced DO sag may occur downstream due to the presence of a residual DO demand. Furthermore, nutrients and metals present in hypolimnetic waters would also be included with these releases.

PART III: RATIONALE FOR DEVELOPMENT OF A RESERVOIR SITE PREPARATION STUDY

32. A reservoir site preparation study is conducted for the purpose of obtaining data that will facilitate selection of suitable reservoir site preparation practices. Since most of the information needed is concerned with the materials released from decomposing vegetation and soil/water interactions, a site preparation study is designed to provide these data. This part of the report summarizes the major factors to consider in conducting a reservoir site preparation study, based on experience of the US Army Engineer Waterways Experiment Station (WES) with preimpoundment investigations. An outline of the procedures developed at WES is presented; this is given in summary form in Table 1. The application of laboratory results to potential changes in water quality as a consequence of impoundment is also discussed. More detailed descriptions of the procedures used and the interpretation of results are available in several publications by Gunnison et al. (1979; 1980 a,b; 1984) and Gunnison, Chen, and Brannon (1983).

Laboratory Investigations

33. Laboratory tests are conducted for the overall objective of assessing the potential for changes in water quality occurring with both initial and long-term contact with water using soil and vegetation samples collected from the proposed reservoir site. The rationale for selection of sampling sites is based on the specific objectives for undertaking the reservoir site preparation study, as described below.

- a. To assess a specific contaminant (for example, mercury deposits), sampling locations should be restricted to areas in and downstream of sources of the contaminant.
- b. To determine the effects of soil/water interactions and decomposition of vegetation on water quality, sampling locations should be selected on a basinwide basis. Sampling is normally restricted to the predominant types of soil and vegetation in the reservoir basin to minimize cost.

Table 1

Reservoir Site Preparation Studies

Procedure	Specific Concerns	Parameters Measured*	Reference/Other Source of Information**
Selection of sample locations	Samples most widely representative of soils and vegetation or of contaminant occurrence in the reservoir basin	N/A	Gunnison et al. 1979, 1984 US Soil Conservation Service soil maps Corps District Office surveys of impoundment area Local university authorities on area soils and vegetation Local residents
Sample acquisition and transport	Obtaining samples of sufficient amounts for all testing needs; obtaining samples of proper size for use in test chambers; transporting samples with minimum degradation of sample quality	N/A	Gunnison et al. 1979, 1984
Soil extraction and characterization	Obtaining knowledge of the materials present and available for mobilization from soil into the water column; obtaining an understanding of initial soil properties	Total organic carbon Total inorganic carbon Total Kjeldahl nitrogen Nitrate-nitrogen Total phosphorus Orthophosphate-phosphorus Total iron Total manganese Cation exchange capacity Particle size	Gunnison et al. 1979, 1984 Jackson 1958 US Soil Conservation Service soil manuals
Soil/water interactions	Dissolved oxygen (DO) depletion rate and extent	DO	Gunnison et al. 1979, 1984; Gunnison, Chen, and Brannon 1983; American Public Health Association (APHA) 1980
	Biochemical oxygen demand (BOD) release rate and extent	BOD	Gunnison et al. 1979, 1984; APHA 1980
	Rate and extent of nutrient releases	Total organic carbon Total inorganic carbon Total Kjeldahl nitrogen Nitrate-nitrogen Ammonium-nitrogen Total phosphorus Orthophosphate-phosphorus Total sulfide	Gunnison et al. 1979, 1984
	Rate and extent of metal releases	Soluble manganese Soluble iron	Gunnison et al. 1979; Kennedy, Zellweger, and Jones 1974
	Other water quality parameters	pH Conductivity Color	Gunnison et al. 1979, 1984; APHA 1980
Vegetative decomposition	BOD	BOD	Gunnison et al. 1979
	Rate and extent of nutrient releases	Total organic carbon Total inorganic carbon Total Kjeldahl nitrogen Nitrate-nitrogen Total phosphorus Orthophosphate phosphorus	Gunnison et al. 1984
	Rate and extent of metal releases	Soluble manganese Soluble iron	Gunnison et al. 1984

* See Table 2 for a listing of analytical methods and detection limits for individual parameters.
** References given are for the procedures and specific concerns rather than for individual parameters.

34. Laboratory test data can be compared with water quality criteria, extrapolated to basinwide conditions, or transformed into release rates suitable for use in mathematical models (see Therien and Spiller (1981) for vegetation modeling and Chen, Brannon, and Gunnison (1984) for water quality modeling).

35. Procedures for sampling site selection, sample acquisition, and examination of various aspects of soil flooding and vegetative decomposition are cited in the references and other sources of information cited in Tables 1 and 2.

Soil flooding

36. Soil extraction and characterization. Use of soil extraction and characterization procedures is recommended because they will provide an understanding of soil properties and information on the kinds and total amounts of the various nutrients and metals present in the soil prior to flooding. Data on the kinds and amounts of metals and nutrients present are important as an indication of which constituents to monitor in soil flooding studies. The data also permit comparisons with laboratory data on the levels of these substances in the water column after flooding; such comparisons provide an understanding of the mobility of the metals and nutrients during and after flooding.

37. In addition, the data obtained from the laboratory soil extraction and characterization tests may be of use later, after the reservoir has been built and is in operation, in the event that unforeseen problems with water quality occur or if changes in the reservoir and/or its operational procedures are anticipated. Such changes could involve, for example, raising the water level to increase storage capacity or changing the operational pattern with the addition of a pumpback storage capability. These changes may result in flooding of new soils or the resuspension of flooded soils into the water column. In each case, knowledge of initial soil properties is necessary to predict the impact of these changes on reservoir water quality.

38. Soil/water interaction studies. Soil/water interaction tests are required if it is necessary to assess the impact of initial or prolonged contact of soils in the river basin with the water column.

Table 2

Analytical Methodology and Detection Limits for Water Quality Parameters Measured in Preimpoundment Studies*

Reference	Parameter	Method	Detection Limit
USEPA (1979)	Sulfate	375.4	5.0 mg/ℓ
	Orthophosphate-phosphorus	365.1	0.01 mg/ℓ
	Nitrate-nitrogen	353.2	0.01 mg/ℓ
	Chemical oxygen demand	410.2	5.0 mg/ℓ
	Ammonium-nitrogen	350.1	0.01 mg/ℓ
	Total Kjeldahl nitrogen	351.2	0.10 mg/ℓ
	Total phosphorus	365.4	0.10 mg/ℓ
	Iron	236.1	0.05 mg/ℓ
	Manganese	243.1	0.05 mg/ℓ
	Potassium	258.1	0.05 mg/ℓ
	Calcium	215.1	0.05 mg/ℓ
	Chloride	325.3	5.0 mg/ℓ
APHA (1980)	Magnesium	242.1	0.05 mg/ℓ
APHA (1980)	Sulfide**	427C	0.1 mg/ℓ
	Dissolved oxygen	421B	20.0 mg/ℓ
	Total inorganic carbon†	505	0.1 mg/ℓ
	Total organic carbon†	505	1.0 mg/ℓ
	Biochemical oxygen demand	507	5.0 mg/ℓ

* Methods of preservation and storage are given in the indicated reference.

** Detection limit for sulfide can be lowered severalfold by use of zinc acetate to concentrate the sulfide (APHA 1980, Method 427B).

† Beckman Model 865 Infrared Analyzers, Beckman Instruments, Inc., Fullerton, Calif. (1975).

The parameters to be measured, sampling methods, and sampling intervals require special consideration and are discussed in the references given in Table 1. Specific important considerations, as well as the rationale for those procedures listed as specific concerns in Table 1, are discussed in the following paragraphs. The investigator must weigh the results of all the tests in making a decision to recommend leaving, removing, or covering a given body of soil during reservoir site preparation.

a. Methods of testing. Various methods for conducting soil/water interaction tests are available from the literature (cf. Sylvester and Seabloom 1965; Campbell et al. 1976; Gunnison, Chen, and Brannon 1983). Procedures developed at WES involve the use of large reaction chambers equipped for continuous aerated flow-through of the contact water. The large chamber volume allows removal of large water samples with minimal impact on the soil/water system while the continuous-flow system mimics, to some extent, the reservoir ecosystem and prevents the development of stagnant conditions within the reaction chamber. Stagnant conditions do not promote the efficient release of many materials from the flooded soil into the water column and thus can prevent the investigator from determining the maximum exchange rates in the soil/water system.

b. Type of water.

(1) Another important consideration in setting up a soil-water contact system is the type of water to use. Distilled water is of advantage in that the investigator knows that any water quality constituent (except DO) found to be present in the water column must have come from the soil. Use of water that has in it the same constituents as the river to be impounded has the advantage of providing a better model of the prototype system.

