

Environmental & Water Quality Operational Studies



TECHNICAL REPORT E-83-13

LITERATURE SURVEY OF RESERVOIR CONTAMINANT PROBLEMS

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SUBJECT: Transmittal of Technical Report E-83-13

TO: All Report Recipients

1. I am transmitting herewith this technical report which contains the results of a study conducted within the US Army Corps of Engineers (CE) Environmental and Water Quality Operational Studies (EWQOS) Program. The US Army Engineers Waterways Experiment Station (WES) manages the eight-year EWQOS Program for the Office, Chief of Engineers (OCE), by applying research to selected high-priority environmental quality problems associated with Civil Works activities of the CE. The report reviews, analyzes, and interprets from existing data the nature and magnitude of CE reservoir chemical contaminant problems.

2. Comparison of contaminant data collected in this survey with selected criteria suggested that some of the CE reservoirs for which data existed had certain contaminants which exceeded EPA and/or FDA criteria during the periods when sampling was conducted. Although apparently indicative of contaminant problems, the contaminants data base contained many potential sources of error and variability which limit its usefulness. The data base was obtained from different sources and lacked uniformity in sampling techniques, sampling depth, sample pretreatment, and accuracy and precision of analytical methods used. These factors make data evaluation difficult and cast doubt on definitive evaluations or conclusions.

3. Corps of Engineers reservoirs face the same potential contaminant problems that other lakes and reservoirs in the United States face due to watershed characteristics and waterway activities. The Corps is addressing known problems in a direct manner on a case by case basis. We will address potential problems within the framework of the overall Corps water quality management procedures already in place.

FOR THE COMMANDER:


JOHN E. WALL
Major General, USA
Director of Civil Works

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>This study was conducted to review, analyze, and interpret the existing data on the nature and magnitude of Corps of Engineer (CE) reservoir toxic chemical contaminant problems and to suggest interim guidelines, if possible, for operational and management techniques to minimize contaminant problems based on the behavior of contaminants in reservoir ecosystems.</p> <p>Reservoir contaminant data were collected from published literature, the U.S. Environmental Protection Agency (EPA) STORET system, CE Division and District personnel, and reports from various other Federal and state agencies.</p>		

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The EPA water quality criteria for toxic pollutants and the Food and Drug Administration (FDA) limits on toxic substances present in aquatic food species were used in this report to compare contaminant levels reported in CE reservoirs.

Chemical contaminants data reported for CE reservoirs were of necessity collected from different sources and may lack uniformity in sampling techniques, sampling depth, sample pretreatment, and accuracy and precision of analytical methods used. Due to these and numerous other factors, such as reporting of detection limits, the data should only be used for general interpretation of potential chemical contaminant problems existent in CE reservoirs.

The procedures used to evaluate available contaminants data were based on comparisons with applicable Federal and state criteria. The data base was, however, subject to many sources of error which limited its usefulness in these evaluations. The results of the survey also show that while data on the various inorganic contaminants were limited and reported for only a small fraction of CE reservoirs, data on the organic contaminants were even more limited.

Information was generally insufficient to accurately determine the nature and magnitude of contaminant problems in CE reservoirs. Exceptions existed where intensive, quality monitoring had been conducted on a few selected reservoirs. For most reservoirs, however, there has been inadequate monitoring, and much of the limited information available is of doubtful reliability or is in a format that makes the data difficult to evaluate. Data evaluation, therefore, served chiefly to illustrate the sources and types of data available, but could not reliably establish the nature and magnitude of CE reservoir contaminant problems. Due to data quality and quantity, alternative data evaluation procedures would be expected to produce similar results.

Due to unavailability of data on reservoir toxic chemical contaminants in all CE Divisions, the authors could not establish regional patterns of reservoir contamination. However, acidic pH of certain CE reservoir waters due to acid mine discharges and high water salinity showed some regional patterns.

A review of the published literature indicated that limited information was available on the loss of sediments from watersheds, sediment transport in streams and rivers, sedimentation in reservoirs, and sediment discharge in reservoir release waters. Research studies were also lacking on the contaminant loadings of reservoirs and release waters.

The results of this study also indicate that very little information is available on which to base guidelines for managing reservoir contaminants. Management of temperature levels and dissolved oxygen concentration of reservoir pool and release waters has received a high priority in the past. This points to the need for project-specific research to provide needed information for contaminant management.

Based on the results of this study, it is suggested that an assessment of all available data and potential inputs of contaminants to reservoirs be conducted, followed by selected monitoring as necessary. Monitoring for reservoir contaminants should be flexible and be conducted on a project-specific basis because of site-specific reservoir differences.

A review of the published literature indicates that although a considerable amount of information is available on the environmental chemistry of most classes of contaminants in sediment-water systems, there remains a need for basic project-specific research on the chemistry and fate of toxic contaminants in reservoir systems.

PREFACE

This study (Work Unit IIC.1) was performed for the Environmental and Water Quality Operational Studies (EWQOS) Program, administered by the Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The EWQOS Program is sponsored by the Office, Chief of Engineers, U. S. Army. This study forms part of the Work Unit, Operational and Management Strategies for Reservoir Contaminants. The work was conducted during the period January 1980-September 1982.

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The authors of this report wish to acknowledge the assistance of the EWQOS Field Review Group and personnel in various Corps of Engineers (CE) Divisions and Districts in providing access to the published as well as unpublished data on the CE reservoir water quality problems. The assistance of the U. S. Environmental Protection Agency (EPA) regional offices and various state water pollution control agencies in providing information on the water quality criteria and standards is acknowledged. The assistance of Mr. Dale Givens, Chief, Water Pollution Control Division, Department of Natural Resources, State of Louisiana, for the EPA STORET search is acknowledged, along with Ms. Chintata Haas of the Center for Wetland Resources, LSU, for the reduction and statistical analysis of contaminants data.

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Commander and Director of WES during publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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LITERATURE SURVEY OF RESERVOIR
CONTAMINANT PROBLEMS

PART I: INTRODUCTION

Background

1. The Civil Works Program of the U. S. Army Corps of Engineers (CE) has been involved in the planning, design, construction, and operation of water resource projects for navigation, flood control, hydropower, and associated activities. Over the last two decades increasing national concern for the preservation and protection of the environment has resulted in legislation that makes the environment and water quality additional considerations in the management of water resources. For example, Section 313 of the Federal Water Pollution Control Act Amendments of 1972 (Public Law (PL) 92-500) required Federal agencies having jurisdiction over any activity which may result in the discharge or runoff of pollutants to comply with the substantive requirements of Federal, state, interstate, and local laws for pollution abatement. This legislation was reinforced by issuance of Executive Order 11752 (Executive Order, 1973), which directed Federal agencies to provide leadership in the national goal to protect and enhance the quality of the nation's waters. The Clean Water Act of 1977 (PL 92-500) strengthened Section 313 of PL 95-200 by requiring Federal agencies to meet both substantive and procedural requirements of pollution abatement laws and by allowing citizens to sue for noncompliance. Executive Order 12088 (Executive Order, 1978), which related to Federal compliance with Pollution Control Standards, further reinforced the Clean Water Act provisions.

2. Several law suits have been filed against the U. S. Environmental Protection Agency (EPA), the Department of the Interior, and the CE charging that certain reservoir water releases were unlawful and violated Section 301 of PL 92-500, and requested that these releases be classified as point sources for pollution purposes under Section 502 of the Act. In a recent court case, National Wildlife Federation vs Gorsuch F, 6935.2d 156 (D. C. Cir. 1982), however, it was ruled that reservoir

releases should not be defined as point sources of pollution. If defined as point sources of pollution, reservoir releases would be governed by the National Pollutant Discharge Elimination System (NPDES) under the provisions of Section 402. Future impacts of the court decisions in these law suits on CE management policies have been discussed in a recent article (Eiker, 1977).

3. The trend of Federal legislation and the President's directives to fulfill the national goal of water quality improvement have prompted the U. S. Army Corps of Engineers to include environmental and water quality considerations in water projects under planning as well as those already in operation. The collection, interpretation, and evaluation of CE reservoir water quality data have been the subject of several CE-sponsored symposia in recent years (Committee on Water Quality, 1977, 1978, 1980). The Environmental and Water Quality Operational Studies (EWQOS) Program was initiated by the CE in fiscal year 1978 to develop new or improved technology to solve environmental quality problems while meeting project objectives.

Purpose and Scope

4. The study reported herein was initiated to review, analyze, and interpret the existing data on the nature and magnitude of CE reservoir chemical contaminant problems and to suggest interim guidelines, if possible, for operational and management techniques to minimize contaminant problems based on contaminant behavior in aquatic systems. These findings should be of wide interest because potential contaminant problems are not confined to Corps reservoirs.

5. The initial objectives of this study were:

- a. To conduct a state-of-the-art assessment of the nature and magnitude of chemical contaminant problems in CE reservoirs and their tributaries.
- b. To determine the relationship between the contaminant levels found and the applicable Federal and state water quality criteria.
- c. To identify the effects of physical, chemical, and biological properties of surface waters and sediments on the

transport, persistence, and bioavailability of contaminants in reservoirs and their tributaries.

- d. To propose management guidelines to minimize adverse environmental impacts due to the presence and bioaccumulation of contaminants in CE reservoirs and their tributaries.

6. This project was approached in three phases: information acquisition; evaluation and interpretation of the literature; and consideration of management practices to minimize reservoir contaminant problems. The information gathered in these three phases was synthesized and reorganized and is presented in the following pages.

PART II: INVENTORY OF APPLICABLE WATER QUALITY CRITERIA AND STANDARDS

7. The 1980 EPA water quality criteria for 65 toxic pollutants, the EPA 1976 Red Book criteria for the pollutants not covered in the list of 65 pollutants, and state standards for the pollutants not covered in any EPA criteria, are discussed in this section of the report. These criteria and their relationships to National Drinking Water Standards and state water quality standards will be discussed in the following paragraphs. A description of the Food and Drug Administration's (FDA) allowable-contaminant limits is also given.

1980 EPA Water Quality Criteria for Toxic Pollutants

8. Pursuant to Section 304(a) of the Clean Water Act of 1977 (PL 95-217) and a court order, the EPA published in 1980 water quality criteria for the protection of human health and aquatic life for 64 toxic pollutants (Federal Register, 1980). It should be pointed out that these proposed criteria are based solely on current scientific knowledge and have no regulatory impact. These water quality criteria will become the basis of water quality standards enacted and enforced by state pollution control agencies. A list of the 65 toxic pollutants is given in Table A7.

9. Criteria were not proposed by the EPA to protect recreational, agricultural, or industrial uses due to a lack of scientific data available.

Protection of human health

10. The criteria proposed by the EPA for the protection of human health are estimates of the ambient water concentrations which, in the case of noncarcinogens, represent safe levels for humans, and, in the case of suspect or proven carcinogens, represent various levels of incremental risk. The basis of criteria formulations for specific toxic pollutants is presented in detail elsewhere (U. S. EPA, 1979) and will not

be discussed in this report. For the purpose of our report, the levels of chemical contaminants identified in CE reservoirs were compared with proposed criteria. The water quality criteria to protect human health from the toxic pollutants identified in CE reservoirs are given in Table 1. For suspected or proven carcinogens, the criteria proposed for an additional lifetime estimated cancer risk level of 10^{-5} are given. To compare the 1980 criteria with levels established earlier, Table 1 also contains contaminant levels established in the EPA 1976 Red Book criteria (U. S. EPA, 1976) and in the U. S. Public Health Service (PHS) Drinking Water Standards (Code of Federal Regulations, 1980a, b).

Protection of aquatic life

11. The EPA has proposed criteria derived separately for saltwater and fresh water. However, since CE reservoirs under investigation are freshwater reservoirs, only the criteria developed for freshwater organisms will be documented in this report. Two sets of criteria were proposed for aquatic life protection: the average concentration of toxic pollutants that should not be exceeded during any 24-hour period, and a recommended maximum or ceiling concentration that should not be exceeded at any time. The 24-hour average concentration was an estimate designed to protect aquatic organisms against adverse chronic effects, while maximum concentration was an estimate designed to protect aquatic organisms from acute toxic effects. The basis for the calculation of estimated criteria is discussed elsewhere (U. S. EPA, 1979). Water quality criteria for the protection of freshwater aquatic life from the toxic effects of contaminants identified in CE reservoirs are given in Table 2. The aquatic life criteria proposed in the EPA 1976 Red Book are also given in Table 2 for comparison.

EPA 1976 Red Book Criteria

12. Pursuant to the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), the EPA in 1976 published water quality criteria reflecting the latest scientific knowledge on the effects of pollutants on health and welfare of humans, plankton, fish, shellfish, wildlife,

Table 1
EPA and PHS Water Quality Criteria for Toxic Pollutants to
Protect Human Health

<u>Parameter</u>	<u>EPA 1980 Criteria</u>	<u>EPA 1976 Red Book Criteria</u>	<u>PHS National Drinking Water Standards</u>
	----- $\mu\text{g}/\ell$ -----		
<u>Inorganic Chemicals</u>			
Arsenic	0.02*	50	50
Beryllium	0.037	---**	--
Cadmium	10	10	10
Chromium (trivalent)	170,000	50	50
Chromium (hexavalent)	50	--	--
Copper	1000	1000	1000
Lead	50	50	50
Mercury	0.14	2.0	2.0
Nickel	13.4	--	--
Selenium	10	10	10
Silver	50	50	50
Zinc	5000	5000	5000
Iron	--	300	300
Manganese	--	50	50
pH	--	5-9	6.5-8.5
<u>Organic Chemicals</u>			
Aldrin/Dieldrin	0.00074/ 0.00071*	ME†	--
α BHC	0.092*	--	--
γ BHC	0.163*	4.0	4.0
Chlordane	0.00024*	ME	--
DDT	0.00098*	ME	--
Endrin	1.0	0.2	0.2
Heptachlor/Heptachlor Epoxide	0.000278	ME	--
Toxaphene	0.0007*	5.0	5.0
PCB's	0.00079*	ME	--
Methoxychlor	--	100	100
2,4-D	--	100	100
2,4,5-TP (Silvex)	--	10	10

* Based on the additional lifetime estimated cancer risk level of 10^{-5} .