(2) In addition, the inflows of the proposed reservoir may bring into the system one or more chemical constituents either not found or else found only in low levels in the test soil. Several dissolved chemical compounds (e.g., sulfate and nitrate) undergo profound changes when interacting with flooded soils, and it is important to determine the impacts of these changes upon water quality. Also, if the proposed reservoir system will receive acid mine drainages or other acidic inflows, it is important that the water of the soil/water contact system contain similar forms and amounts of acidity to obtain an accurate understanding of the influence of soil/water interactions on water quality.

c. Incubation.

(1) Incubation temperature and length of incubation are also important in soil/water contact studies. While reservoir temperatures are often below the 20° C, use of a 20° C incubation temperature is acceptable and encourages soil/water interactions to occur at high rates (see section, Changes in Water Quality as a Result of Impoundment). Whatever temperature is

selected, it is important to maintain a constant temperature throughout the incubation period because variations in temperature will cause variations in release rates.

(2) Duration of incubation is important because the soil/water contact must be of sufficient duration to permit all reactions to occur and for all releases to achieve maximum levels. This process is site specific; thus, it is difficult to set limits for the minimum incubation period. At WES, experience has shown that a 100-day incubation period is generally long enough to allow for all reactions to occur and for release rates to reach maximum levels (Gunnison et al. 1979, 1984).

d. Test rationales.

(1) Dissolved oxygen. Dissolved oxygen depletion rate and extent are assessed for three reasons: to provide data for computation of the oxygen demand by the flooded soil on an areal basis in the reservoir basin; to provide an indication of when sampling for DO is no longer required if the system's oxygen demand is high enough to deplete all DO from the water column; and to determine when and if sampling procedures for nutrients and metals require special precautions for anaerobic conditions.

(2) Nutrient and metal releases and biochemical oxygen demand (BOD). The rate and extent of nutrient and metal releases are examined to determine the pattern and magnitude of releases. Knowledge of the pattern and magnitude of releases enables assessment of the rates of releases for each of the nutrients and metals resulting from soil/water interactions and gives an approximation of the highest levels that each constituent will reach in the water column. This information can be used to predict nutrient and metal loadings to reservoir waters based on the surface area in the reservoir occupied by each test soil. Changes in BOD in the water column over each test soil are measured for the same reasons.

(3) pH. Measurement of pH is conducted mainly to determine if soil flooding will cause marked variations in water column pH with respect to the original pH of the water prior to exposure. Most flooded soils tend to buffer the pH of floodwaters toward the range of neutrality (pH 6.5 to 7.5) during anaerobic conditions, rather than causing a raising or lowering of pH from neutrality.

(4) Conductivity. Conductivity measurements provide an indirect measurement of total dissolved solids added to the water from the soil.

(5) Color. Color measurements provide a knowledge of how much color is added (intensity), spectral nature of the color (hue), and duration of color release. Since color added to water by the soil-flooding process has aesthetic as well as chemical ramifications, an understanding of color release is important from both a public relations standpoint and a water quality viewpoint.

Vegetation decomposition

39. The main purposes for studying the effects of decomposition of flooded vegetation are the same as for studying the effects of soil flooding on water quality. Oxygen depletion caused by the decomposition process can be examined by placing samples of the vegetation into a BOD bottle and running a BOD test (Gunnison et al. 1979). Patterns of BOD, nutrient, and metal releases to the water column caused by vegetative decomposition are monitored by submersing samples of the vegetation in a large water column and monitoring the release of these constituents over a 50-day incubation period (Gunnison et al. 1984). Unlike the soil/water interaction studies, vegetative decomposition studies are conducted in water fully saturated with DO to promote maximum decomposition rates.

40. Again, the data obtained from these studies can be used to compute the potential releases of nutrients and metals occurring on an areal basis in the newly filled reservoir. However, because the exact amount of vegetation within a reservoir basin is often uncertain, a large error is introduced by extrapolating from an approximation of the grams of plant tissue per square metre in the reservoir basin to the amount of nutrient or metal actually released to the water column. Thus, it becomes difficult to make exact recommendations concerning the clearing of plant material during reservoir site preparation. Nonetheless, the decomposition tests can give the investigator an approximation of the kinds and amounts of materials to be released from vegetation as well as the rates of release. This information will thus indicate whether clearing should be done.

Changes Expected in Water Quality as a Result of Impoundment

41. To illustrate the types of information and ranges of data that may be obtained from laboratory studies on soil flooding and decomposition of vegetation, representative data are presented for: Twin Valley Lake, Wild Rice River, Minnesota (Gunnison et al. 1979); B. Everett Jordan Lake, Haw and New Hope Rivers, North Carolina;* and Richard B. Russell Lake, Savannah River, Georgia-South Carolina border (Gunnison et al. 1984). Results of the data obtained from these studies indicate that, following impoundment, changes in the water quality of these reservoirs should follow the trends illustrated in this section. The discussions are based on results obtained at 20° C. While hypolimnetic temperatures near the dam are likely to be considerably below this, upstream temperatures may well reach or exceed 20° C. In addition, rates of decomposition and nutrient and metal releases tend to increase exponentially with temperature. Based on these points, the following discussion will present a worst-case estimate of what may happen in a reservoir compared to discussions based on studies conducted at lower temperatures.

Soil flooding

42. Results obtained by repeat runs using the same soil sample during these studies are reproducible; however, variations between soils even in replicate samples from a given study site may be so large that differences, if any, occurring between the study sites may not be apparent. Thus, water quality data may need to be presented as averages of results obtained with all reaction chambers for a particular proposed reservoir. While some of the results given in this section are displayed in tabular form, most are presented graphically. In the latter case, the variability observed in the studies can be determined by calculating the mean standard error for each study. This will provide the investigator an idea of the variation for each study.

43. Depletion of DO and its relationship to BOD. Depletion of DO

* Unpublished data compiled by the authors of this report.

is likely to occur in any situation where labile soil organic matter and its attendant microflora are brought into contact with water. The consequences of oxygen depletion processes with regard to reservoir water quality are dependent on several environmental factors, including aeration status, inflow placement, retention time, and temperature. The causes and consequences of DO demand are given extensive treatment by Gunnison, Chen, and Brannon (1983) and will not be repeated. Figure 1 depicts comparative oxygen depletion curves for soil from each of the impoundment areas when incubated at 20° C. On an areal basis, the oxygen demand rates for the soils were 410, 183, and 98.4 mg/m^2/day for Twin Valley, Richard B. Russell, and B. Everett Jordan soils, respectively.

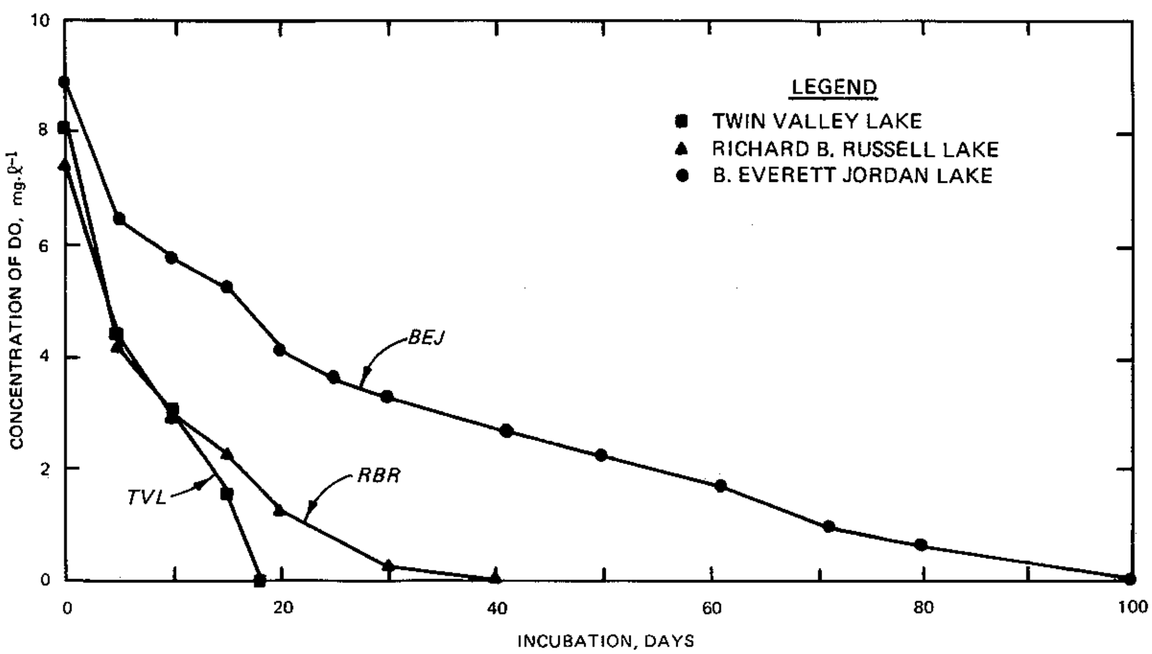

Figure 1. Comparison of DO depletion in the water columns above soils from the study areas at 20° C

44. Biochemical oxygen demand is intended as a measure of biologically available material either suspended in water or dissolved in water. However, the BOD test is optimized for utilization of organic carbon, while other materials such as NH_4^+, which are also biologically available, are not consumed. In this regard, BOD may be considered as an index of that portion of total organic carbon that is biologically

available. In the past, the BOD of soil has been measured directly by immersing a known quantity of soil in the standard BOD solution (Gunnison et al. 1979). However, in terms of the BOD that enters the water column from a flooded soil, measurement of BOD within the water column of a soil/water interaction chamber is a more accurate reflection of what may be expected to occur in a newly impounded reservoir (Gunnison et al. 1984). For Richard B. Russell soil, the BOD released (averaged for the steady-state conditions over the 100-day incubation cycle) was 1.10 ± 0.308 mg/ℓ. Based on the volume of the reaction chamber water column (210 ℓ) and the surface area of the soil/water interface (0.2025 m^2), this is equivalent to a release of 37.0 $mg/m^2/day$ of BOD-producing materials from the flooded soil.