** No criteria established.

† Cautioned to keep minimum exposure.

Table 2
EPA Water Quality Criteria for Toxic Pollutants to Protect
Freshwater Aquatic Life

Parameter	1980 Criteria		1976 Red Book Criteria Concentration
	24-hour Average Concentration	Maximum Concentration	
	----- µg/l -----		
<u>Inorganics</u>			
Arsenic	40	440	--*
Beryllium	5.3	130	11-1100
Cadmium	--depends on hardness--**		0.4-12.0
Chromium (Trivalent)	--depends on hardness--		100
Chromium (Hexavalent)	0.29	21	--
Copper	--depends on hardness--		0.1 of 96-hr LC50
Lead	--depends on hardness--		0.01 of 96-hr LC50
Mercury (total recoverable)	0.00057	0.0017	0.05
Nickel	--depends on hardness--		0.01 of 96-hr LC50
Selenium	35	260	0.01 of 96-hr LC50
Silver	--depends on hardness--		0.01 of 96-hr LC50
Zinc	--depends on hardness--		0.01 of 96-hr LC50
Iron	--	--	1000
Manganese	--	--	--
pH	--	--	6.5-9.0
<u>Organics</u>			
Aldrin/Dieldrin	--/0.0019	3.0/2.5	0.003
γBHC	--	--	0.01
Chlordane	0.0043	2.4	0.01
DDT	0.0010	1.1	0.001
Endrin	0.0023	0.18	0.004
Heptachlor/Heptachlor Epoxide	0.0038	0.52	0.001
Toxaphene	0.013	1.6	0.005
PCB's	0.014	2.0	0.001
Methoxychlor	--	--	0.03
Kepone	--	0.014†	--
Mirex	--	--	0.001
Guthion	--	--	0.01
Malathion	--	--	0.01
Parathion	--	--	0.04
2,4-D	--	--	--
2,4,5-TP (Silvex)	--	--	--

* No criteria established.

** See Federal Register (1980) for equations to calculate contaminant criteria.

† Huggett and Bender (1980).

plant life, shorelines, beaches, aesthetics, and recreation resources (U. S. EPA, 1976). These water quality criteria, referred to in this report as the EPA 1976 Red Book criteria, were the basis of water quality standards enacted and currently in effect in many states. The EPA 1980 criteria will replace the EPA 1976 Red Book criteria as a basis for enacting state water quality standards. The EPA 1976 Red Book criteria for the protection of human health and freshwater aquatic life are given in Tables 1 and 2, respectively.

National Drinking Water Standards and Their Relationship
to the EPA Criteria

13. The National Drinking Water Standards were established under the PHS Act as amended by the Safe Drinking Water Act (PL 93-523) and are comprised of primary and secondary standards (Code of Federal Regulations, 1980a, b). The primary standards for inorganic and organic chemicals went into effect on June 24, 1977, and secondary standards for several other parameters went into effect on January 1, 1981. The concentration limits established in the National Drinking Water Standards for the contaminants reported in CE reservoirs are given in Table 1.

14. The comparison of proposed water quality criteria with the National Drinking Water Standards (Table 1) suggests that the maximum limits proposed for a contaminant may be different in the two criteria. It should be pointed out that the mandate for establishing standards for drinking water at the tap under the Safe Drinking Water Act expressly requires consideration of economic and technical feasibility, whereas feasibility was not a factor in developing water quality criteria under Section 304 of the Clean Water Act. In addition, the extrapolation model used to estimate the risk associated with the National Drinking Water Standards was different from that used in calculating water quality criteria. The water quality criteria, therefore, were not intended to serve as drinking water standards.

State Water Quality Standards and Their Relationship
to the Proposed EPA Criteria

15. The EPA's regional offices were contacted to get information on state water quality standards in effect in various states in each EPA region. Copies of state water quality standards were received from several EPA regions for states in their jurisdiction. For other states, the appropriate water pollution control agencies were contacted and information on water quality standards in effect or proposed was gathered. These water quality standards enacted by various states for human health protection and aquatic life protection are summarized in Tables 3 and 4 and Tables 5 and 6, respectively.

16. State water quality standards, although based on the EPA 1976 Red Book criteria, are modified to consider local conditions. The local conditions generally considered include actual and projected uses of water; natural background levels of particular contaminants; presence or absence of sensitive, important species; characteristics of the local biological community; temperature and weather; flow characteristics; and synergistic or antagonistic effects of combinations of pollutants. Several states have nonspecific standards for toxic pollutants with vague and qualitative requirements for pollutant limitations, while others follow the EPA 1976 Red Book criteria verbatim (compare Table 1 with Tables 3 and 4, and Table 2 with Tables 5 and 6).

17. In evaluating the contaminants data for CE reservoirs in this report, the EPA water quality criteria will be used as a primary reference instead of the water quality standards of the states in which CE reservoirs are located. This will allow a scientifically based, uniform evaluation of the contaminant problems in the CE reservoirs located in different geographical regions.

FDA's Allowable Limits on Toxic Chemical
Contaminants in Aquatic Organisms

18. The FDA has established maximum limits on certain contaminants present in aquatic food species. The list presented in Table 7 includes

Table 3
State Ambient Water Quality/Domestic Water Supply Standards to Protect Human Health from Toxic Inorganic Contaminants*

State	Year	Inorganic contaminant, µg/l											pH				
		Arsenic**	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Zinc		Iron	Manganese		
Alabama	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0-8.5
Arizona	1979	50	—	10	50	100	50	2	—	50	5000	—	—	—	—	—	6.0-9.0
Arkansas	1979	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
California	1976	100	—	10	50	—	50	5	—	10	—	—	—	—	—	—	5.0-9.0
Colorado	1979	50	—	10	50(25) [†]	1000	50	2	—	10	5000	300	50	—	—	—	6.0-8.5
Connecticut	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0-9.0
Georgia	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0-8.5
Indiana	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0-9.0
Iowa	1977	50	—	10	(50)	1000	50	2	—	10	1000	—	—	—	—	—	6.5-9.0
Kansas	1978	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
Kentucky	1979	50	—	10	(100)	1000	50	2	—	10	5000	—	—	—	—	—	6.0-9.0
Massachusetts	1978	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
Minnesota	1980	10	—	10	(50)	1000	50	0.05	—	10	5000	—	—	—	—	—	6.5-8.5
Missouri	1977	50	—	12	50	1000	50	2	—	10	5000	300	50	—	—	—	6.5-8.5
Montana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nebraska	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
New Hampshire	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
North Dakota	1979	50	—	10	50	50	50	2	—	10	1000	—	—	—	—	—	5.5-9.0
Ohio	1979	50	—	10	50	1000	50	2	—	10	5000	300	50	—	—	—	—
Oklahoma	1976	50	—	10	50	1000	50	2	—	10	5000	—	—	—	—	—	6.5-8.5
Oregon	1980	50	—	—	100	—	—	0.05	—	—	—	—	—	—	—	—	—
Pennsylvania	1980	50	—	—	50	—	—	—	—	—	—	300	1000	—	—	—	6.0-9.0
South Carolina	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
South Dakota	1979	50	—	10	50	—	50	2	—	10	—	—	—	—	—	—	6.0-9.0
Tennessee	1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Texas	1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vermont	1978	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Virginia	1980	50	—	10	50	1000	50	2	—	10	5000	300	50	—	—	—	6.5-8.0
West Virginia	1980	50	—	0.8-30	50	5	25-100	0.2	50	50	50-600	1000	50	—	—	—	6.0-9.0

* Information acquired from appropriate state or Federal agencies.

** No specific standard established.

† Hexavalent chromium.

Table 4
State Ambient Water Quality/Domestic Water Supply Standards to Protect Human Health from
Toxic Organic Pollutants*

State	Year	Organic contaminant, ug/l ₂									
		Aldrin/ ** Dieldrin	BHC †	Chlordane	DDT ††	Endrin	Heptachlor LC50	Heptachlor/ ** Epoxyde	Toxaphene	PCBs	
Alabama	1977	0.003	—	—	0.001	0.004	—	—	0.005	0.01	
Arizona	1979	—	—	—	—	—	—	—	—	—	
Arkansas	1979	—	—	—	—	—	—	—	—	—	
California	1976	17.0	56	3.0	42.0	1.0	18.0	5.0	—	—	
Colorado	1979	—	4.0	—	—	0.2	—	0.005	—	—	
Connecticut	1977	—	Follows Clean Water Act and Safe Drinking Water Act guidelines								
Georgia	1977	—	—	—	—	—	—	—	—	—	
Indiana	1977	—	Follows EPA criteria								
Iowa	1977	—	—	—	—	—	—	—	—	—	
Kansas	1978	—	—	—	—	—	—	—	—	—	
Kentucky	1979	—	4.0	3.0	—	0.2	—	—	—	—	
Massachusetts	1978	—	Follows EPA Red Book criteria								
Minnesota	1980	—	—	—	—	—	—	—	—	—	
Missouri	1977	0##	0	0	0	0	0	0	0	0	
Montana	1977	—	Data not available								
Nebraska	1977	—	—	—	—	—	—	—	—	—	
New Hampshire	1977	—	—	—	—	—	—	—	—	—	
North Dakota	1979	—	—	—	—	—	—	—	—	—	
Ohio	1979	1.0	4.0	3.0	5.0	0.2	0.1	5.0	0	—	
Oklahoma	1976	1.0	—	—	1.0	1.0	—	1.0	1.0	—	
Oregon	1976	0.003	0.01	0.01	0.001	0.004	0.001	0.005	0.001	—	
Pennsylvania	1980	—	—	—	—	—	—	—	—	—	
South Carolina	1977	—	Follows EPA criteria								
South Dakota	1979	—	Follows EPA criteria for human health								
Tennessee	1976	—	—	—	—	—	—	—	—	—	
Texas	1978	0##	0	0	0	0	0	0	0	0	
Vermont	1980	—	—	4	—	0.2	—	5	—	—	
Virginia	1980	0.003	—	0.01	0.001	0.004	—	0.005	0.001	—	
West Virginia	1980	—	—	—	—	—	—	—	—	—	

* Information acquired from appropriate state or Federal agencies.
 ** Concentration of one or both contaminants added.
 † Data include all isomers of BHC.
 †† Data include all metabolites of DDT.
 # No specific standard established.
 ## Contaminant prohibited in water.

(Continued)

(Sheet 1 of 2)

Table 4 (Concluded)

State	Year	Organic contaminant, µg/l				
		Methoxychlor	Diazinon	Guthion	Parathion	Malathion
Alabama	1977	---	---	---	---	---
Arizona	1979	---	---	---	---	---
Arkansas	1979	---	---	---	---	---
California	1976	1.0	---	100.0	---	100
Colorado	1979	0.03	---	---	---	---
Connecticut	1977	---	---	---	---	---
Georgia	1977	---	---	---	---	---
Indiana	1977	---	---	---	---	---
Iowa	1977	---	---	---	---	---
Kansas	1978	---	---	---	---	---
Kentucky	1979	---	---	---	---	---
Massachusetts	1978	100.0	---	---	---	100
Minnesota	1978	---	---	---	---	---
Missouri	1980	---	---	---	---	---
Montana	1977	0	0	---	---	100
Nebraska	1977	---	---	---	---	---
New Hampshire	1977	---	---	---	---	---
North Dakota	1979	---	---	---	---	---
Ohio	1979	100	---	---	---	100
Oklahoma	1976	---	---	---	---	---
Oregon	1976	0.03	0.009	---	0.04	0.1
Pennsylvania	1980	---	---	---	---	---
South Carolina	1977	---	---	---	---	---
South Dakota	1979	---	---	---	---	---
Tennessee	1976	---	---	---	---	---
Texas	1976	---	---	---	---	---
Vermont	1978	0	0	0	0	0
Virginia	1980	100	---	---	---	100
West Virginia	1980	0.03	---	---	---	---

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Table 5
State Ambient Water Quality Standards to Protect Freshwater Aquatic Life from Toxic Inorganic Contaminants*

State	Year	Arsenic **	Beryllium	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Zinc	Iron	Manganese	pH
Alabama	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
Arizona	1979	50	—	10	50	50	50	2	—	10	50	5000	—	—	—
Arkansas	1979	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0-9.0
California	1976	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
Colorado	1979	50	10-110 [†]	4-15	100(25) ^{††}	5-40	4-150	0.05	50-400	50	0.1-0.25	50-600	1000	1000	6.5-9.0
Connecticut	1977	—	—	—	—	—	—	Follows EPA criteria	—	—	—	—	—	—	6.5-8.0
Georgia	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
Indiana	1977	—	—	—	—	—	—	0.1 of 96-hr LC50	—	—	—	—	—	—	6.0-8.5
Iowa	1977	100	—	1.2-10	(50)	20	100	50	—	100	—	1000	—	—	6.5-9.0
Kansas	1978	—	—	—	—	—	—	—	—	—	—	—	—	—	6.5-8.5
Kentucky	1979	50	11-1100	4-12	50	0.1	.01	0.05	0.1	.01	.01	.01	1000	—	6.0-9.0
						96-hr LC50	96-hr LC50		96-hr LC50	96-hr LC50	96-hr LC50	96-hr LC50			
Massachusetts	1978	—	—	—	—	—	—	Follows EPA 1976 Red Book criteria	—	—	—	—	—	—	6.5-9.0
Minnesota	1980	—	—	—	20	10	—	—	—	—	—	—	—	—	6.5-8.5
Missouri	1977	50	1100	1.2-12	100	20	50-100	0.05	100	—	—	100-300	1000	—	6.5-9.0
Montana	1977	—	—	—	—	—	—	Data not available	—	—	—	—	—	—	—
Nebraska	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—
New Hampshire	1977	—	—	—	—	—	—	—	—	—	—	—	—	—	6.0-8.5
North Dakota	1979	50	—	10	50	50	50	2.0	10	—	—	1000	—	—	5.5-9.0
Ohio	—	—	1100	12	50	5	30	0.2	25	.01	.01	30	1000	—	6.5-9.0
									96-hr LC50	96-hr LC50	96-hr LC50				
Oklahoma	1976	50	—	0.4	—	5	—	0.05	—	—	—	5	—	—	6.5-8.5
Oregon	1979	50	—	0.4-12.0	100	10-50	100-150	0.05	40	—	—	50-400	—	—	6.5-9.0
Pennsylvania	1977	—	—	0.05 of 96-hr LC50 for noncumulative and 0.01 of 96-hr LC50 for cumulative pollutants	—	—	—	—	—	—	—	—	—	—	—
South Carolina	1979	—	—	—	—	—	—	Follows EPA criteria	—	—	—	—	—	—	6.0-8.5
South Dakota	1979	—	—	—	—	—	—	Follows EPA criteria	—	—	—	—	—	—	—
Tennessee	1976	—	—	—	—	—	—	0.01 of 96-hr LC50	—	—	—	—	—	—	—
Texas	1978	—	—	—	—	—	—	0.1 of 96-hr LC50	—	—	—	—	—	—	—
Vermont	1978	—	—	—	—	—	—	0.1 of 96-hr LC50 for nonpersistent contaminants; 0.05 of 96-hr LC50 for persistent contaminants	—	—	—	—	—	—	—
Virginia	1980	—	—	4-12	100	0.1	.01	0.05-1.0	.01	.01	0.0	.01	1000	100	6.5-8.5
						96-hr LC50	96-hr LC50		96-hr LC50	96-hr LC50		96-hr LC50			
West Virginia	1980	50	—	0.8-30	50	5	25-100	0.2	50	50	50	50-600	1000	50	6.0-9.0

* Information acquired from appropriate state or Federal agencies.