45. High BOD values for soil and vegetation samples are indicative of a situation that will likely cause significant depletion of DO from overlying waters, especially if the impoundment develops strong thermal stratification. Oxygen depletion rates reported in the studies ranged from low (B. Everett Jordan) to moderate and high (Richard B. Russell and Twin Valley, respectively). However, such comparisons among reservoirs suffer from the overall site-specific properties of individual reservoirs. Nonetheless, with oxygen depletion rates of more than 100 mg $O_2/m^2/day$ exerted by newly flooded soils, bottom waters will tend to become anoxic quickly if a lake becomes stratified with temperatures in the 20° C region. Actual in-lake oxygen depletion times will depend upon: (a) the depth of the water column between the bottom of the reservoir and the metalimnetic-hypolimnetic interface; (b) the nature and fate of organic loadings entering the hypolimnion from the watershed above the reservoir and from the littoral zone and epilimnion of the reservoir; and (c) two additional factors described in the following paragraph.

46. Water in the Richard B. Russell and B. Everett Jordan soil/water interaction studies required much longer to become anoxic relative to water in the Twin Valley Lake soil/water interaction study. However, in both the Richard B. Russell and the B. Everett Jordan studies, soil oxygen demand resulted in a rapid initial and prolonged

drop of DO levels below the levels of incoming flows. This has added significance when placed into the context of reservoir systems wherein waters entering the impoundment may not be fully saturated with DO, as was the case in these studies.

47. If, for example, waters released from an upstream project have low DO levels, then oxygen demand by newly flooded soils can be intense enough to remove the remaining DO, even at lower temperatures. Alternatively, aeration of inflows prior to entry into a reservoir project may yield waters supersaturated with DO. To what extent this process will influence hypolimnetic DO levels cannot be evaluated at present because such an assessment requires laboratory simulation of cumulative effects, which is presently beyond the state-of-the-art. Also beyond the state-of-the-art is the application of the methodologies described in this report to lake hydrodynamics.

48. After the study sites have been flooded for 3 to 4 years, the oxygen demand can be expected to diminish due to loss of readily available organic matter through decomposition, leaching, and/or suspension and washout of particulates. The procedures described in this report do not account for alteration in oxygen demand due to inflow and deposition of inorganic soil/sediment components over the existing soil; nor do these studies examine the potential sustaining effects or increase in oxygen demand that may occur should additional soils of the existing type be washed in and deposited, thus replenishing the oxygen-demanding materials initially present. If the bottom waters remain aerobic during the first year of impoundment, a larger decrease in oxygen demand would tend to occur as a consequence of efficient and complete utilization of organic matter under aerobic conditions relative to anaerobic circumstances (Thimann 1963, Brock 1967, Alexander 1977).

49. Inundation of vegetation is expected to result in a BOD that initially exceeds that of soil at 20° C, since vegetation is very susceptible to biological degradation. Degradation of organic matter in flooded soil tends to occur more slowly than vegetation; however, the former process occurs more steadily with time as compared to vegetative decomposition. The BOD of the vegetation should eventually become

comparable to the BOD of the soil after a period of incubation. The case for chemical oxygen demand (COD) is similar to that for BOD, but COD will normally be several orders of magnitude larger because of its general characteristics. While BOD is a measure of oxygen demand exerted by materials readily available to microorganisms, COD includes BOD plus materials less readily available to microorganisms plus materials that are only oxidizable chemically.

50. Nutrient releases. Figure 2 presents comparative data on dissolved total organic carbon (TOC) and total inorganic carbon (TIC) releases for each of the study projects. Twin Valley Lake soil released the largest amount of TOC but the least amount of TIC. Richard B. Russell soil had the most irregular pattern of TOC release. The TIC releases from all three study sites followed a similar pattern.

51. In general, the releases of TOC from soil are not predictable but rather behave erratically, with the amount of material released being site specific. Thus, to assess the pattern of release from a given impoundment site, site-specific tests need to be conducted. By contrast, releases of TIC behaved in a predictable manner, although the amount of TIC accumulated within the water column remains site specific. The chemistry of TIC interactions with various other water column constituents is, in many respects, more complex than for TOC interactions; formation of various insoluble precipitates as carbonates is possible, depending on prevailing pH conditions.

52. Figure 3 presents comparative data for total Kjehldahl nitrogen (TKN) and ammonium-nitrogen (NH_4-N) releases into the water from each of the soils, while Figure 4 presents a comparison of nitrate-nitrogen (NO_3-N) losses from the water columns overlying these soils. Twin Valley soil caused the largest changes in each of these constituents and also had the most erratic release pattern for TKN. By contrast, Richard B. Russell soil exhibited prolonged and steadily increasing releases for TKN and NH_4-N, with nearly linear trends being demonstrated. B. Everett Jordan soil released the least amount of TKN and NH_4-N, with marked increases in release patterns not becoming evident until after half the incubation period was over. The relationship

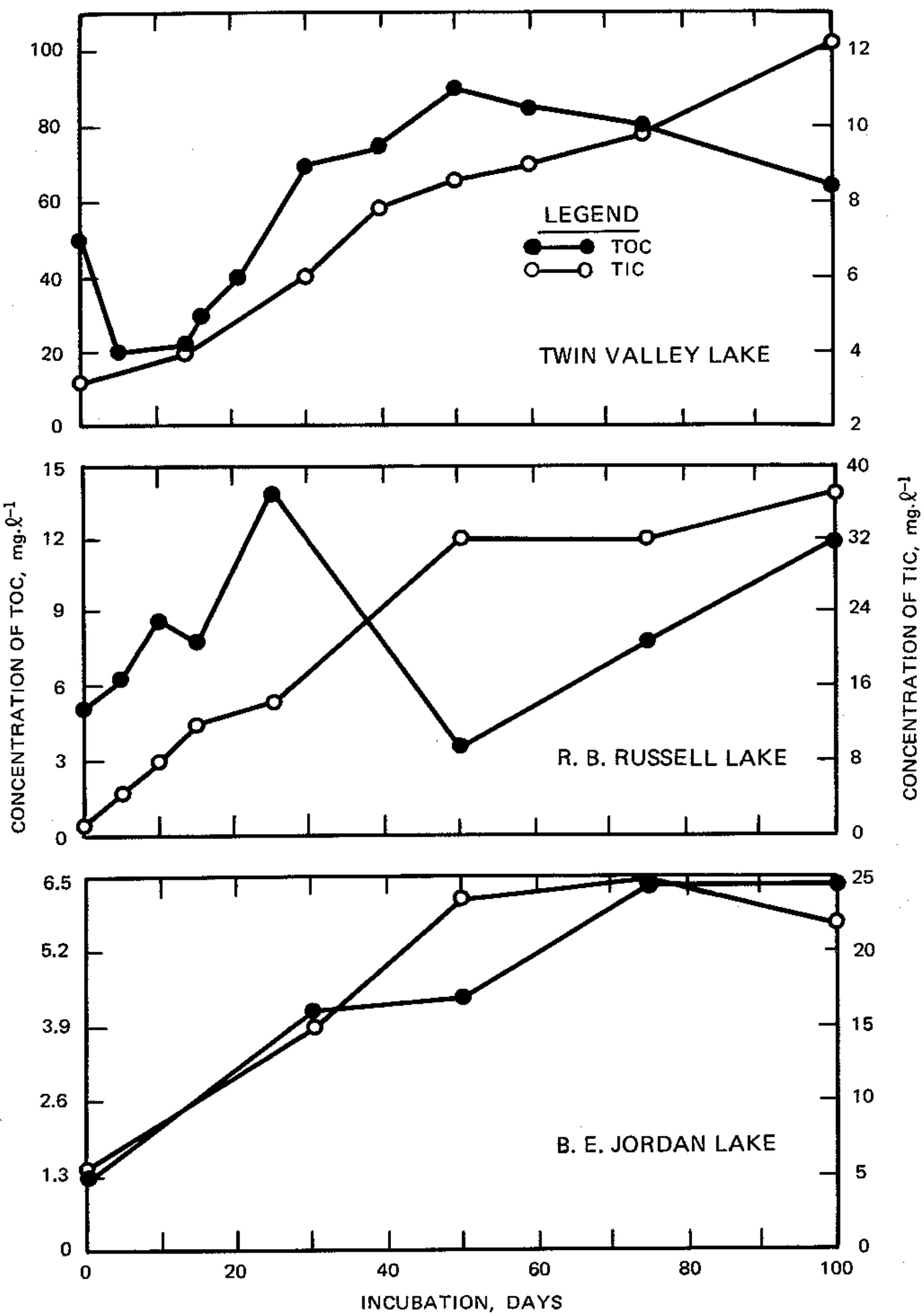

Figure 2. Comparative releases of dissolved TOC and TIC observed in the water columns above soils from the study areas

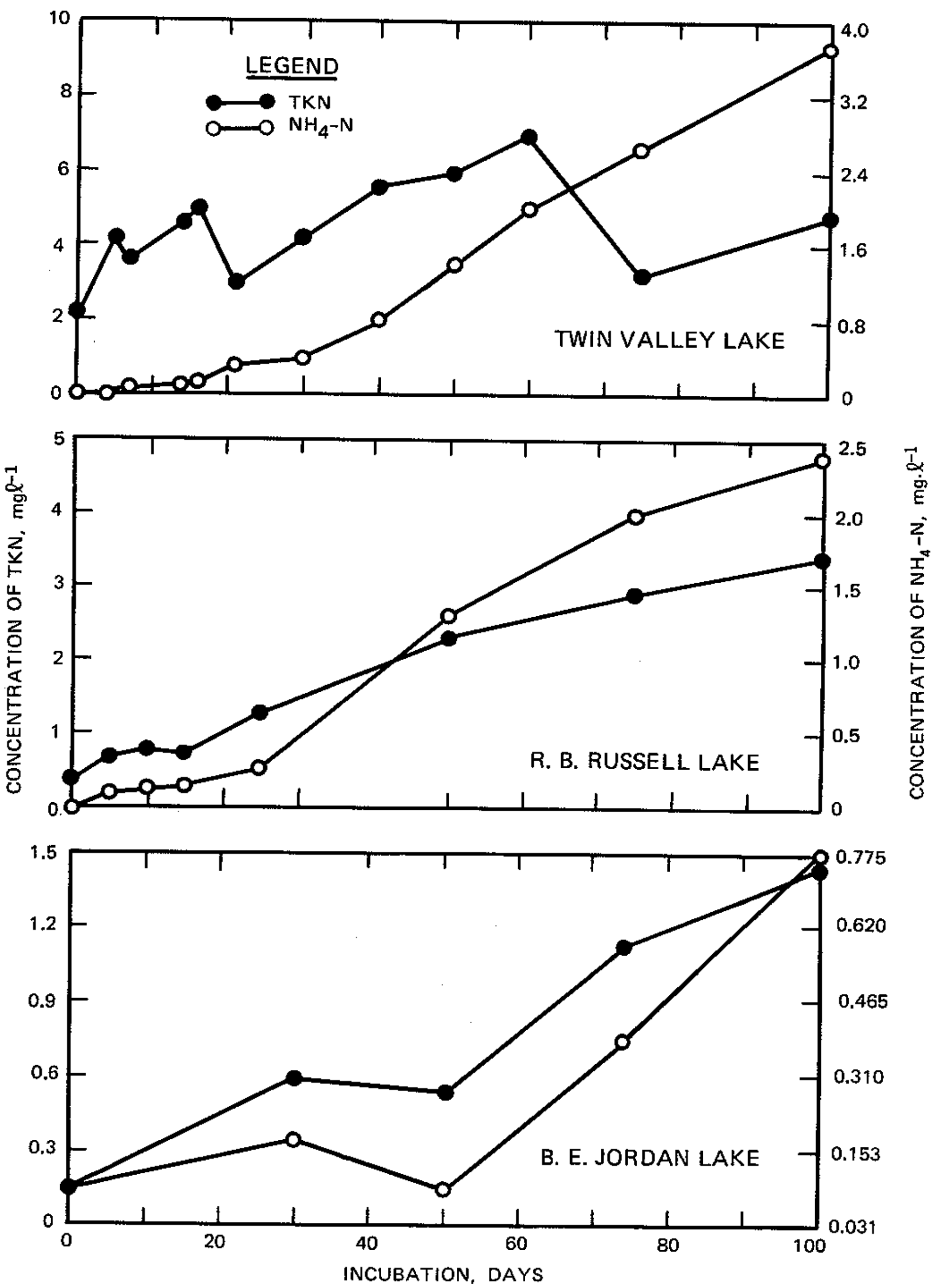

Figure 3. Comparative releases of TKN and NH_4-N observed in the water columns above soils from the study areas

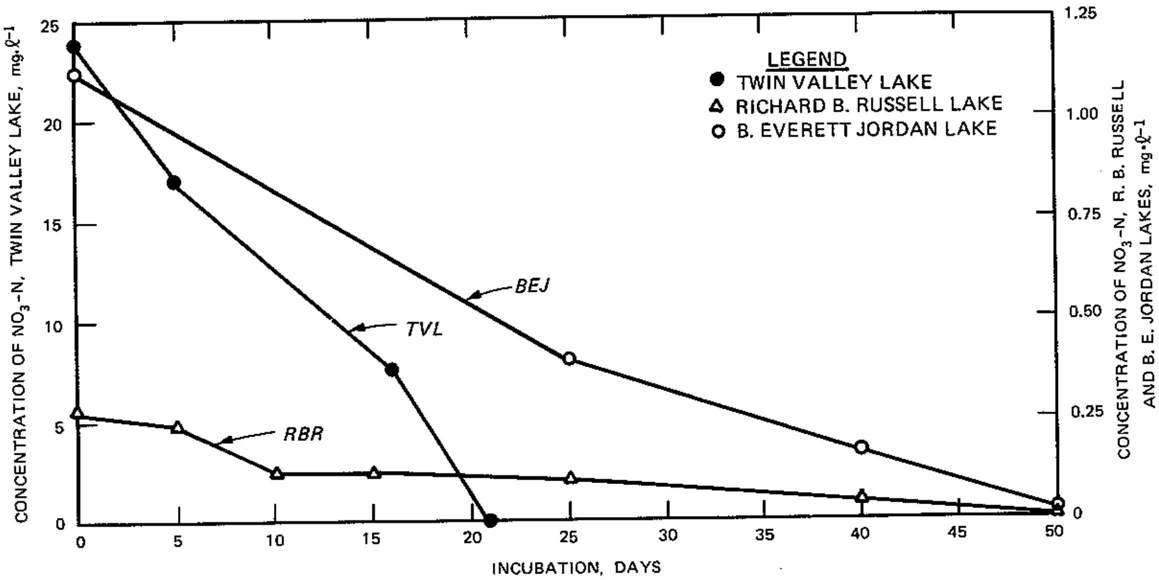

Figure 4. Comparison of NO_3-N losses observed in the water columns above soils from the study areas

of initial soil content TKN and NH_4-N to the appearance of these constituents in the water column will be considered later.

53. The dynamics of NO_3-N changes within the water column are reflective of two processes. First, oxidation of NH_4-N occurring at the flooded soil/water interface, along with NO_3-N-bearing inflows, will add NO_3-N to the water column. Second, denitrification, microbial reduction of NO_3-N to N_2, will remove NO_3-N from the water column. In spite of a requirement for anaerobiosis, the latter process can occur under aerobic conditions in the water column because NO_3-N diffuses into the anaerobic flooded soil and/or into the anaerobic interior of suspended particulates. If the water column becomes anaerobic, then denitrification can also occur at the soil/water interface.

54. The water columns over the three test soils showed decreases in NO_3-N with time (Figure 4). However, only the water overlying Twin Valley soil exhibited rapid and complete disappearance of this constituent at a time closely approximating the complete removal of DO (17 days). The water column overlying Richard B. Russell soil also demonstrated a complete loss of NO_3-N, but the loss rate was lower, with the time required being slightly longer than that needed for total removal of DO (40 days). B. Everett Jordan water still had detectable concentrations of DO (Figure 1) and NO_3-N (Figure 4) at 50 days. Both Richard B. Russell and B. Everett Jordan soils had comparatively low levels of NO_3-N in their waters at the beginning of incubation, with the values for the waters over these soils being approximately 0.01 and 4.5 percent of the initial value for the Twin Valley system, respectively.