** No specific standard established.

† Concentration varies with water hardness.

†† Hexavalent chromium.

Table 6
State Ambient Water Quality Standards to Protect Freshwater Aquatic Life from Toxic Organic Contaminants*

State	Year	Organic contaminant, $\mu\text{g/l}$						
		Aldrin/ Dieldrin**	BHC†	Chlordane	DDT††	Endrin	Heptachlor/ Heptachlor Epoxide**	Toxaphene PCBs
Alabama	1977				0.1 of 96-hr LC50			
Arizona	1979	0.003	‡	—	0.001	0.004	—	0.005
Arkansas	1979	0.003	—	0.001	0.001	0.004	—	0.001
California	1976	—	—	—	—	—	—	—
Colorado	1979	0.003	0.01	—	0.001	0.004	0.001	0.005
Connecticut	1977	—	—	—	Follows EPA criteria	—	—	—
Georgia	1977	—	—	—	Follows EPA criteria	—	—	—
Indiana	1977	—	—	—	—	—	—	—
Iowa	1977	—	—	—	—	—	—	—
Kansas	1978	—	—	—	—	—	—	—
Kentucky	1979	—	—	—	—	—	—	—
		0.1 of 96-hr LC50 for short-lived noncumulatives; 0.01 of 96-hr LC50 for long-lived cumulative toxic substances						
		Follows 1976 Red Book criteria						
Massachusetts	1978	—	—	—	—	—	—	—
Minnesota	1980	0††	0	0	0	0	0	0
Missouri	1977	—	—	—	—	—	—	—
Montana	—	—	—	—	—	—	—	—
Nebraska	1977	—	—	—	—	—	—	—
New Hampshire	1977	—	—	—	—	—	—	—
North Dakota	1979	—	—	—	—	—	—	—
Ohio	—	0.01-0.005	0.01	0.01	0.001	0.002	0.001	0.005
Oklahoma	1976	1.0	—	—	1.0	1.0	—	1.0
Oregon	—	0.003	0.01	0.01	0.001	0.004	0.001	0.005
Pennsylvania	—	0.05 of 96-hr LC50 for noncumulative and 0.01 of 96-hr LC50 for cumulative pollutants						
South Carolina	1977	—	—	—	—	—	—	—
South Dakota	1979	—	—	—	—	—	—	—
Tennessee	1976	—	—	—	Follows EPA criteria	—	—	0.001
Texas	—	0.01 of 96-hr LC50 for nonpersistent contaminants; 0.05 of 96-hr LC50 for persistent contaminants						
Vermont	1978	0	0	0	0	0	0	0
Virginia	1980	0.003	0.004-	0.004-	0.001	0.004	0.001	0
			0.01	0.01				
West Virginia	1980	0.003	—	0.01	0.001	0.004	—	0.005

* Information acquired from appropriate state or Federal agencies.

** Concentration of one or both contaminants added together.

† Data include all isomers of BHC.

†† Data include all metabolites of DDT.

‡ No specific standard established.

‡‡ Contaminant prohibited in water.

(Continued)

(Sheet 1 of 2)

Table 6 (Concluded)

State	Year	Organic contaminant, µg/l				
		Methoxychlor	Diazinon	Guthion	Parathion	Malathion
Alabama	1977			0.1 of 96-hr LC50		
Arizona	1979					
Arkansas	1979					
California	1976					
Colorado	1979	0.03		0.01	0.04	0.1
Connecticut	1977			Follows EPA criteria		
Georgia	1977			Follows EPA criteria		
Indiana	1977					
Iowa	1977					
Kansas	1978					
Kentucky	1979					
Massachusetts	1978			0.1 of 96-hr LC50 for short-lived noncumulative; 0.01 of 96-hr LC50 for long-lived cumulative toxic substances		
Minnesota	1980			Follows EPA 1976 Red Book criteria		
Missouri	1977	0		0.01	0.04	0.1
Montana						
Nebraska	1977					
New Hampshire	1977					
North Dakota	1979					
Ohio		0.005	0.009	0.005	0.008	0.1
Oklahoma	1976					
Oregon		0.03	0.009		0.04	0.1
Pennsylvania		0.05 of 96-hr LC50 for noncumulative and 0.01 of 96-hr LC50 for cumulative pollutants				
South Carolina	1977			Follows EPA criteria		
South Dakota	1979			Follows EPA criteria		
Tennessee	1976			0.01 of 96-hr LC50 for nonpersistent contaminants; 0.05 of 96-hr LC50 for persistent contaminants		
Texas				LC50 for persistent contaminants		
Vermont	1978	0	0	0	0	0
Virginia	1980	0.03		0.01	0.04	0.1
West Virginia	1980	0.03				

(Sheet 2 of 2)

Table 7

Maximum Concentration of Chemical Contaminants in Aquatic Organisms Allowed by FDA

<u>Chemical Contaminant</u>	<u>Aquatic Species*</u>	<u>Concentration mg/kg</u>
Aldrin/Dieldrin (individually or in combination)	Fish, Shellfish (raw, processed)	0.3
Chlordane**	Fish (raw, processed)	0.3
DDT, DDE, TDE (individually or in combination)	Fish (raw, processed)	5.0
Endrin	Fish, Shellfish (raw, processed)	0.3
Heptachlor/Heptachlor Epoxide (individually or in combination)	Fish, Shellfish (raw, processed)	0.3
Toxaphene	Fish (raw, processed)	5.0
Kepone	Crabmeat (raw, processed)	0.4
	Fish, Shellfish (raw processed)	0.3
Mirex	Fish (raw processed)	0.1
PCB's	Fish, Shellfish	5.0
Mercury	Fish, Shellfish	1.0

* Guidelines are established based on the edible portion.

** Includes cis and trans chlordane; cis and trans nonachlor; oxychlordane; and alpha, beta, and gamma chlordanes and chlordane.

mercury, PCB's, and several insecticides (U. S. FDA, 1979). No maximum limits on the remaining 65 toxic pollutants, for which the EPA proposed water quality criteria, are established for edible foods. The FDA allowable limits for the specified contaminants will be used to evaluate the degree of contamination in fish samples reported in the CE reservoirs contaminant survey.

PART III: DATA ACQUISITION METHODOLOGY

Sources of Information

19. A meeting was held at WES, Vicksburg, Miss., at the start of the project to establish procedures and strategies to acquire contaminants data from various agencies and sources. A list of EWQOS Field Review Group (FRG) personnel, who would assist in getting access to the available information on CE reservoirs in the CE Districts and facilitate contacts with the CE District water quality personnel, was also obtained at the preliminary meeting. The resources and references made available through the EWQOS Program at the initial meeting and during subsequent visits/contacts were utilized to identify various Federal and state agencies involved in research and monitoring of contaminants in CE reservoirs. The following paragraphs describe the sources of information that were utilized during the course of the study to collect data on potential contaminant problems existing in CE reservoirs and their tributaries.

CE District and Division personnel

20. Contacts were made with the CE personnel involved in reservoir water quality management through FRG representatives in various CE Divisions. The initial contacts were followed by personal visits with CE District personnel in some CE Districts, as well as telephone conversations and written correspondence with other CE District water quality personnel. Pertinent published and unpublished in-house documents on CE reservoir contaminant problems, analytical data on specific contaminants, and information on morphological/hydrologic/sedimentation characteristics of reservoirs and river basins were acquired through these CE District contacts. In CE Districts where computerized systems for contaminants data storage (such as the EPA STORET System) were used, reservoir sampling station identifications in terms of STORET numbers or latitude-longitude coordinates were recorded for retrieval of the stored data. Where available, annual water quality management reports for various CE Districts and/or Divisions with up-to-date information on contaminant problems in CE-operated reservoirs were obtained.

U. S. Geological Survey

21. The U. S. Geological Survey (USGS), independently or in cooperation with several Federal and state agencies, has been involved in collecting limnological data for the waters of the United States, including reservoirs, for many years. The USGS offices in various states which were/had been involved in monitoring water quality parameters in CE reservoirs and their tributaries were contacted for data acquisition. In addition to the specific research reports, USGS Water-Data Reports for the states in which the reservoirs were located were searched for any additional data available.

Other organizations and groups

22. Federal and state agencies involved in research or monitoring of contaminants in water, sediments, and aquatic organisms in CE reservoirs and their tributaries were contacted. These included the U. S. Water and Power Resources Service, U. S. Department of the Interior, U. S. Forest Service, U. S. Department of Agriculture, U. S. Fish and Wildlife Service, U. S. Department of the Interior, and various state offices responsible for fish and wildlife, natural resources, and public health. Several university research groups involved in cooperative or contracted research with the CE or USGS on reservoir contaminant problems were also contacted for any published or unpublished data and/or reports relevant to the project.

STORET data base

23. Contacts with the various CE District Offices and USGS staff indicated that contaminants data monitored by CE and USGS generally had been stored in the EPA STORage and RETrieval (STORET) system and could be retrieved by identifying sampling station areas (latitudes and longitudes) and/or STORET codes assigned by the monitoring and storing agencies. After evaluation of the information gathered from various CE and other sources, a list of reservoirs with potential contaminant problems was prepared for STORET search. Reservoir sampling stations were identified by latitude and longitude coordinates and STORET identification codes.

24. A data base development report on CE reservoirs submitted by Walker (1979) to WES as a part of the EWQOS Program was extensively used

for determining the location of reservoir monitoring stations. This report contained information on project location, morphology, hydrology, sedimentation, monitoring activity, and water quality for 243 CE reservoirs. In addition to this STORET identification source, information on reservoir sampling areas acquired from various CE District Offices and USGS staff was used for the retrieval of data from the STORET system.

25. The STORET retrieval program "Inventory 120" (U. S. EPA, 1977), which lists station descriptions and statistical summaries of water quality parameters monitored, was used to retrieve contaminants data. Reservoir or stream stations for which monitoring activity ceased after 1974 were excluded from the retrieval process. Computer facilities for the STORET search were provided by the Louisiana Department of Natural Resources, Water Pollution Control Division, Baton Rouge, La. (courtesy of D. Givens, Chief, WPC Division).

Library search

26. An in-depth review was conducted of the literature published in the United States and elsewhere on the nature and magnitude of contamination problems in freshwater reservoirs and the processes involved in the environmental cycling of the contaminants. It included a search of library resources as well as the utilization of numerous computerized data bases through the Bibliographic, Library and Information Search Service (BLISS) of Louisiana State University (LSU). Specifically included in the library search were reports and documents of research funded by various United States agencies such as EPA, National Science Foundation (NSF), National Institute of Health (NIH), USGS, and others. Many of these reports were available through the National Technical Information Service (NTIS). The results of the related published material were abstracted and summarized for use in the project.

Reduction and Processing of Data

27. Contaminants data collected from various sources described earlier were reduced to a format that could be easily compared with the existing or proposed EPA criteria for water quality and FDA limits for specific contaminants. The reduced data summaries included the following:

- a. Location of a reservoir identified by state, CE Division, and CE District.
- b. Period during which monitoring activity was carried out and the data were recorded.
- c. Range of concentrations of various contaminants for the entire monitoring period and all sampling stations.
- d. A gross mean of all analytical values for a specific contaminant recorded during the monitoring period for all sampling stations.
- e. A reference to the data source.

28. Since the objectives of the project included identifying reservoirs with potential chemical contaminant problems and establishing the magnitude of the problem, it was decided to initially examine only the range of concentrations for the known period of monitoring activities. The high value for a contaminant in the range of concentrations reported was compared with various criteria to indicate a potential contaminant problem. No attempt was made to examine contaminant levels for individual monitoring stations or for specific monitoring periods. This procedure was especially applied to contaminant data retrieved from the STORET system. The computer printouts from the STORET data base also included standard deviations around the mean as indications of sample variability. The range of concentrations for the individual contaminants was generally large as were the standard deviations. It was felt that a range of contaminant concentrations for the different monitoring stations around the reservoirs for the monitoring period was a sufficient indication of the contaminant variability. Standard deviations were, therefore, not included in the data summaries prepared for inclusion in Appendix A.

29. A breakdown of the sources presented in Table 8 indicates that contaminant data for 49 CE reservoirs were extracted from STORET. Published reports contained data on 41 CE reservoirs, while unpublished documents contained contaminant information on 99 reservoirs. Information for many CE reservoirs was obtained from more than one source. Numerical data on analytical measurements for one or more contaminants listed as toxic in the EPA criteria for human health and freshwater

aquatic life protection (U. S. EPA, 1976; Federal Register, 1979a, b, c), or in the FDA limits (U. S. FDA, 1979) were reported for 109 CE reservoirs (Table 8). In many other CE reservoirs, one or more toxic substances were reported to be potential problems, but no data were available to quantify the degree of contamination.