55. Figure 5 presents data for release of total phosphorus (TP) and orthophosphate-phosphorus (OPO_4-P) for each of the soils. Twin Valley soil, again, had the largest amount of release of each constituent and also had the most erratic pattern for TP release. Richard B. Russell and B. Everett Jordan soils exhibited similar trends and magnitudes of TP release. Total phosphorus is the sum of organic phosphate-P plus OPO_4-P. Thus, comparison of TP with OPO_4-P will give an approximation of the partitioning of TP into inorganic and organic fractions.

From the data in Figure 5 it is apparent that TP is consistently larger than OPO_4-P for two of the soils tested. In the case of Twin Valley soil, the maximum levels for OPO_4-P were 50 to 60 percent of the corresponding values for TP, while for Richard B. Russell soil, the maximum values for OPO_4-P were 57 to 71 percent of the corresponding values for TP. B. Everett Jordan soil exhibited releases of OPO_4-P that achieved nearly 100 percent of the value for TP at 100 days.

56. Results of the studies presented here indicate that releases of organic forms of carbon (C), nitrogen (N), and phosphorus (P) from the soils into the water column occur extensively, even under fully aerated conditions. Release of organic materials from these soils is not surprising in view of the large amounts of organic matter originally present in most cases (Table 3). The relationship of the individual components of organic matter to those organic constituents appearing in the water column becomes apparent when the soils are compared with each other for TKN, TP, and TOC (Table 4), and to the concentrations appearing in their respective water columns. Thus, Twin Valley soil, which had the highest (average) values for TKN, TP, and TOC, also demonstrated the largest releases of these components into the water column. By contrast, B. Everett Jordan soil had the lowest (average) levels of these constituents and also had the lowest releases into the overlying waters. In addition, Twin Valley soil, with the highest BOD values for the soils examined, also exhibited the most rapid DO depletion rates among all of the soils.

57. The values for the total dissolved and inorganic forms of C, N, and P obtained for the three soils are not necessarily the concentrations that will be achieved in the natural ecosystems; such values will of necessity be determined by the movement of nutrients from the flooded soil to the water column in combination with mixing occurring within the water column itself. Water columns of reservoirs are, under stratified conditions, not as well mixed as the reaction columns used for these studies. Microstratification will prevent the net flux of materials released from the flooded soils from being evenly disbursed throughout the water columns, and the concentration of nutrients will increase

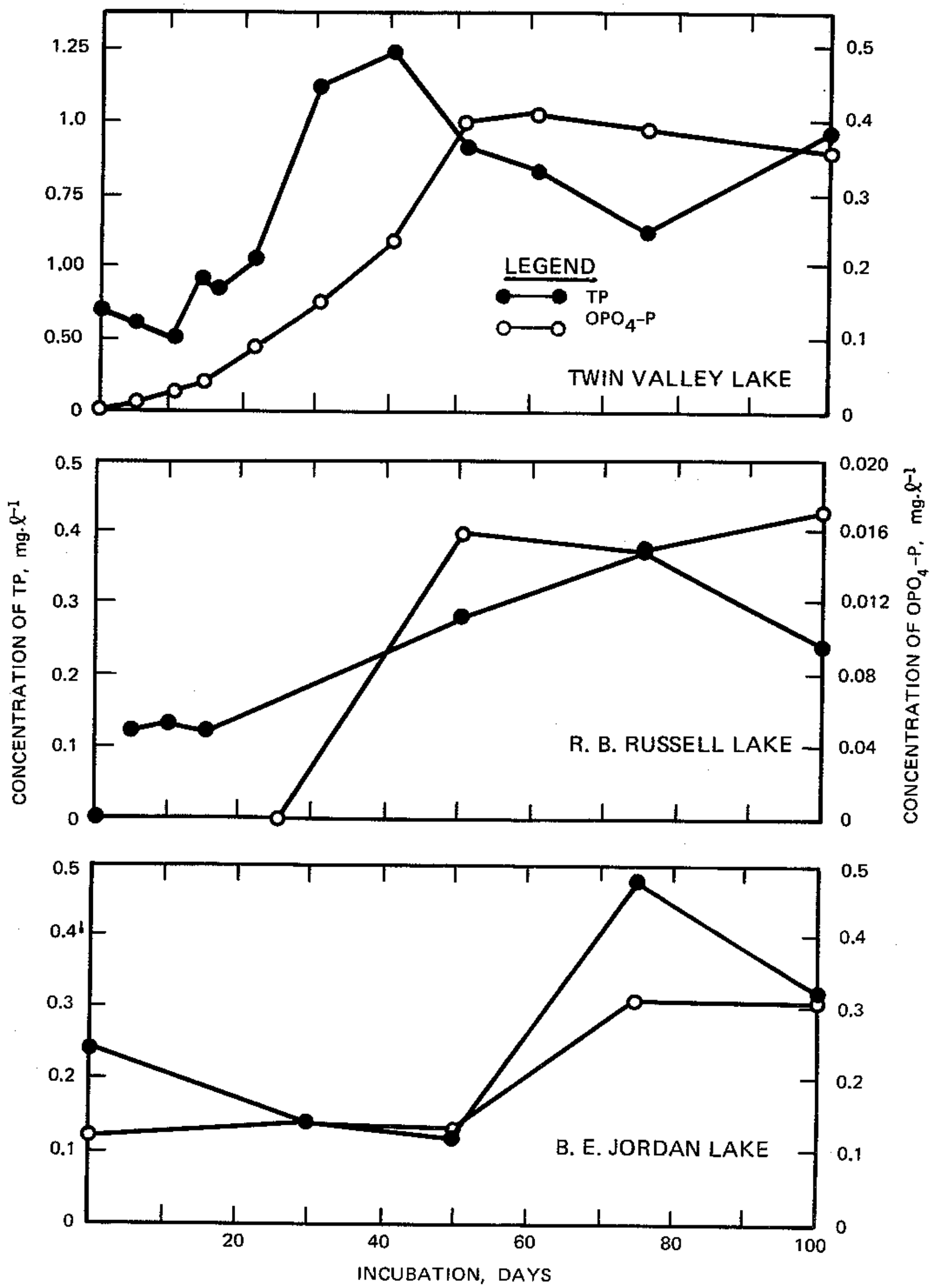

Figure 5. Comparative releases of dissolved TP and OPO_4-P observed in the water columns above soils from the study areas

Table 3

Organic Matter Originally Present in Test Soils*

Source of Soil	Study Site	TOC, percent	TOM, percent**
Wild Rice River, Minnesota†	1	7.1	12.2
(Twin Valley Lake)	2	6.5	11.2
Haw and New Hope Rivers,	1	4.6	7.91
North Carolina††	2	7.3	12.6
(B. Everett Jordan Lake)	3	3.0	5.16
	4	7.4	12.7
Savannah River, Georgia-	1	5.2	8.94
South Carolina border‡	2	7.2	12.4
(Richard B. Russell Lake)	3	1.6	2.75

* Based on the transformation factor (1.72) of Broadbent (1953) after initial TOC content using the methods of Allison, Bolles, and Moodie (1965) and Davies (1974).

** TOM = total organic matter.

† Gunnison et al. (1979).

†† Unpublished data compiled by the authors of this report.

‡ Gunnison et al. (1984).

significantly toward the bottom of the water columns. Alternatively, a river that plunges and flows along the bottom of a water column will remove nutrients as they are released from the flooded soil. The impacts of these processes on the chemistries of the reservoirs and on releases from the reservoirs cannot be predicted at this time.