30. In order to differentiate CE reservoirs with potential chemical contaminant problems from those with no apparent problems, water contaminant data were compared with the existing or the proposed EPA criteria for human health and freshwater aquatic life protection. In reservoirs where aquatic organisms were analyzed for chemical contaminants, the FDA limits on contaminant concentrations in aquatic food species were used as reference values. The CE reservoirs which exceeded the EPA or the FDA guidelines for one or more chemical contaminants were classified as reservoirs with potential chemical contaminant problems. The data presented in Table 8 indicate that 71 of the CE reservoirs surveyed in this study had one or more potential chemical contaminant problems existent during certain periods when monitoring was conducted. The contaminant data base upon which these evaluations of potential problems were based were subject, however, to many sources of error. These sources of error, detailed in Part IV of this report, severely limited the usefulness of water quality criteria comparisons for determining the true extent of potential contaminant problems. Chemical contaminants data for the 71 reservoirs that were apparently subject to contaminant problems are presented in Appendix A. A more detailed examination of the chemical contaminants data of the 71 reservoirs is presented in Appendix B.

Table 8

Information Sources for Contaminants in CE Reservoirs

CE Division	Source of Information*		No. of reservoirs with concentrations on one or more contaminants reported	No. of reservoirs with one or more contaminants \geq EPA criteria or FDA limits**	
	STORET Literature	Unpublished Literature			
	----- No. of reservoirs -----				
New England	8	0	36	31	9
North Atlantic	4	2	14	3	2
South Atlantic	4	0	0	4	4
Ohio River	21	8	1	19	19
North Central	2	3	15	3	3
Lower Mississippi Valley	1	0	0	0	0
Southwestern	0	8	3	9	7
Missouri River	8	10	25	26	14
North Pacific	0	1	2	2	2
South Pacific	1	9	3	12	11
TOTAL	49	41	99	109	71

* Qualitative or quantitative information was reported on contaminants and one or more sources reported information for the same reservoir.

** Appendix A provides additional information on comparisons of specific contaminants with each criterion considered.

The data base is subject to many sources of error which limits its usefulness for water quality evaluations.

PART IV: DATA BASE PROBLEMS

STORET Data

31. The great majority of contaminant data in this report were obtained from the STORET data system. It appears, however, that problems exist in the STORET system that seriously limit its usefulness as an evaluative tool for assessing the contamination status of reservoirs and reservoir discharges irrespective of the evaluation procedures used. Some of these problems will be discussed in this section of the report.

Whole water analysis

32. All analytical results reported in this study consist of analyses of whole water samples. Contaminants associated with particulate matter (suspended material) are therefore included in the contaminant concentration along with the dissolved portion. Since many contaminants are strongly bound to suspended materials and sediments (Gibbs, 1973; Kubota et al., 1974; Chen and Hendricks, 1974; Gardiner, 1974; Warren, 1981; Hart and Davies, 1981a, b; Saleh et al., 1978), the concentration of contaminants measured on whole water samples will be influenced by the amount of suspended material in the sample. In fact, on page 79359 of the 28 Nov 1980 Federal Register in response to Comment 19, the EPA stated that "suspended solids probably do sorb and detoxify significant amounts of some pollutants, but high concentrations of suspended solids also stress some aquatic organisms."

33. The EPA criteria, however, are based for the most part on laboratory studies where aquatic organisms are exposed to water-soluble contaminants. Criteria do not consider current levels of exposure but are estimates of safe level or incremental risk level exposures (Federal Register, 1980). If such criteria are used to promulgate standards, both natural and anthropogenic inputs should be considered (Federal Register, 1980).

34. There may be substantial differences in concentrations measured on filtered and whole water samples. This is illustrated by data reported in Baumann et al. (1979) that is summarized in Table 9. As can

be seen, total analyses on digested, whole water samples averaged as much as twice the concentration of filtered samples. Such differences are largely unpredictable because the whole water concentration is a function of the amount of suspended material in the water, the amount of and manner in which contaminants are associated with the suspended material, the amount of contaminants in the dissolved fraction, and the digestion/extraction procedure.

Entering of detection limits

35. It appears that detection limit values were commonly entered into the STORET system in lieu of a lower than detection limit designation or that the retrieval procedures did not adequately identify such numbers. Examinations of the STORET data summarized in Appendix B reveal that in almost every reservoir for which data are available there are instances where the maximum and minimum values as well as the mean value are the same number. Some of these raw data were subjected to frequency analyses, the results of which are summarized in Tables 10, 11, 12, and 13. Tables 10, 11, and 12 summarize STORET retrievable data on five reservoirs in the New England Division. Data from these five reservoirs are included together because the similarity of sampling dates and analytical concentrations over several years (1973-1978) strongly suggests that these data were obtained during the course of a single, long-term study. Until 1975, the only concentration reported for Pb in these five reservoirs was 200 $\mu\text{g}/\ell$ (Table 10). Then, after June 1975, a few concentrations were reported at 100 $\mu\text{g}/\ell$ and 20 $\mu\text{g}/\ell$ for the five reservoirs. The seven 500- $\mu\text{g}/\ell$ concentrations reported in the five reservoirs occurred entirely during the period from 16 to 24 August 1976. It is highly likely that the 313 concentration values of 200 $\mu\text{g}/\ell$ reported over a four-year period were the lower detection limits of the analysis. As shown in Tables 11 and 12, concentration values of 0.2 $\mu\text{g}/\ell$ and 20 $\mu\text{g}/\ell$ predominated for Hg and Cd, respectively. For Hg, the higher concentration values were reported prior to any 0.2- $\mu\text{g}/\ell$ values. All Cd concentration values reported, with the exception of three 50- $\mu\text{g}/\ell$ values, were 20 $\mu\text{g}/\ell$. Coincidentally, the three 50- $\mu\text{g}/\ell$ Cd concentrations in West Thompson Reservoir were from samples taken the same day as the three 500- $\mu\text{g}/\ell$ Pb

Table 9

Soluble and Total Concentrations of Some ParametersMeasured Near the Red Rock Reservoir Discharge(Station 9) by Baumann et al. (1979)

<u>Parameter</u>	<u>Concentration, $\mu\text{g}/\ell$ *</u>	
	<u>Dissolved</u>	<u>Total</u>
Arsenic	11.8 \pm 18.3	15.4 \pm 20.8
Cadmium	2.0 \pm 5.6	4.0 \pm 5.1
Chromium	0.0	2.0 \pm 4.1
Lead	13.1 \pm 12.5	25.6 \pm 12.1
Silver	0.6 \pm 2.5	1.3 \pm 3.4

* Between 14 and 16 observations were used in calculating each mean concentration and standard deviation.

Table 10

Reporting Frequency of All STORET Retrievable Lead Concentrationsin Five New England Division Reservoirs

<u>Reservoir</u>	<u>Concentration Reported in STORET, $\mu\text{g}/\ell$</u>			
	<u>500</u>	<u>200</u>	<u>100</u>	<u>20</u>
Conant Brook	1	111	3	6
Hop Brook	0	32	1	2
Hopkinton	1	25	1	2
Surrey Mountain	2	42	2	4
West Thompson	3	103	3	6
TOTALS	7	313	10	20

Table 11
Reporting Frequency of All STORET Retrievable Mercury
Concentrations in Five New England Division Reservoirs

<u>Reservoir</u>	<u>Concentration Reported in STORET, $\mu\text{g}/\ell$</u>		
	<u>0.3</u>	<u>0.2</u>	<u>0.1</u>
Conant Brook	1	2	--
Hop Brook	--	--	--
Hopkinton	--	--	--
Surrey Mountain	--	--	--
West Thompson	<u>1</u>	<u>19</u>	<u>1</u>
TOTALS	2	21	1

Table 12
Reporting Frequency of All STORET Retrievable Cadmium
Concentrations in Five New England Division Reservoirs

<u>Reservoir</u>	<u>Concentration Reported in STORET, $\mu\text{g}/\ell$</u>	
	<u>50</u>	<u>20</u>
Conant Brook	0	10
Hop Brook	--	--
Hopkinton	--	1
Surrey Mountain	--	3
West Thompson	<u>3</u>	<u>10</u>
TOTALS	3	24

Table 13
Reporting Frequency for STORET Retrievable Concentrations
of Some Trace Metals from Dewey Reservoir

<u>Parameter</u>	<u>Concentration, $\mu\text{g}/\ell$</u>	<u>Reporting Frequency</u>
Cd	50	21
Cr	50	168
	60	1
Cu	50	92
	75	1
Pb	50	76
Ni	50	21
Ag	50	21

samples taken in the same reservoir. Table 13 summarizes the reporting frequency for concentrations of a number of trace metals retrievable from STORET in Dewey Reservoir in the Huntington District. It can be seen that with rare exceptions the same number was consistently reported as the concentration value. These examples are presented to illustrate trends that occur repeatedly in data retrieved from STORET during this study. Examination of Standard Methods (1971) and Methods for Chemical Analysis of Water and Wastes (1974) revealed that, in almost all instances, the repeatedly reported analytical values were in close proximity to the lower end of the working range of the method or near the detection limit for the parameter. It is almost a surety that large numbers of concentration values retrieved from STORET are merely the minimum detection limits rather than actual concentration values for the contaminant in that specific water sample.

36. Inclusion of detection limits causes problems when a data set containing such numbers is used because it introduces a serious source of bias into the data. For example, if the actual concentration is much lower than the detection limit, averaging in the higher number will bias the mean upwards. An even more serious problem is that the detection limits so reported are higher than the criteria in the Nov 28, 1980, Federal Register causing the data to be uninterpretable in relation to water quality criteria. This means that comparisons between such data and these criteria will indicate that there is a water quality problem 100% of the time, when an artifact of the way the data were reported or retrieved is actually being observed.

Methodology

37. It is difficult to determine from the STORET data how the water samples were pretreated prior to analysis and if the analytical methods used by the various reporting laboratories were uniform and up-to-date. There is also no indication of what, if any, quality control procedures were in place while the analyses were conducted. These considerations are particularly important when comparing data in the same reservoir obtained from several sources or comparing data between reservoirs. These difficulties are illustrated by STORET data on Atwood Reservoir.

Two stations, LAT1W0002 and LAT1W0006, whose data are summarized in Table 14, appear to have been generated during a monitoring program from September 1974 to October 1977. The data in Table 14, however, are apparently reported detection limits rather than actual concentrations. The remaining data, consisting of only 21 total analyses for 7 parameters, are summarized in Table 15. The contaminant concentrations in Table 15 are generally lower, except for Zn, than the concentrations presented in Table 14, but little significance can be attached to those differences. Useful conclusions cannot be reached with these data (Tables 14 and 15) because the great majority of the data appear to be detection limits, while the remaining data are few and isolated. In addition, even when detection limits were not entered, the concentrations reported span a decade in time, subject to all the potential errors that different sample collection methods and different analytical methods, analysts, and quality control procedures can impart to analytical data. The data in Tables 14 and 15 illustrate the difficulty involved in determining the extent of contaminant problems in one reservoir based on STORET data. Meaningful comparisons of such data between reservoirs or to water quality standards and criteria would be equally difficult.

Varying detection limits

38. During the last decade, immense progress has been made in the development of analytical instrumentation. This progress has resulted in a dramatic lowering of analytical detection limits for most contaminants. For example, in Atwood Reservoir (Table 14), Cd concentrations were reported as 100 $\mu\text{g}/\ell$ until 19 September 1974 after which 50 $\mu\text{g}/\ell$ was reported. This is only one instance, but such changes in detection limits can be expected to occur with some regularity in the data base. Changes in detection limit can also occur when working with the same instrument due to changes in proficiency of the analyst, instrument calibration, and the mechanical efficiency of the instrument. The entering of detection limits into the STORET data base is a big problem, but varying detection limits entered into the data base complicate this problem by making it more difficult to distinguish between actual concentration values and detection limits.

Table 14
Reporting Frequency for STORET Retrievable Concentrations of
Some Trace Metals from Atwood Reservoir Stations
1AT1W0002 and 1AT1W0006

<u>Parameter</u>	<u>Concentration, $\mu\text{g}/\ell$</u>	<u>Reporting Frequency</u>
Cd	50	19
	100	5*
Cr	50	45
Cu	50	50
Pb	50	50
Ni	50	20
Zn	100	43
	125	1
	150	1
Ag	50	15

* Reported until 19 Sept 1974.

Table 15
Reporting Frequency for STORET Retrievable Concentrations of
Some Trace Metals from Atwood Reservoir Stations
Other Than 1AT1W0002 and 1AT1W0006

<u>Parameter</u>	<u>Concentration, $\mu\text{g}/\ell$</u>	<u>Reporting Frequency</u>
Cd	5	1
Cr	10	2
	30	2
Cu	20	1
	30	1
Pb	5	1
	10	1
Ni	3	1
Zn	20	1
	90	1
	110	1
	300	1
	570	1
Ag	0	5
	30	1

Recent Compared to Historical Data in Red Rock Reservoir

39. As previously discussed, changes in methodology, varying analytical detection limits, and the practice of entering detection limits into the STORET data base have introduced many inaccuracies and biases into the historical analytical data. This can result in substantial differences between older data and more recently acquired analytical data.