58. Metal releases. Releases of manganese (Mn) are shown in Figure 6. The pattern of Mn release was similar for each of the soils; however, the accumulation of appreciable levels of Mn in the water above each of the soils was delayed until after the onset of anaerobiosis (after 15 days, 20 to 30 days, and 70 days for Twin Valley, Richard B. Russell, and B. Everett Jordan soils, respectively). The accumulation of Mn in water is important from several viewpoints. First, occurrence of Mn in water is undesirable because this constituent can cause "objectionable and tenacious stains" in laundry and on laundry and plumbing fixtures (APHA 1980). The presence of Mn has a low limit

Table 4

General Physical and Chemical Properties of Soils from Several Impoundment Areas

Constituent	Concentration* Site 1	Site 2	Site 3	Site 4
	Twin Valley Lake, Wild Rice River, Minnesota**			
TKN, μg/g soil	3,566 ± 3,215	3,290 ± 329	N/A	N/A
Total iron, μg/g soil	9,458 ± 2,595	9,463 ± 630		
Total manganese, μg/g soil	393 ± 99.0	411 ± 20.8		
Total phosphorus, μg/g soil	501 ± 117	511 ± 37.4		
Cation exchange capacity, meq/100 g soil	22.4 ± 17.7	22.2 ± 1.4		
TOC, percent	7.1 ± 7.7	6.5 ± 0.2		
TIC, percent	0.7 ± 0.1	0.7 ± 0.1		
	Everett Jordan Lake, Haw and New Hope Rivers, North Carolina†			
TKN, μg/g soil	161 ± 9.22	262 ± 7.12	106 ± 5.84	210 ± 16.9
Total iron, μg/g soil	6,233 ± 83.2	20,175 ± 156	5,358 ± 253	15,292 ± 1,242
Total manganese, μg/g soil	291 ± 6.11	1,093 ± 7.57	218 ± 2.40	1,438 ± 27.5
Total phosphorus, μg/g soil	56 ± 2.40	470 ± 14.0	101 ± 8.88	156 ± 9.20
Cation exchange capacity, meq/100 g soil	2.15 ± 0.046	2.46 ± 0.131	1.52 ± 0.028	3.81 ± 0.188
TOC, percent	4.61 ± 1.10	7.32 ± 0.275	3.04 ± 0.064	7.38 ± 0.177
TIC, percent	0.040 ± 0.000	0.043 ± 0.006	0.037 ± 0.006	0.060 ± 0.000
Particle size, percent				
Sand	35.0	32.5	65.0	30.0
Silt	52.5	47.5	21.2	43.7
Clay	12.5	20.0	13.8	26.3
	Richard B. Russell Lake, Savannah River, Georgia-South Carolina Border††			
TKN, μg/g	202 ± 18.3	357 ± 5.29	78.1 ± 3.94	N/A
Total iron, μg/g	17,575 ± 505	36,675 ± 2,089	13,500 ± 552	
Total manganese, μg/g	422 ± 8.2	1,465 ± 44.0	512 ± 28.8	
Total phosphorus, μg/g	115 ± 5.1	1,595 ± 32.8	114 ± 9.4	
Cation exchange capacity, meq/100 g soil	0.15	0.15	0.15	
TOC, percent	5.22 ± 0.175	7.22 ± 0.147	1.63 ± 0.243	
TIC, percent	0.02 ± 0.008	0.04 ± 0.008	0.02 ± 0.014	
Particle size, percent				
Sand	50.0	51.2	88.8	
Silt	30.0	29.4	8.1	
Clay	20.0	19.4	3.1	

* Data are expressed as the mean ±95-percent confidence interval.
** Gunnison et al. (1979).
† Gunnison et al., unpublished data.
†† Gunnison et al. (1984).

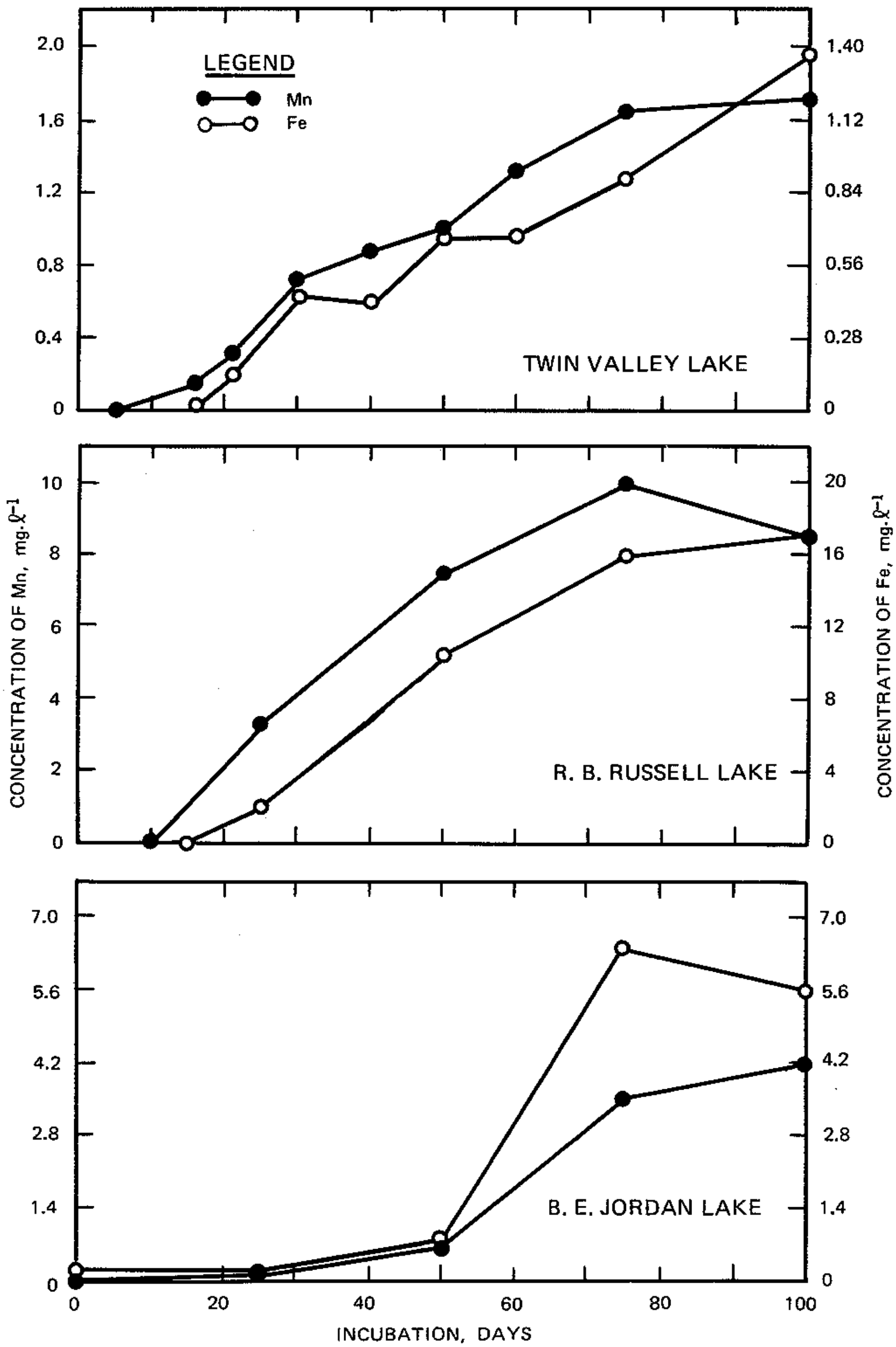

Figure 6. Comparative releases of soluble reduced forms of Mn and Fe observed in the water columns above soils from the study areas

(1 mg/ℓ) imposed because of these properties, rather than for toxicological reasons, and the removal of Mn at a water treatment plant often requires special (and expensive) means of removal (APHA 1980). Relative to chemical and microbial processes occurring in a new reservoir, the presence of low levels of Mn is indicative of anaerobic conditions in the flooded soils; in high levels, its presence signifies the development of anaerobic conditions in the water column. For reservoir operations, the presence of Mn is undesirable because the black oxidation product MnO_2 can be deposited on rocks and structures in the tailwater area, presenting an unsightly appearance. Moreover, present research suggests that MnO_2 may serve a catalytic function, particularly with regard to iron oxidation and humate chemistry, giving the presence of MnO_2 on tailwater rocks and structures added significance.

59. Figure 6 also depicts iron (Fe) releases into the water column above each of the soils. The presence of iron is important because iron is soluble only in the Fe^{2+} state, and reduction of Fe^{3+} to Fe^{2+} requires anaerobic conditions. While Fe is extremely abundant in the earth's crust, Fe normally occurs in variable but minor amounts in natural waters (APHA 1980). The appearance of Fe in appreciable levels in waters is significant in the stains it imparts to laundry and porcelain and in the taste it imparts to potable waters.

60. In the reservoirs examined, accumulation of Fe began earliest in waters above Twin Valley soil, the levels barely exceeding 1.0 mg/ℓ (Figure 6). By contrast, the onset of Fe accumulation in waters above Richard B. Russell and B. Everett Jordan soils required considerably longer, but reached much higher levels than for the Twin Valley soil; this was particularly true in the case of Richard B. Russell, where Fe levels were an order of magnitude greater than those achieved for the Twin Valley soil.

61. In the case of Richard B. Russell Lake, and to a lesser extent B. Everett Jordan Lake, the levels of Fe and Mn released from the soils into the water column are fairly high by virtue of the solubility of their reduced forms, approaching those achieved under anaerobic conditions in optimum situations (Brannon et al. 1978). Reaeration of

anoxic waters generated during the study of Richard B. Russell soil produced a reddish-colored precipitate due to the formation of ferric oxyhydroxides, which occur when anaerobic waters containing ferrous iron are exposed to oxygen. Bottom withdrawal from an anoxic hypolimnion would, therefore, be expected to yield a reddish coloration in downstream waters. Insoluble suspensions of ferrous sulfides may also be released during bottom withdrawals. Once released, materials such as ferrous iron and ferrous sulfides oxidize rapidly, resulting in problems with odors (from the sulfide), taste and stains (from the iron), and immediate oxygen demand and longer term BOD. Reduced Mn is more slowly oxidized, although deposits of MnO_2 on downstream rocks and structures may accelerate oxidation through autocatalysis as described previously.

62. Sulfide release. If the sulfate content of the waters over the flooded soils is high, as in the case of Richard B. Russell Lake (9.66 µg/ℓ), and if the proposed impoundment follows the trends observed in the laboratory study of this reservoir, the hypolimnion will become anoxic and hydrogen sulfide will be released into the water column (see Figure 7). While the resultant levels of sulfide in the water can be limited to a certain extent by the formation and precipitation of insoluble ferrous sulfide, the possibility cannot be excluded that some of the sulfide will escape and release its rotten egg odor from the lake. More likely, however, is the potential release of sulfide (primarily in the suspended particulate ferrous sulfide form) with any bottom releases made from a reservoir project having hypolimnetic withdrawal; this will result in odor and oxygen demand problems downstream from the impoundment. Because of its generally lower sulfur content, vegetation is less important in this regard, but contribution of sulfide by decomposing vegetation cannot be dismissed because sulfhydryl groups (-SH) in amino acids and other compounds in plant life are high.

63. Color. In all cases, some color was released from the soils. However, more intense coloration was imparted to water from soil having high humic content (Twin Valley) or iron content (Richard B. Russell) than by soil having lower values of these constituents (B. Everett Jordan). Release of organic color-producing materials will occur under

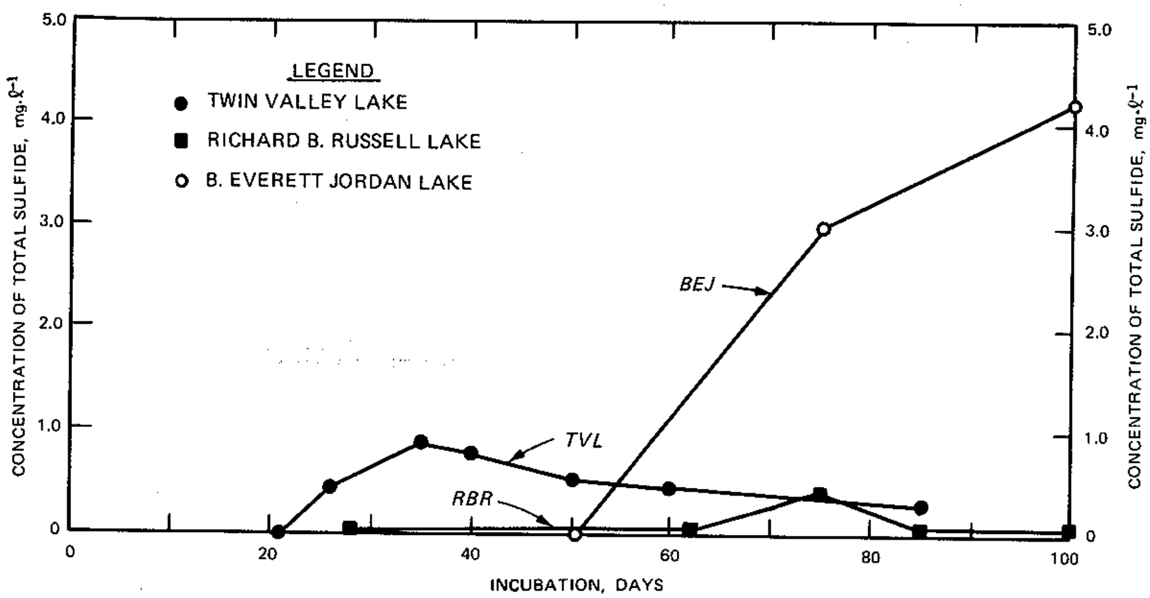

Figure 7. Comparative releases of total sulfide observed in the water columns above soils from the study areas. (NOTE: In the cases of Twin Valley and Richard B. Russell lakes, release of soluble sulfide was limited by immediate formation of insoluble ferrous sulfide)

aerobic or anaerobic conditions. Release of iron-containing color-producing materials will occur to some extent under aerobic conditions. However, the release of iron is enhanced under anaerobic conditions, with the appearance of reddish coloration becoming apparent only with the reestablishment of aerobic conditions. While the duration of color release cannot be accurately predicted, this phenomenon has been observed to be short lived for organic substances, lasting for the first 1 or 2 years of impoundment.

Vegetation decomposition

64. This area of investigation requires more research before the results can be applied with confidence to reservoir site preparation activities. It is known from the work of Gunnison et al. (1979, 1984) and others (cf. Godshalk and Barko 1985) that decomposing vegetation can impart tremendous loading to new reservoir waters. An appreciation for this loading is obtained by performing the BOD procedure described in Gunnison et al. (1984). If the value obtained from this procedure is then extrapolated by first multiplying the BOD (in milligrams of oxygen

per litre per gram of vegetation) by the vegetational coverage in grams/per square metre and then multiplying by the area estimated to be flooded upon filling (in square metres), an approximation of the BOD imparted to the total reservoir can be computed (between 4.6 and 19.4 g/m^2). However, the input information is difficult to obtain and can provide only an estimate.

Influences of Site Preparation on Water Quality

Reservoir clearing

65. The practice of leaving vegetation in the hypolimnetic region where residues of trees and shrubs can have negative impacts on water quality is often undesirable. This is particularly true when the vegetation is of a shrubby and/or herbaceous nature; the BOD of such material is generally high due to its readily biodegradable composition. In this case, removal of bottomland herbaceous vegetation will considerably reduce the BOD loading to reservoir waters. However, removal is not necessarily desirable when maintaining a high biological productivity in support of a desired reservoir fishery (see paragraph 8). Generalizations become difficult to make, and retention or removal of vegetation must be decided on a case-by-case basis, depending on the specific reservoir project purposes.

Soil removal

66. The amount of BOD contained in the soil from a given study site is reflected in the oxygen depletion rates observed in the soil/water reaction units. One means of removing this loading to the reservoir is to strip the upper soil layer. Although costs are prohibitive for many large reservoir projects, the procedure is a proven means of decreasing oxygen demand for the first years after flooding (see Campbell et al. 1976). In addition, preliminary examination of releases from subsurface soil layers has indicated that these layers will release a much lower level of plant-growth-supporting nutrients to the overlying water compared to the upper layers. No attempt is made here to predict the amount or nature of upper-layer material that will enter the

reservoir from upstream areas and settle in the reservoir. Obviously, materials of a highly organic nature will tend to aggravate DO depletion; those of a more mineral nature will tend to seal off the bottom of the reservoir after deposition and thus lower the oxygen demand.

Filling practices

67. Although not part of the reservoir site preparation process, filling practices can sometimes be used to supplement or reduce the need for clearing and stripping activities. Because both color and oxygen demand problems are reduced by reflooding and reexposure of the soil to fresh water, the practice of filling and flushing the impoundment two to three times prior to final filling can have a positive effect on reservoir water quality. However, since much of the aging process depends as much on the breakdown of moderately degradable components (cellulose, hemicellulose) as on the movement of readily soluble components out of the reservoir, those filling practices that tend to accelerate degradation of organic matter while avoiding BOD problems are advisable. This suggests a sequence similar to that described by Sylvester and Seabloom (1965) wherein two or three flushings are used to remove readily soluble or leachable components; flushing is followed by slow incremental filling to keep the reservoir shallow for as long as possible to promote oxygen exchange with the atmosphere and enhance efficient aerobic decomposition of organic matter.

68. A series of fillings and flushings can be difficult to apply to some reservoir projects, particularly if they are downstream from another project or upstream of another project. Other alternatives are possible, but these also require a temporary setting aside of operational activities for a period after the project would normally become operational. For example, if the project has a selective withdrawal facility, project releases may be made from the epilimnion rather than from lower levels. This particular strategy increases the possibility for algal blooms to occur within the reservoir during periods of overturn because nutrients released into the hypolimnion are accumulated during periods of maximum decomposition, i.e., the warm late spring, summer, and early fall months.

69. The nutrients in the hypolimnion are combined with the rest of the water in the reservoir during periods of mixing. However, the nutrients in the hypolimnion are also subject to dilution (a) because of mixing with waters in the metalimnion and epilimnion, and (b) because periods of overturn and mixing are likely to occur at times when flows through the reservoir are high due to heavy runoff in the watershed. In addition, because reduced substances dissolved in hypolimnetic waters have had an opportunity to mix with oxygenated surface waters, these reduced materials will have an opportunity to oxidize. In the case of ferrous iron, the oxidized forms may settle to the bottom, as ferric oxyhydroxide. Or, the oxidized form may be less toxic than its reduced predecessor, as in the case of sulfate. However, the consequences of releasing warm epilimnetic water in the summer months and nutrient-enriched waters during the cooler months must be balanced against the consequences of cold hypolimnetic releases bearing nutrients plus reduced iron and manganese and sulfide.