40. Red Rock reservoir is an example of how the STORET data retrieved during this study can overstate the extent of contaminant problems in a reservoir. Summarized in Table 16 are contaminant data retrieved from the STORET data base. Examination of the data reveals that the 16 reported values for selenium were probably detection limits since 10 $\mu\text{g}/\ell$ was the only number reported. An examination of the raw data from which the summary table was produced showed that detection limit reporting was even more pervasive than can be deduced from Table 16. For most parameters, the same concentration value was reported almost 100 percent of the time between 1970 and 1976. Over the entire period for which data were retrieved, a concentration of 10 $\mu\text{g}/\ell$ was reported 57 percent, 71 percent, 68 percent, 88 percent, 51 percent, 100 percent, and 54 percent of the time for As, Cd, Cr, Cu, Ni, Se, and Ag, respectively. For Hg, 0.1 $\mu\text{g}/\ell$ was reported 9 consecutive times after which 0 was the only value reported. Nickel concentrations of 100 $\mu\text{g}/\ell$ were reported 16 times in addition to the 20 times that 10 $\mu\text{g}/\ell$ was reported, possibly indicative of a change in detection limits.

41. An indication of the impact that inclusion of detection limits and data of unknown quality has on mean contaminant concentrations can be gained by comparing the mean values of common parameters in Table 16 with those in Table 17. It can be seen that the data in Table 17, obtained with modern equipment and methodology, are orders of magnitude lower in concentration than the data retrieved from STORET in Table 16. An uncritical evaluation of water quality using only the STORET data base would lead to false assumptions regarding the severity of the potential water quality problems in the reservoir and invalid conclusions would be drawn.

Table 16
Concentration ($\mu\text{g}/\ell$) and Statistical Distribution of Contaminants
in the Red Rock Reservoir, Iowa, Water Samples
Monitored From 1970 to 1979

<u>Contaminant</u>	<u>Number of Obs.</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Maximum</u>	<u>Minimum</u>
Arsenic	49	13.87	13.32	64.00	0.00
Cadmium	62	8.58	6.69	40.00	0.00
Chromium-Tot	66	17.27	25.14	180.00	0.00
Copper	41	12.19	9.35	60.00	0.01
Iron	112	86.53	137.00	1200.00	0.00
Lead	66	59.69	107.40	660.00	0.00
Manganese	27	75.62	124.68	430.00	0.01
Mercury	14	0.64	0.49	1.00	0.00
Nickel	39	51.79	50.72	200.00	0.10
Selenium	16	10.00	0.00	10.00	10.00
Silver	50	5.42	5.01	10.00	0.00
Zinc	41	41.48	42.37	240.00	1.00

Table 17
Concentration and Statistical Distribution of Contaminants
in Red Rock Reservoir, Iowa, Water Samples
Monitored from 1977 to 1978*

<u>Contaminant</u>	<u>Number of Stations</u>	<u>Number of Obs.</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Mean</u>	<u>Standard Deviation</u>
			----- $\mu\text{g}/\ell$ -----			
Arsenic	4	14	0.01	0.063	0.025	0.021
Cadmium	4	15	0.00	0.01	0.004	0.005
Chromium	4	16	0.00	0.01	0.002	0.004
Lead	4	16	0.01	0.04	0.03	0.01
Silver	4	16	0.00	0.01	0.001	0.003
Dieldrin	4	8	0.02	0.01	0.005	0.003
Atrazine	4	8	0.07	0.82	0.30	0.26
2,4-D	4	7	0.00	.009	0.001	0.003
Alachlor	4	8	0.01	0.23	0.085	0.094
Bladex	4	8	0.04	2.19	0.38	0.74

* Baumann et al. (1979).

Frequency of Contaminant Monitoring

42. A total of ten or less analyses per inorganic contaminant were generally reported in the data base for a majority of the reservoirs followed by the 11-50 observations per contaminant group (Table 18). Only a few reservoirs had >50 observations/contaminant. Exceptions to this general trend were iron, manganese, lead, and zinc for which >50 analyses/contaminant were reported in many reservoirs.

43. No separate table was constructed for the frequency distribution of organic contaminants because such data were reported in only a very few reservoirs. In all but two reservoirs reporting organics data, the number of analyses done for various contaminants was 50 or less each, with a majority in the <10 group.

44. It appears from these results that the frequency of sampling and contaminant analysis has been very limited in the past and the baseline data are too few in most cases to draw any meaningful conclusions on the magnitude of contaminant problems in CE reservoirs.

Problems Applying Water Quality Criteria to Existing Data

45. As shown previously, the data base retrieved from STORET during this study was subject to many sources of error. Since STORET constituted a majority of the available data, these sources of error, particularly the presence of detection limits in the data base, result in an inflated mean value for a contaminant in a reservoir. This apparent upward bias of contaminant levels greatly affects the usefulness of water quality criteria comparisons as an indicator of potential contaminant problems. The newly published water quality criteria concentration levels are generally much lower than the detection limits that were routinely attainable when the majority of the available data base was generated. Inclusion of detection limits in the data base as an actual value will therefore almost invariably result in a violation of the water quality criteria which may be an artifact of the data base. Therefore, only the most generalized, nonquantitative conclusions, if any, can be drawn from comparisons of water quality criteria with the present data base.

Table 18

Frequency of Inorganic Contaminants Occurrence in Corps Reservoir Waters
in the Contaminants Data Base

Contaminant	Number of Observations Reported for Each Contaminant					
	≤10	11-50		51-100		>100
	STORET*	Other Sources**	STORET	Other Sources	STORET	Other Sources
Arsenic	10	2	8	2	2	0
Beryllium	3	0	6	0	2	0
Cadmium	10	9	13	2	3	0
Chromium-tot	16	9	12	3	4	1
Chromium-hex	1	0	0	0	0	0
Copper	16	6	16	2	5	0
Iron	14	12	14	9	13	7
Lead	12	7	14	3	6	2
Manganese	18	11	11	9	12	6
Mercury	12	9	12	3	4	2
Nickel	16	1	11	0	2	1
Selenium	5	0	7	0	0	0
Silver	9	1	14	2	0	0
Zinc	13	10	13	1	6	3

----- Number of reservoirs reporting contaminants† -----

* These data were extracted from Tables B6 through B101.

** These data were extracted from Tables B102 through B124.

† Contaminants data extracted from the reservoir in lake stations and the outside-the-lake stations were considered as separate reservoir units for computations of this table.

PART V: SOURCES OF CHEMICAL CONTAMINANTS AND ENVIRONMENTAL
FACTORS AFFECTING THEIR FATE

46. Chemical contaminants mobilized from agricultural fields or discharged from industrial or municipal wastes are transported to streams and reservoirs where the physical, chemical, and biological environments differ from that at the point of application or discharge. For example, river and reservoir sediments are often characterized by a narrower pH range, finer soil particles, greater organic matter content, and more reduced (anoxic) conditions than well-drained agricultural soils. A change in the physicochemical environment has been shown to critically affect the mobility of chemical contaminants in sediment-water systems and their persistence in the aquatic environment (Sethunathan, 1973; Gambrell et al., 1977a, 1980b).

47. One of the objectives of this project was to suggest interim operational and management techniques for minimizing reservoir contaminant problems based on existing knowledge of the behavior of toxic contaminants identified in CE reservoirs. A knowledge of contaminant behavior in various components of the reservoir environment would provide a scientific basis for developing interim management guidelines to minimize potential harmful effects of contaminants present in the CE reservoirs. This section includes a synthesis of the pertinent information on the sources, transport, persistence, and bioconcentration of toxic chemicals. Transport of sediments in the reservoir systems is also discussed because of the role of sediments in moving contaminants.

Sources of Toxic Chemical Contaminants

48. Potentially toxic metals are indigenous constituents of the earth's crust and are found in the terrestrial as well as aquatic environment from both natural and anthropogenic sources. The concentrations of metals measured in reservoirs and their tributaries are therefore a result of both natural and man-introduced sources. Synthetic organic contaminants such as pesticides, herbicides, and PCB's are manufactured

for various uses and their presence in the environment is directly related to man's agricultural and industrial activities. Contamination problems with synthetic organics in reservoirs are therefore almost always man induced and a result of sources and transport phenomena that are beyond the control of the CE.

49. Many contaminants introduced into reservoirs are strongly associated with particulate matter. In such cases, sedimentation processes in reservoirs act to lower the contaminant load in reservoir water. Following sedimentation, sediment resuspension processes and the persistence (for organics) and the adsorption/desorption chemistry of a particular compound or element will largely determine if further problems with the same contaminant species recur. In general, if contaminant release and transport to a reservoir (generally beyond the control of the CE) were curtailed, reservoir water quality would improve. Contaminant problems can occur, however, in reservoirs that stratify and develop anaerobic hypolimnions. In such cases, known problems are largely confined to mobilization of iron, manganese, sulfides, and nutrients into the water column. In general, the sources of chemical contaminants may be divided into the classes described in the following paragraphs.

Geological weathering

50. This is a source of indigenous levels of metals and may result in high metal concentrations in sediments and water of areas characterized by metal-bearing formations. High concentrations of arsenic in Oregon; mercury in areas of Oregon and California; and lead, cadmium, zinc, and copper in the Missouri lead belt surface waters are examples of metals originating from natural sources at concentrations greater than the state standards or the EPA criteria (Larson, 1980^{*}; Wixson, 1978).

Industrial processing of ores and metals

51. During the processing of ores, metal-bearing dust particles are formed which may be only partially filtered out by air purification systems. Appreciable quantities also go to waste during chemical metal

* D. W. Larson, U. S. Army Engineer District, Portland, personal communication, 1980.

processing (e.g., galvanizing and pickling) by way of toxic metal solutions (Foil, 1975; Wixson, 1978; Forstner and Prosi, 1979).

Industrial use of
metals and metal compounds

52. In addition to ore mining and processing, industries that utilize various metals in the manufacturing processes discharge high concentrations of toxic metals into the atmosphere or through liquid and solid waste discharges into receiving streams (D'Itri, 1972; American Chemical Society, 1978; Forstner and Prosi, 1979), though these discharges have been reduced in recent years due to more stringent environmental regulations.

Agricultural use of pesticides

53. The widespread use of insecticides, herbicides, fungicides, and other pesticides including toxic metals and organics in pest control programs for crop production in the United States has resulted in potentially toxic levels of contaminants in the atmosphere, soils, and runoff waters that ultimately find their way into streams and reservoirs (Wauchope, 1978; McEwen and Stephenson, 1979). In addition to use of pesticides in crop production, application on forested lands also results in residues in the terrestrial and aquatic environments (Hobart, 1977).

Municipal waste discharges

54. Solid and liquid municipal waste discharges contain significant quantities of toxic metals, pesticide residues, and other toxic organic residues from domestic uses and add to the pollution loadings in the atmosphere and in the receiving streams (American Chemical Society, 1978).

55. A report on environmental pollution by PCB's prepared by the National Academy of Sciences (NAS, 1979) indicated that municipal waste effluents from publicly owned wastewater treatment works discharged about 110×10^6 kg/year PCB's in the aquatic environment each year. The release of PCB's from sewage sludge to the environment was estimated to be 240×10^3 kg a year. The report also indicated that a significant quantity of PCB's was discharged in the aquatic environment from industrial effluents.

56. Discharges of significant quantities of synthetic pesticides and other toxic organics during manufacturing, storage, and transportation may cause a potential pollution problem in the surrounding aquatic

environment. The contamination of James River by Kepone discharged from a manufacturing plant in Hopewell, Virginia, and of Indian Creek, the Tennessee River and Wheeler Reservoir, Alabama, by DDT discharged from another manufacturing plant (discussed in paragraphs 242-246) are two examples of such contamination. Discharges of toxic, persistent organics from landfill sites also constitute a big source of pollution in the environment (American Chemical Society, 1978; NAS, 1979).

Transport of Toxic Chemical Contaminants

57. The toxic chemical contaminants released in the environment as a result of geological weathering and human activities are carried to streams, lakes, and reservoirs and finally to the ocean through several mechanisms including the atmosphere, surface waters, suspended material, and sediments. The relative magnitude of the contaminants transported depends on contaminant properties, climatic conditions, soil and sediment properties, and topographic conditions. The role of various transport mechanisms in the dispersion of toxic contaminants is briefly discussed in the following paragraphs.

Atmospheric

58. Toxic chemicals released from point and nonpoint sources are carried through the atmosphere as volatiles and/or through attachment to the fine particulate matter. The loss of contaminants to the atmosphere depends on contaminant properties, soil characteristics, and environmental factors. The important contaminant properties that influence losses to the atmosphere include vapor pressure, solubility in water, and chemical and structural makeup of the compound (Guenzi and Beard, 1974). Soil characteristics that greatly influence contaminant volatilization include sorption capacity and the amount of soil organic matter present (Weber, 1972; Haque, 1975; Spencer and Cliath, 1975; NAS, 1978; McEwen and Stephenson, 1979). Other important environmental parameters that significantly affect the contaminant losses to the atmosphere include soil moisture, contaminant concentration, wind velocity, temperature, and diffusion of the contaminant through the soil in aqueous and gaseous phases (Letty and Farmer, 1974; Guenzi and Beard, 1974; Wollast et al., 1975).

59. The atmosphere plays an important role in the mobilization of mercury in the environment. The National Academy of Sciences (NAS, 1978) estimated that 31 percent of the total anthropogenic mercury in the United States was lost to the atmosphere with a residence time of 11 to 36 days in the air. Elemental mercury (Hg^0) is reported to be the major form of mercury vapor. Billings et al. (1973) and Klein et al. (1975) reported that more than 97 percent of mercury emitted from the coal-fired steam plants was in the form of elemental mercury. Johnson and Braman (1974) analyzed atmospheric mercury around Tampa, Florida, and reported that 96 percent of total mercury was present in the vapor form and only 4 percent was associated with the particulate matter. A significant fraction of the atmospheric mercury is removed through rain over the land and sea with a consistent increase of mercury in soils, lakes, and rivers (Wollast et al., 1975; NAS, 1978).

60. Arsenic, beryllium, cadmium, chromium, copper, lead, and nickel are also mobilized through the atmosphere as a result of coal and oil combustion and emission from various industrial processes utilizing these metal compounds (Waldichuk, 1974; Nriagu, 1978, 1979). Nriagu (1978) reported that major sources of lead emission into the atmosphere included combustion of leaded gasoline, production of steel and base metals, mining and smelting of lead, and nonautomotive burning of fossil fuels. Nriagu (1979) reported that about 17 percent of cadmium released from industrial sources, agricultural fertilizer, and other sources dissipated in the air. Rainfall, snowfall, and dry deposition play an important part in the removal of toxic metals from the atmosphere and their deposition on the land and reservoirs. The deposition of toxic metals decreases exponentially with distance from point sources and is also significantly related to the wind direction and speed, resulting in localized hot spots (Nriagu, 1979). However, the information collected from the survey was insufficient to determine the sources of toxic metals reported in CE reservoirs.

61. Volatilization of pesticides (herbicides, insecticides, fungicides, etc.) occurs during and after application in agricultural fields (Edwards, 1973a; Guenzi and Beard, 1974; Spencer and Cliath, 1975; McEwen and Stephenson, 1979). Volatilization was reported to be significantly

higher for compounds with higher vapor pressure and lower water solubility (Guenzi and Beard, 1974; Spencer and Cliath, 1975). Vapor pressure and water solubility data for the pesticides reported in the CE reservoirs are given in Table A15. Spencer et al. (1973) concluded from a review of published literature that although vapor pressure of the pesticide was the main criterion in determining the rate of volatilization from nonadsorbent surfaces, volatilization under natural conditions was influenced by a variety of other factors associated with the nature of the medium in which the pesticide was distributed. For example, any factors that restrict pesticide movement to the soil surface would reduce volatilization, while factors (such as increased moisture) that enhance movement also enhance vaporization. The effects of various factors controlling the volatilization of pesticides from soil have been discussed in detail by Guenzi and Beard (1974) and Spencer and Cliath (1975). Volatilization has been reported to be a significant factor in the loss of DDT, dieldrin, heptachlor, lindane, aldrin, toxaphene, and chlordane after field application (Edwards, 1973a, b; Spencer and Cliath, 1975; McEwen and Stephenson, 1979).

62. Pesticides carried in the atmosphere are primarily redeposited on the land surface and in rivers and lakes by precipitation or by dry deposition. Although some estimates are available on the level of pesticides deposited from rain and dustfall, very little work has been reported on the magnitude of atmospheric fallout (Edwards, 1973a; McEwen and Stephenson, 1979).

63. Literature studies indicate that atmospheric transport is an important factor in the distribution of PCB's both on local and global scales (Bidleman et al., 1978; NAS, 1979). PCB's are removed from the atmosphere via wet or dry deposition, but the relative importance of each mode has not been established (NAS, 1979). Since significant sources of PCB contamination are industrial and municipal wastes, leakage, and accidental spills, the atmospheric concentration of PCB's in urban areas is much higher than in rural areas or in the atmosphere over oceans (NAS, 1979).

Surface waters
and bottom sediments

64. Toxic contaminants discharged from various sources are carried in runoff and surface waters as dissolved chemical species or adsorbed to suspended material. The relative distribution of soluble and adsorbed contaminant species depends on the contaminant properties, nature of the particulate matter, physicochemical parameters, stream flow conditions, and sediment depositional patterns in the streams and reservoirs (Weber, 1972; Merkle and Bovey, 1974; Haque, 1975; Willis et al., 1976; NAS, 1979; McEwen and Stephenson, 1979). The interactions between various contaminants and environmental factors make it difficult to make generalizations on the transport behavior of various inorganic and organic contaminants.

65. The particulate matter that constitutes suspended materials in surface waters is composed of sand, silt, clay, and organic particles. The solid particles may be coated with thin films of organic matter, metallic oxides, and microorganisms (Weber, 1972). The nature of clay particles and organic materials present in the particulate matter is a major factor affecting the adsorption/desorption behavior of various contaminants and therefore must be carefully studied to predict the potential of contaminant movement in a flowing stream in the adsorbed form (Haque, 1975).

66. Toxic metals. Toxic metals discharged in municipal and industrial wastes or used in pesticide applications are transported by flowing streams in the dissolved form or attached to particulate matter of suspended and bottom sediments. The factors which affect the relative distribution of dissolved and insoluble metal ions in the transport medium include sediment texture, pH, organic matter, amorphous oxides of iron, aluminum, manganese, and oxidation-reduction conditions (Jenne, 1968; Forstner and Prosi, 1979; Khalid, 1980; Gambrell et al., 1980a). The dissolved metals may be present as ions or as soluble organometallic complexes. The insoluble metals fraction may be adsorbed to clay minerals and organic matter or precipitated as hydroxides, carbonates, and sulfides.

67. Research studies conducted by Fuller et al. (1976), Korte et al. (1976), and Fuller (1977) indicate that retention in the soil of cationic

trace metals (copper, lead, beryllium, cadmium, nickel, mercury, and zinc) was best correlated with clay and free iron oxides. The sorption of toxic anionic elements (selenium, arsenic, and chromium) was best correlated with free iron oxides. Brannon et al. (1976) reported a strong correlation of organic-bound nickel and copper with total organic carbon. Forstner et al. (1979) concluded from his studies that in both less and strongly polluted sediments, cadmium, chromium, copper, nickel, lead, and zinc were mainly associated with hydrous oxides of iron and manganese and humic acids.

68. The solubilities of cationic toxic metals are reported to increase with decreasing pH, while that of anionic metals increase with pH increase (Stumm and Morgan, 1970; Page et al., 1980). The low pH of surface water and sediments caused by acid mine discharges in some New England, North Atlantic, Ohio River, and Missouri River Division reservoirs was reported to result in toxic metal concentrations potentially harmful to human health and aquatic life.

69. The soluble levels of toxic metals are generally low under strongly reduced sediment conditions due to sulfide precipitation, except for iron and manganese, which are more soluble under reduced conditions (Gambrell et al., 1977a; Khalid et al., 1977). However, toxic metal concentrations exceeding the equilibrium calculations of metal sulfide complexes may be present in CE reservoirs due to the formation of metal-organic complexes and the release of toxic metals with the solubilization of iron and manganese hydrous oxides under reducing sediment conditions (Chen et al., 1976).

70. The transport of metals in streams and rivers and their occurrence in reservoirs in the dissolved form is very low as the metals are generally associated with particulate matter (Gibbs, 1977). Research studies reviewed by Forstner and Prosi (1979) indicated that over 90 percent of the heavy metals transport in unpolluted rivers was associated with the insoluble fraction, whereas the dissolved discharges in the polluted rivers were significantly higher than from unpolluted rivers. It should be pointed out that the low dissolved metal concentrations may exceed the criteria for human health or aquatic life protection, and also

be subject to bioconcentration and move up the food chain. Therefore, the low dissolved metal concentrations need to be evaluated for their potential toxic effects.

71. Toxic organics. Pesticides used in agricultural and forestry operations wash off treated soils and plants as a result of runoff and enter surface waters. The lateral movement of pesticides with runoff water is high for pesticides with high water solubility and low adsorption potential. In addition to the dissolved pesticide losses through runoff, transport of soil particles due to water erosion would also result in the transport of pesticides adsorbed to soil particles (Bailey and White, 1964). Research studies reviewed by Merkle and Bovey (1974) and Haque (1975) indicated that the loss of pesticides adsorbed to soil particles was greater from fine-textured soils than from coarse-textured soils. Other factors that affect the loss of pesticides from the field to surface waters include rate of application, slope, vegetative cover of the treated area, amount and intensity of rainfall, and moisture content of the soil (Barnett et al., 1967; Green and Obien, 1969; McEwen and Stephenson, 1979).

72. The properties of organic compounds can play an important role in regulating their transport in runoff waters and mobility in suspended and bottom sediments. DDT, a chlorinated hydrocarbon, has a low water solubility and is strongly adsorbed on soils and sediments. Adsorption of DDT is also reported to be directly related to organic matter content (Weber, 1972). The water solubilities of other chlorinated hydrocarbons - endrin, dieldrin, and aldrin - are considerably higher than that of DDT and the compounds are slightly mobile in soil (Table A15). The adsorption of endrin, aldrin, dieldrin, toxaphene, chlordane, and heptachlor is also highly related to the organic matter content of soils and sediments and occurs through weak physical intermolecular forces at lipophilic sites (Weber, 1972; Weed and Weber, 1974). Lindane is much more soluble and is more mobile in the soil system.

73. Organophosphorus pesticides such as malathion, parathion, and disulfoton, although more soluble than chlorinated hydrocarbons, are strongly adsorbed by soil particles and organic matter and are ranked

along with the chlorinated hydrocarbons as having high adsorption and low mobility in soil systems (Harris, 1969). Acidic herbicides, 2,4-D and 2,4,5-TP, are very soluble in water and exhibit very little adsorption under aquatic conditions (Weber, 1972). Wauchope (1978) conducted an extensive review of pesticide contents in runoff waters draining from agricultural fields and concluded that 0.5 percent or less of the major commercial pesticides applied were generally lost in runoff waters, unless severe rainfall conditions occurred within 1-2 weeks after application. Loss of organochlorine insecticides was suggested to be about 1 percent, regardless of weather conditions, because of their long persistence. Herbicide losses of up to 5 percent could occur depending on weather and slope because of the ease of washoff of wetttable powder formulations and high solubilities. Based on the field data, Wauchope (1978) suggested that pesticides with solubilities of 10 ppm and higher were lost mainly in the water phase of runoff, while organo-chlorines, paraquat, and arsenal pesticides, which were strongly adsorbed by soils, would be transported mainly through eroded soil particles.

74. PCB's introduced into the aquatic environment are readily adsorbed onto suspended sediments, especially those high in organic matter (Hamelink et al., 1971; Dexter and Pavlou, 1978). Adsorption of PCB residues on the organic fraction of suspended solids and the subsequent incorporation of these particles into sediments of aquatic systems is considered a major means of PCB transport and immobilization (Haque et al., 1974; Hetling et al., 1978). The role of adsorption mechanisms in the transport, persistence, and immobilization of toxic organics in soils and sediments has been extensively reviewed (Weber, 1972; Poinke and Chesters, 1973; Weed and Weber, 1974; Haque, 1975; Faust, 1977).

75. Sediments carrying toxic substances from the watersheds may be deposited and become relatively immobile, especially in deeper parts of reservoirs. Conversely, contaminated sediments may remain in suspension until they pass through the reservoir. Sediment residence time varies with water releases, climatic conditions, and engineering considerations. Since sediment is a carrier of contaminants, sediment transport in reservoir systems is a major environmental concern. The subject of sediment transport is discussed later in paragraphs 107-125.

Persistence of Toxic Chemical Contaminants

76. Toxic contaminants reported in CE reservoir waters and aquatic organisms include heavy metals, organic pesticides, and PCB's. An important point that must be considered in the assessment of deleterious effects of heavy metals in the environment is that metals cannot be destroyed through chemical or biological degradation as is the case with most toxic organics. The form of a heavy metal may be altered due to biogeochemical processes, so that the particular salt in which it originally entered the environment no longer exists, but the total amount of the metal present remains unchanged. Heavy metals tend to accumulate in bottom sediments of rivers and lakes through adsorption, complexation, and precipitation and may also be bioaccumulated through the food chain, adversely affecting various living organisms.

77. Toxic organics are biodegradable in terrestrial and aquatic environments and range from very persistent (such as chlorinated hydrocarbons) to nonpersistent (such as guthion and 2,4-D). Their degradation in the environment is affected by the compound properties and several environmental factors. The degradation behavior of various toxic organics is summarized in the following paragraphs.

Chlorinated hydrocarbons

78. Chlorinated hydrocarbon pesticides and PCB's are among the most persistent residues in the environment. The chlorinated hydrocarbons identified in CE reservoirs include DDT and metabolites, aldrin, BHC isomers, chlordane, dieldrin, endrin, heptachlor and metabolites, toxaphene, and mirex (Tables A11, A12). Although the use of many of these compounds has been restricted or banned, they still persist in the environment because of their resistance to degradation and strong adsorption properties.

79. A review of published literature on the relative persistence of various chlorinated hydrocarbons indicates that pesticide residues remain in the environment for several months to many years. The relative persistence of chlorinated hydrocarbons and other toxic organic compounds is presented in Tables 19 and 20.

Table 19

Persistence of Organochlorine Insecticides in the Environment*

<u>Chemical</u>	<u>Period of Persistence years</u>
Aldrin	1-6
BHC	6-11
Chlordane	4-12
DDT	10
Dieldrin	6-8
Endrin	1-7
Heptachlor	3.5-9
Toxaphene	8-10

* Source: Edwards (1973a, b); Weber (1972); McEwen and Stephenson (1979); U. S. EPA (1979).

Table 20

Relative Persistence of Some Pesticides in Natural Waters*

<u>Not Persistent**</u>	<u>Slightly Persistent†</u>	<u>Moderately Persistent††</u>	<u>Persistent‡</u>
Alachlor	Aldrin	Atrazine	Dieldrin
Demeton	Amitrole	Bladex	Endrin
Dichlorvos	Diazinon	Chlordane	Hexachlorobenzene
Diquat	Disulfoton	Ethion	Heptachlor
Fenitrothion	Fenuron	BHC	DDT
Guthion	MCPA	Propazine	
Malathion	Methoxychlor	Simazine	
Methyl parathion	Phorate	Toxaphene	
Parathion		2,4,5-TP	
2,4-D			

* Adapted from Goring et al. (1975); McEwen and Stephenson (1979).

** Half-life less than 2 weeks.

† Half-life 2 to 6 weeks

†† Half-life 6 weeks to 6 months.

‡ Half-life more than 6 months.

80. DDT. Extensive research has been conducted on the degradation of DDT in the environment. Generally, two separate reductive pathways produce the primary end-point metabolites of DDT degradation, DDE and DDA. Reductive dechlorination results in the formation of DDA. The other primary pathway proceeds via reductive dehydrochlorination and results in the formation of DDE, the major storage product in mammals and humans (Sethunathan, 1973; Williams, 1977; McEwen and Stephenson, 1979; U. S. EPA, 1979). Several research reports (Ko and Lockwood, 1968; Castro and Yoshida, 1971; Lichtenstein et al., 1971; Gambrell et al., 1980b) indicated a more rapid degradation of DDT under anaerobic conditions than under aerated soil conditions. Several strains of bacteria and fungi have been reported to accelerate DDT degradation under anaerobic conditions and this subject has been extensively reviewed (Fries, 1972; Williams, 1977; U. S. EPA, 1979). However, the breakdown of DDT in many aquatic environment is reported to be slow, resulting in the persistence of residues for an extended period (Edwards, 1973a, b; McEwen and Stephenson, 1979; U. S. EPA, 1979).