70. Another alternative is to allow as much water as possible to pass through the sluice gates during initial filling and for the first 3 to 4 years after filling. The procedure will decrease the retention time of the water in the hypolimnion and serve to move materials out of the project rather than permitting them to accumulate. However, this activity may release some anoxic water during the summer with adverse impacts on downsteam water use.

<u>Other procedures</u>

71. There are other alternatives that do not involve reservoir site preparation in the strict sense. However, many of these activities do require implementation before or during dam construction or prior to initial filling. For example, provision for penstock or draft tube injection or turbine ventilation must be made during the planning and construction phases. While facilities for hypolimnetic reaeration or oxygen injection may be added after filling, the positioning and placement of a diffuser pipe would be more easily accomplished prior to filling. It should be reiterated that these alternatives are designed to remedy a problem--little or no DO in the water column--but focus

on the symptom, rather than on the cause of a high oxygen demand in the reservoir. Nonetheless, these alternatives may be the least expensive and/or most practical means of solving the problem. However, past strategies have too often involved waiting for the problem to manifest itself, rather than conducting appropriate studies during the planning phase and devising appropriate methods for dealing with apparent problems.

72. Another treatment methodology used is applied in some of the reservoirs affected by acid mine drainage. The traditional means of dealing with this condition has been to use acid-resistant materials in the dam. More recently, other strategies have been applied, such as installating liming devices in acid drainage-bearing tributaries and filling in (sealing) abandoned mines.

Additional Value of Preimpoundment Studies

73. As is apparent from the preceding discussion, preimpoundment studies are an important source of information in the evaluation of various reservoir site preparation activities. Often, the need for information supplied by preimpoundment studies is not apparent because site preparation activities are not envisioned. Such information, because of its usefulness in assessing what is likely to occur in a new reservoir, is of value in anticipating future operational and management problems. The information is of use in anticipating water treatment requirements for downstream water users. The information may be needed for future project modifications or operational changes, i.e., addition of pumpback capacity, elevation of the reservoir level, or addition of storage as a project purpose.

PART IV: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

74. Present Corps regulations and guide specifications pertaining to reservoir site preparation do not make allowances for the impact of soil flooding and inundation of vegetation on reservoir water quality. Existing literature on reservoir clearing, soil stripping, initial reservoir filling, and reservoir aging provides much of the information needed to formulate guidance on the evaluation of these impacts. Several technical reports (see Gunnison et al. 1979, 1984), papers (Gunnison, Chen, and Brannon 1983; Gunnison, Engler, and Patrick 1985) and this report synthesize the available information and provide general guidance.

75. The WES has used information from the literature, coupled with laboratory studies, to develop a methodology for investigation of the potential water quality impacts of soil flooding relative to reservoir site preparation activities. The methodology, applied in several preimpoundment studies, permits assessment of the effect of soil flooding on DO depletion and on the release of sulfide; various forms of carbon, nitrogen, and phosphorus; and iron and manganese. The trends demonstrated by these parameters in the laboratory should be verified by monitoring the same parameters when proposed impoundments are filled.

76. Application of the results of the laboratory procedures will provide the means to predict the impacts of soil flooding on overall water quality of the proposed reservoir. This predictive information can then be used to evaluate various alternatives when formulating reservoir site preparation activities.

77. The WES has also developed a methodology for investigating the potential water quality impacts of decomposition of vegetation; however, the methodology is not as refined as the soil-flooding procedures. The methodology for studying the decomposition of vegetation may be used to give rough estimates of the impacts of leaving vegetation in place in the reservoir basin, but it should not be relied upon for accurate predictions.

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APPENDIX A: CHRONOLOGY OF THE DEVELOPMENT OF A METHODOLOGY FOR RESERVOIR SITE PREPARATION TO MEET WATER QUALITY OBJECTIVES

1. Existing regulations and specifications on reservoir site preparation require removal of vegetation, debris, and man-made structures as necessary to meet project construction, maintenance, and hazard removal objectives (ER 415-2-1 and Civil Engineering Guide Specification (CE) 1301). ER 415-2-1 also specifies that reservoir site preparation planning will consider the following: (a) achieving a good general appearance, particularly in those areas most used by the public; (b) eliminating pollution; and (c) considering the environment and aesthetics of the area. However, the means by which these objectives are to be accomplished are not stated nor is there an indication that these objectives must be met during the construction and operational phase. Both ER 415-2-1 and CE 1301 provide details of horizontal and vertical clearing for reservoir projects and describe areas of the reservoir to be included in these limits.

2. Engineer Technical Letter (ETL) 1110-2-231 provides guidance for initial filling of Corps reservoirs. However, the methodologies supplied are oriented toward "the first test of the dam to perform the function for which it was designed"; as such, methodologies are given for monitoring new projects for water control, dam performance, fisheries protection, and safety. The need for close coordination with the public is also discussed. No consideration is given to the consequences of initial filing or to conducting initial filling in a manner that will minimize adverse impacts of soil flooding and decomposition of vegetation upon reservoir water quality.

3. Engineer Manual 1110-2-1911 describes construction control for earthen and rock-fill dams. This manual gives brief consideration to clearing, grubbing, stripping, and cleaning of areas upon which a compacted earthen or rock-fill dam will lie for the purposes of removing materials that have undesirable engineering or permeability characteristics or that would interfere with compaction operations. An additional purpose for such activities is to provide a surface that will form an

acceptable bond to the overlying fill. The manual does not make provision for removal of materials that potentially have an adverse impact upon water quality.

4. During the last two decades, increasing national concern for the preservation and protection of the environment has resulted in Federal legislation that makes the environment and water quality mandatory considerations in the management of water resources. The Corps must meet the goals mandated by the Clean Water Act (Public Law (PL) 95-217) for restoring and maintaining the chemical, biological, and physical integrity of the waters of the United States as well as fulfilling requirements under the National Environmental Policy Act (NEPA) of 1969 and other related legislation, such as the National Drinking Water Standards (PL 93-523) and State water quality legislation. In response to the Fish and Wildlife Coordination Act of 1958 (PL 85-264), NEPA, and the increasing Corps involvement in recreational activities, additional attention is being given to maintaining productive fish and wildlife habitats in project areas and decreasing habitat losses associated with these projects.

5. In meeting all these requirements, the Corps has on occasion been caught between opposing forces. For example, to achieve low reservoir release temperatures sufficient to sustain a downstream coldwater fishery, the Corps might have to release hypolimnetic waters from a new reservoir project which contain, from a water quality standpoint, unacceptable levels of dissolved iron and manganese. However, release of epilimnetic waters containing acceptable levels of iron and manganese might result in unacceptably high downstream temperatures for maintenance of a coldwater fishery.

6. Conflicting requirements could be addressed early if the predictive capability existed within the project planning phase to assess the impact of site preparation and initial filling upon water quality. Evaluations would be required that are at or beyond the present state-of-knowledge; lack of this capability has, in the past, resulted in confusion, difficulty, and costly project delays for Corps Districts to assess properly the impact of reservoir construction. This is

particularly true for new reservoirs where rapid depletion of dissolved oxygen accompanied by massive releases of nutrients may occur upon filling.

7. To develop a predictive capability, EWQOS Work Unit IIF (Reservoir Site Preparation) was designed to determine the most environmentally compatible strategies for reservoir site preparation, clearing, and initial filling and to provide appropriate guidance for Corps field offices. Assessment of the strategies required two approaches: literature surveys and laboratory studies.

8. To implement the first approach, extensive literature surveys were conducted both in-house and through agreements with other Federal agencies and universities to provide specific reports, each addressing a particular area of concern for reservoir site preparation. Some aspects mentioned in the literature were examined during the laboratory studies.

9. The second approach involved the use of laboratory soil/water reaction columns in a series of preimpoundment water quality studies to determine project-specific effects of soil flooding and the relationship of this process to reservoir water quality. In this case, studies were either funded by the EWQOS work unit or conducted as a part of special project studies being conducted for Corps Districts. Wherever possible, close coordination was maintained between groups collecting water quality data for reservoirs during initial filling to allow comparisons between the real system and results obtained in the laboratory. When necessary, separate studies were conducted to evaluate processes of particular interest.

10. Several other EWQOS work units provided allied information that, although not directed toward reservoir site preparation, is also useful for predictive purposes. These work units include: IB.2 (Reservoir Chemical Processes), IC.1 (Improve and Verify Existing One-Dimensional Reservoir Water Quality and Ecological Predictive Techniques), and IIC.2 (Reservoir Contaminants).