81. Cyclodienes. The cyclodienes, a major group of chlorinated cyclic hydrocarbons that includes aldrins, dieldrin, endrin, heptachlor, chlordane, and endosulfan, are generally recognized as some of the most persistent organic pesticides in the environment. Aldrin metabolizes to dieldrin, which is equally toxic but more stable and persistent in the environment (Kaufman, 1974; U. S. EPA, 1979). Dieldrin is reported to undergo slow microbial degradation both under aerobic and anaerobic conditions to photodieldrin, an aldehyde, and a number of acidic compounds formed by the loss of carbon from the ring (Matsumura et al., 1968; Kaufman, 1974).

82. Endrin also undergoes slow microbial degradation to ketoendrin and several unidentified products (Patil et al., 1972; Matsumura et al., 1971). Endrin metabolites produced in mammals (anti-12-hydroxyendrin, syn-12-hydroxyendrin, and 12-ketoendrin) were reported to be more toxic than endrin (U. S. EPA, 1979).

83. Chlordane. Technical chlordane is a mixture of several major components including isomers of chlordane, alpha and gamma chlordane,

heptachlor, and transnonachlor. Because of a large number of products involved, little has been reported on the metabolites of technical chlordane (McEwen and Stephenson, 1979). Chlordane is persistent in soils, and one study reported that about 16 percent of applied chlordane was present after 15 years (McEwen and Stephenson, 1979). The major routes of metabolism for both cis- and trans-chlordane are via dichlorochlordene and oxychlordane. The metabolites are further degraded to compounds less toxic than the original chlordane or the intermediates (Tashiro and Matsumura, 1977). Alpha and gamma chlordanes were reported to be more persistent than other components of technical chlordane in a freshwater lake study, and these isomers were more adsorbed to bottom sediments (Oloffs et al., 1978).

84. Heptachlor. Heptachlor metabolizes to heptachlor epoxide in soils, microorganisms, plants, and mammals (Kaufman, 1974; U. S. EPA, 1979). Both compounds are equally toxic to aquatic organisms and mammals and are persistent in the environment. Heptachlor is also microbially degraded to chlordene, chlordene epoxide, and several other metabolites that are considerably less toxic than heptachlor (Kaufman, 1974; Oloffs et al., 1978). In a controlled laboratory study, Guenzi et al. (1971) showed that in a flooded soil the degradation rate of chlorinated insecticides followed the order of heptachlor > DDT > lindane > endrin. Dieldrin and DDD degradation was not affected by flooding.

85. Mirex. Mirex is a persistent insecticide, resistant to degradation by soil microorganisms. However, slow metabolism of mirex to a monohydro derivative by anaerobic microorganisms and photolytic dechlorination to form various mono and dihydro derivatives, toxic to aquatic organisms, has been reported in the literature (Mahendale et al., 1972; Alley et al., 1973). Jones and Hodges (1974) reported that mirex was stable for 6 months in aerobic soils and lake sediments. The persistence of mirex and its photoproducts with a high toxicity to aquatic organisms may have a considerable environmental impact in aquatic systems.

86. γ BHC. Lindane, a gamma isomer of hexachlorocyclohexane (γ BHC), is generally less persistent than DDT or cyclodiene insecticides. It is resistant to chemical and biological degradation under aerobic soil conditions, but undergoes rapid microbial degradation under anaerobic

conditions (Leigh, 1969; Sethunathan, 1973; Williams, 1977). Lindane degradation is accelerated by an increase in soil reduction conditions, temperature, and organic matter content (Sethunathan, 1973). The conversion of lindane to alpha or delta isomers of hexachlorocyclohexanes by microorganisms and plants has been reported (U. S. EPA, 1979). Disappearance of lindane by volatilization under flooded conditions has also been reported (Guenzi and Beard, 1970).

87. Toxaphene. Toxaphene, a complex mixture of polychlorinated camphenes and bornanes, is a persistent insecticide and can remain adsorbed on bottom sediments or suspended solids for many years (Terriere et al., 1966). The results of the study speculated that toxaphene was partially metabolized by plants and animals. Parr and Smith (1976) concluded from their studies that microbial degradation of toxaphene was more rapid under anaerobic conditions in the presence of an energy source.

88. Methoxychlor. Methoxychlor, a DDT-analog, is a relatively non-persistent insecticide with no significant bioaccumulation potential. Methoxychlor is more biodegradable than DDT under anaerobic conditions and is a good substitute for DDT for pest control (Sethunathan, 1973). However, very little is known about its behavior in the environment.

89. PCB's. Polychlorinated biphenyls, PCB's, the chlorinated derivatives of biphenyls extensively used in industrial installations, are generally resistant to chemical or biological degradation. PCB's do not undergo oxidation, reduction, addition, elimination, or electrophilic substitution reactions, except under extreme conditions (Hutzinger et al., 1974). Photodegradation of PCB's in the presence of sunlight results in the formation of highly toxic chlorodibenzofurans (CDF's) (Crosby and Moilanen, 1973; McKinney, 1976; Nishizumi, 1978). However, photodegradation of PCB's to CDF's has not been demonstrated in the aquatic environment.

90. Results of pure culture studies indicate Pseudomonas acromobactor and Vibrio spp. have the potential of degrading PCB's in an aerobic aquatic environment (Saylor et al., 1978; Yagi and Sudo, 1980). However, Wong and Kaiser (1975) and Tucker et al. (1975) pointed out

that bacterial degradation of PCB's was dependent on the stereochemical and electronic structure of the substrate molecule as well as the degree of chlorine substitution of the biphenyl. Microbial degradation of PCB's under anaerobic conditions is either extremely slow or nonexistent (Fries, 1972; Carey and Harvey, 1978).

Organophosphorus pesticides

91. Organophosphorus insecticides reported in CE reservoirs include diazinon, guthion, parathion, and malathion. Goring et al. (1975) and McEwen and Stephenson (1979) classified guthion, malathion, and parathion to be nonpersistent pesticides with half-lives of less than two weeks and diazinon to be slightly persistent with a half-life of two weeks to six weeks (Table 20).

92. Sethunathan (1973) reported that diazinon and parathion were more stable in nearly neutral aerated soils. The degradation of these two insecticides was more rapid under acid and flooded soil conditions. Chemical and biological hydrolyses were important mechanisms in the degradation process. Walker and Stojanovic (1973) reported that microbial degradation was the chief mechanism of malathion degradation in Mississippi soils. Malathion was stable under neutral or acid pH conditions, but was susceptible to hydrolysis in alkaline conditions. Chemical degradation was attributed to both alkaline hydrolysis and adsorption by the soil particles. Chemical hydrolysis of malathion is also directly correlated to increasing temperature and salinity (Bourquin, 1975). Edwards (1973b) concluded from the published literature that organophosphorus insecticides were readily hydrolyzed and were not generally taken up by aquatic organisms.

Chlorophenoxy herbicides

93. The chlorophenoxy herbicides 2,4-D and 2,4,5-TP are not persistent in the soil. Warm, moist conditions in soils with appreciable organic matter content are conducive to microbial activity in soils, and 2,4-D may degrade in as little as 2-3 weeks, while 2,4,5-TP could persist for a few weeks to several months (Table 20). Rapid photodegradation of 2,4-D and its derivatives in water by ultraviolet light is reported in the literature (Aly and Faust, 1964). The rate of photodegradation is strongly influenced by pH, becoming more rapid as pH increases.

Triazine herbicides

94. Triazines are widely used herbicides for weed control in corn in the United States and Canada. Atrazine and Alachlor were reported in CE reservoir waters. The triazines are strongly adsorbed to soil clay and organic matter and are moderately persistent with half-lives of a few to several months (Gunther and Gunther, 1970; Anderson, 1971). The persistence of triazine compounds depends on the rate of application, soil organic matter and clay content, soil moisture, temperature, and pH. Triazines are readily photodecomposed in aqueous medium by ultraviolet and infrared radiation. Atrazine is reported to be more photolytic and mobile in neutral pH soils than acid soils (Weber, 1972). Chemical hydrolysis and microbial degradation result in the slow breakdown of triazines to 2-hydroxy and N-dealkylated derivatives, eventual ring cleavage, and the liberation of carbon and nitrogen (Esser et al., 1975).

95. The main environmental concern for the triazine herbicides relates to their moderate persistence in soil and their possible harm to nontarget plants. However, residual herbicidal levels reported in water are too low to affect algae and other aquatic plants and fish (Wauchope, 1978; McEwen and Stephenson, 1979).

Bioconcentration of Toxic Chemical Contaminants

96. The presence of toxic contaminants in terrestrial and aquatic food chains has been a major cause of concern due to the potential chronic or acute harmful effects on living organisms. If present in reservoirs or their tributaries, these contaminants may be bioconcentrated by the aquatic organisms and move up the food chain. Bioconcentration (or bioaccumulation), as used in this report, refers to uptake of contaminants from water, suspended solids, or sediments in concentrations greater than those present in the external environment. The potential of a contaminant for bioconcentration is generally measured as a bioconcentration factor (BCF), which relates the concentration of a chemical in water to the concentration in aquatic organisms (U. S. EPA, 1979).

97. Bioconcentration, persistence, and toxicity of contaminants are generally considered to be the most important variables in assessing potential environmental hazards of toxic contaminants. Weber (1977) classified pesticides and inorganic contaminants into different classes according to the BCF's as follows:

<u>Class</u>	<u>BCF</u>
Nonaccumulative	<60
Slightly accumulative	60-700
Moderately accumulative	700-8000
Highly accumulative	>8000

98. The nonaccumulative contaminant is readily lost when an organism is placed in water without the contaminant, or it is completely degraded by the organism. The highly accumulative contaminant is not lost when the organism is placed in water without the contaminant, or is not degraded by the organism to any appreciable extent over many weeks (Weber, 1977). The property of degradation, however, applies only to synthetic organics such as pesticides and not to the nondegradable metals which exist in the environment permanently. The bioconcentration of various inorganic and organic contaminants identified in CE reservoirs is discussed in the following paragraphs.

Inorganic contaminants

99. BCF's for toxic metals reported in the literature for freshwater and marine organisms, which include invertebrates and fish species, are presented in Table 21. It is apparent from the range of values reported that BCF's may be characteristic of individual species and also depend on the length of time the organism is exposed and the metal concentration in the medium. Waldichuk (1974) compared bioconcentration of metals in plankton, macroinvertebrates, and fish species and concluded that the highest concentrations of metals were detected in the macroinvertebrates such as oysters. The data presented in Table 21 indicate that beryllium, chromium, nickel, selenium, and silver did not bioconcentrate in aquatic organisms to any appreciable degree, as the BCF's were

Table 21
BCF's and Biological Half-Lives for Inorganic Contaminants
Identified in CE Reservoirs

<u>Contaminant</u>	<u>BCF</u>	<u>Biological Half-Life</u>	<u>Source of Information</u>
Arsenic	0-4500	10-60 days	Waldichuk (1974); Woolson et al. (1976); Giddings and Eddleman (1977); U. S. EPA (1979).
Beryllium	5-150	37-53 days	U. S. EPA (1979).
Cadmium	3-182,000	10-30 years	Waldichuk (1974); U. S. EPA (1979); Piotrowski and Coleman (1980); Friberg et al. (1974).
Chromium (trivalent)	1-152	616 days	U. S. EPA (1979).
Copper	0-35,000	very short	Waldichuk (1974); Weber (1977); U. S. EPA (1979).
Lead	42-100,000	10 years	Waldichuk (1974); U. S. EPA (1979).
Mercury Inorganic	129-33,800	40-70 days	Waldichuk (1974); Weber (1977); U. S. EPA (1979); Piotrowski and Coleman (1980).
Nickel	9.8-61	very short	U. S. EPA (1979).
Selenium	2-20	1-several days	U. S. EPA (1979).
Silver	0-368	15-52 days	U. S. EPA (1979).
Zinc	1-27,080	200-400 days	U. S. EPA (1979).

* BCF's reported are for both freshwater and marine organisms. Biological half-life is the estimated time for excretion of 50% of the total ingested metal from the biological system.

less than 400. Arsenic, copper, cadmium, lead, mercury, and zinc showed a high degree of bioconcentration.

100. Bioconcentration of mercury in the aquatic environment occurs in the form of inorganic as well as organic mercury (methylmercury) and the bioconcentration of the organic mercury is proportionately higher (D'Itri, 1972; Wollast et al., 1975; U. S. EPA, 1979). Methylmercury is lipid-soluble, is fairly resistant to biodegradation, and is accumulated in the brain in greater concentrations than other organs (U. S. EPA, 1979; Piotrowski and Coleman, 1980). Due to greater toxicity to aquatic organisms and a longer half-life, methylmercury is reported to be a more serious environmental hazard than inorganic mercury (Friberg and Vostal, 1972; Kramer and Neidhart, 1975; U. S. EPA, 1979; Piotrowski and Coleman, 1980).

101. Biological half-life of metals is another important parameter indicating the duration of harmful effects of contaminants on aquatic organisms, humans, and animals. The published data summarized in Table 21 show that once absorbed in the biological tissue, cadmium, lead, chromium, and zinc were retained for long periods before flushed out of the system. Arsenic, beryllium, mercury, and silver had biological half-lives ranging from 10 to 70 days, while copper and nickel were excreted quickly.

Organic contaminants

102. The toxic organic contaminants identified in CE reservoirs include chlorinated hydrocarbon pesticides, organophosphorus insecticides, herbicides, and PCB's. As discussed earlier in the section, organochlorine pesticides and PCB's are very slow degrading and persist in the environment for long periods, while organophosphorus insecticides and herbicides metabolize at a faster rate (Edwards, 1973b; Kaufman, 1974). Weber (1977) evaluated the relative environmental hazards of pesticides based on toxicity, duration of activity, and bioaccumulation properties and reported that bioaccumulation of pesticides by the organisms was generally directly related to persistence in the environment.

103. BCF's for some organic contaminants reported in the literature are summarized in Table 22. These data and Weber's rating (paragraph 97)

Table 22

BCF's for Organic Contaminants Identified in CE Reservoirs*

<u>Contaminant</u>	<u>BCF</u>	<u>Source of Information</u>
Aldrin	10-141,000	Edwards (1973a, b); Weber (1977); McEwen and Stephenson (1979).
BHC**	7-2500	Edwards (1973a, b); Weber (1977)
Chlordane	10-16,035	Edwards (1973a, b); U. S. EPA (1979).
DDT†	25-287,000	Edwards (1973a, b); Duke and Dumas (1974); Weber (1977); McEwen and Stephenson (1979); U. S. EPA (1979).
Dieldrin	18-236,000	Edwards (1973a, b); Duke and Dumas (1974); Weber (1977); U. S. EPA (1979).
Endrin	200-15,000	Edwards (1973a, b); Duke and Dumas (1974); Weber (1977); U. S. EPA (1979).
Heptachlor/ Heptachlor Epoxide	7-37,000	Edwards (1973a, b); U. S. EPA (1979).
Methoxychlor	10-470	Edwards (1973a, b); Duke and Duman (1974).
Mirex	193-2600	Duke and Dumas (1974).
Toxaphene	550-76,000	Mayer et al. (1975); (1977); U. S. EPA (1979).
PCB's	1000-1,240,000	Duke and Dumas (1974); U. S. EPA (1979).
Parathion	9	Weber (1977).

* BCF's reported are for both freshwater and marine organisms.

** Data include all isomers of BHC.

† Data include all metabolites of DDT.

indicated that DDT and its metabolites, aldrin, dieldrin, toxaphene, chlordane, endrin, heptachlor/heptachlor epoxide, and PCB's were highly accumulative with BCF's greater than 8000. Methoxychlor had a BCF of less than 500 and was slightly accumulative (Weber, 1977). Herbicides and organophosphorus insecticides are easily biodegradable and are not bioconcentrated to any significant degree (Edwards, 1973a, 1973b; Duke and Dumas, 1974; Loos, 1975; Esser et al., 1975; Weber, 1977; McEwen and Stephenson, 1979). A BCF of 9 was reported for parathion, and zero for the other organophosphorus compounds, carbamates, organic acids, and other herbicides (Weber, 1977).

104. Bioconcentration of pesticides by aquatic organisms involves ingestion of contaminated food, uptake from water passing over gill membranes, cuticular diffusion, and direct absorption from sediments (Grzenda et al., 1970; Kenaga, 1975). Hamelink et al. (1971) proposed that bioconcentration of pesticides would vary directly with fat content of each aquatic species and inversely with the water solubility of each pesticide. This means that the biological magnification was controlled by absorption and partition from water. Similar results were reported by Neely et al. (1974) and Kapoor et al. (1973), who demonstrated that bioconcentration of residues by fish was directly related to the n-octanol-water partition coefficient and inversely related to water solubility. In a later study, Hamelink et al. (1977) showed that a large share of the DDE and mercury residues were acquired from aquatic food instead of water. However, these researchers suggested that residues dissolved in water served as the origin for any contamination in the fish.

105. Hamelink et al. (1977) proposed that aquatic organisms continually exchanged stable pesticide residues with water and, given sufficient time, this exchange should reach a finite equilibrium point wherein the organisms lose residues at the same rate that they are acquired. Under such equilibrium conditions, a series of constants, analogous to partition coefficients, could be used to determine the degree of biomagnification. However, the research studies showed that the phenomenon of exchange equilibrium was dependent on the behavior of pesticides and thus was applicable only to certain pesticides. For example, fish can reach and maintain a state of equilibrium with lindane

(Gakstatter and Weiss, 1967) or dieldrin (Reinert, 1972) in the water in a relatively short period of time but not with DDE or mercury (Reinert et al., 1974; Hamelink et al., 1977). The BCF for lindane is 1×10^2 and for dieldrin about 1×10^4 , while that of DDE exceeds 1×10^5 . Based on these data, Hamelink contended that for pesticides with BCF's exceeding 1×10^5 , a considerable amount of time would be required to acquire and equilibrate relatively large amounts of a compound from a highly dilute source. The direct application of exchange equilibria would therefore be limited to those compounds with a BCF factor of less than 1×10^5 (Hamelink et al., 1977).

106. Although the mechanisms of contaminant uptake and concentration are not uniformly explained in the literature, it is likely that chlorinated hydrocarbons and certain toxic metals may be bioconcentrated in aquatic organisms and present a potential for environmental damage. This subject of pesticide uptake by organisms is discussed in detail by Kenaga (1975) and Brown (1978).

Sediment Transport in the Reservoir Systems

107. The transport of sediments containing contaminants from watersheds to reservoirs is generally very limited during low flow conditions such as summer months. However, accelerated erosion resulting from land use activities during snow melt and extended rainy periods, commonly spring and winter months, may result in considerable transport of sediments from watersheds to the streams and rivers and into reservoirs. The reservoirs generally act as depositories for the sediments because of their high sediment trap efficiency. Due to high adsorption capacity, sediments act as sinks for contaminants in the reservoirs and may also cause water quality problems downstream through reservoir releases. Since toxic inorganic and organic contaminants associated with the sediments can be bioconcentrated by the aquatic organisms present in reservoirs and downstream waters, a knowledge of sediment transport would be helpful in understanding the contaminant problems. The movement of sediments from watershed to the reservoirs and downstream waters is discussed in the following paragraphs.

Loss from watersheds

108. Most of the sediment delivered to reservoirs through streams and rivers is a result of soil erosion in the watershed (catchment) area draining into the reservoirs. The potential for soil erosion in the watershed is a unique characteristic of the catchment area and depends on soil type, vegetative cover, intensity of rainfall, land slope, and land use practices (Cherry et al., 1977). The sediment sources include farmlands, rangelands, forest and woodlands, gullies, stream channels, roads and highways, urban development, and construction sites. Cherry et al. (1977) concluded from the results of their data that the sediment discharge at any point was primarily a function of the drainage area, rainfall, and land-use practices.

109. Anderson (1975) reported that sedimentation and stream turbidity amounts and frequencies varied from trivial to critical between different unit areas on parts of watersheds with different characteristics. He developed a series of regression coefficients to predict suspended sediment loading in streams based on the subsystems that characterize the basic sediment-producing potential of meteorological, geologic, topographic, vegetative, and land use conditions existing in California wildlands. Anderson used the existing baseline data of watersheds to demonstrate the usefulness of the model to predict changes in streamflow hazards as a result of changes in subsystem variables.

110. In order to evaluate the magnitude of sediment transport and devise control measures, it is imperative that the source of excessive sediment be evaluated, and that the amount of sediment moved by streams and rivers be estimated. However, the sediment source is generally a nonpoint source which makes it difficult to estimate the sediment production. For example, the main pathway of sediment loss from agricultural fields and forested land is through soil erosion.

111. Willis et al. (1976) and McDowell et al. (1981) investigated sediment and pesticide yields from a small Mississippi Delta watershed (15.6 ha) planted to cotton. The results of a two-year study (1973-1975) indicated that DDT and toxaphene losses were strongly related to sediment yield. Maximum loss of sediment and pesticides occurred during the spring-planting-cultivation period. Also, the sediment and pesticide

losses were strongly affected by rainfall intensity. Based on the 1975 data, McDowell et al. (1981) concluded that 93 percent of the toxaphene was attached to the sediments and only 7 percent was transported in solution.

112. Comparative studies of suspended sediment loss in runoff waters from natural watersheds in different land-use categories in Wisconsin indicated that substantial sediment losses occurred only from cultivated or heavily grazed catchments (Sartz, 1976). Sediment losses from undisturbed forests were minimal. The sediment loss from cropland was greatest during early stages of crop development. Sartz (1976) also reported that sediment loss varied from one catchment to another, probably due to erosion patterns and vegetative cover density.

113. In addition to the sediment loss measurements from small agricultural and forested watersheds, some estimates are also available for sediment yields from urban area construction sites and storm events (Holberger and Truett, 1976; Herb, 1976; McCuen, 1980). But the available data on sediment loss from essentially nonpoint sources in the whole watershed feeding a stream or a river are inadequate to project sediment loadings. The problems encountered in collecting these data are discussed elsewhere (Gessler, 1975; Meyer et al., 1976).

Transport in streams and rivers

114. Sediments lost from various land-use areas as a result of rainfall and soil erosion are transported by streams and rivers and may be deposited in the stream beds, reservoirs, lakes, and eventually in the oceans. The total stream sediment load consists of stream bed plus suspended sediment load. Rivers and streams generally carry suspended sediments in much greater quantities than the bed load. But the movement of bed load material that is limited to flood stages (especially in smaller rivers) and is of short duration significantly affects the geomorphic changes in a river and determines the river profile (Gessler, 1975).

115. Many factors influence the rate of sediment transport such as water discharge, flow velocity, energy slope, sheer stress, water depth, bed configuration, intensity of turbulence, particle size, water temperature, and so forth. Sediment transport equations have been developed,

using a combination of these variables; the most important parameters are velocity and particle size (Molnau et al., 1975; Amar and Thomas, 1976; Jennings et al., 1976; Sutherland and Ellis, 1980). The sediment transport models are not discussed in this report.

116. Hines et al. (1976) reported that temporal and spatial water quality problems and sediment transport in the rivers are a function of river hydrology, and in particular a function of streamflow, water temperature, and channel morphology. The researchers used the Willamette River hydrological data to describe sediment transport and deposition patterns in the various river morphologic reaches.

Sedimentation in reservoirs

117. When a river carrying sediments and associated pollutants enters a reservoir, the flow velocity decreases and the suspended and the bed load sediment materials start settling down. Generally the coarse material will settle first in the outer reaches of the reservoir followed by progressively finer fractions further down towards the reservoir dam. Based on this depositional pattern, the reservoir is divided into three distinct regions: top-set bed, fore-set bed, and bottom-set bed (Fan, 1976). The top-set bed is located in the upper part of the reservoir and is largely composed of coarse material or bed load and generally has little effect on the reservoir storage capacity. The fore-set region represents the live storage capacity of the reservoir and comprises the wash load. The bottom-set region is located immediately upstream of the dam and is primarily composed of suspended sediments brought from upstream by density currents. This region is called the reservoir dead storage and generally does not affect the storage capacity.

118. Sediment deposition in a reservoir depends on the rate of sediment input into the reservoir (which is a function of the watershed drainage area and climatic and land-use properties), reservoir trapping efficiency, sediment properties, retention time, and, if implemented, management practices. Since the incoming sediments and associated pollutants significantly affect the water quality of the reservoir pool and the releases, it is essential that these sediment reservoir interactions be characterized for their deposition behavior, particle-size

distribution, and pollutant concentrations to successfully plan a management strategy (McKee, 1977).

119. Particle-size distribution. Worsley and Dennison (1973) conducted a sedimentation survey of Whites Creek Delta feeding into the Watts Bar Lake, Tennessee, and reported that the coarsest sediment particles accumulated in the upper reaches of the delta while the finest particles settled in the deepest water below the wave action. The results of the study also indicated that high organic content was associated with finer sediments in deep water where oxidation was inhibited. Kennedy et al. (1980) studied the distribution of suspended sediments in Lake Red Rock, Iowa, following a storm event. Their results indicated that silt was deposited in areas of generally higher velocities and in headwaters. Clay deposits dominated in the relatively quiescent lower end of the lake. The occurrence of the sand deposits was related to sandbar deposition in the river meander prior to impoundment. The results of the study also indicated substantial increases in concentration of smaller diameter particles during the storm flow. Progressive enrichment of fluvial suspended sediments by clay due to preferential erosion of clayey soils in the watershed and subsequent transport of fine clays during runoff was attributed to the increase in smaller median particle sizes.

120. Contaminant retention. The reservoirs built for flood control, hydroelectric power generation, and water supply generally retain a high percentage of the incoming sediment load. Reservoirs constructed on the Colorado, Missouri, Tennessee, Des Moines, Mississippi, and several other rivers have sediment trap efficiencies as high as 90 percent. Chemical contaminants originating from various point and nonpoint sources in the upstream watershed and transported with the sediment material may be adsorbed to the sediment mineral and organic fractions and be deposited in the reservoir, thus making the reservoir an indirect source of pollution. However, very few studies have been conducted to evaluate the pollutant loading of river inflows and their association with the reservoir sediments.

121. Cherry et al. (1977) monitored the suspended sediment and pollutant loadings at various points on the upper Chattahoochee River Basin in Georgia located between Buford Dam at the upper end and West

Point Dam at the lower end. Sediment and pollutant inputs are from agricultural, forested, and urban areas including the Atlanta metropolitan area. The results indicated that annual point-source discharges contributed about 53 percent of the total phosphorus loads and about 47 percent of the total nitrogen. Nonpoint sources contributed 78 percent of the dissolved solids and 72 to 89 percent of the heavy metals. The authors concluded from the study that pollutant loadings increased as the land use changed from the forest to urban. Rausch and Schrieber (1977) reported that Callahan Reservoir, Missouri, trapped an average of 87 percent of the incoming sediment, 72 percent of the total phosphorus, and 30 percent of the inorganic nitrogen. In a related study, Olness and Rausch (1977) showed that the Callahan Reservoir sediments served as a phosphorus sink either through chemical adsorption or planktonic and mineral sedimentation.

122. Literathy and Laszlo (1978) studied the heavy metal distribution in various particle-size fractions in bottom sediments of the Sajo River catchment area and the Kiskore Reservoir, Hungary. The results indicated that about 80 percent of mercury and lead were present in the $<50 \mu\text{m}$ fraction, about 80 percent of cadmium in the $25\text{--}50 \mu\text{m}$ fraction, and most of zinc in the $>50 \mu\text{m}$ fraction. At flow rates lower than the mean, the bulk of heavy metals was associated with the bottom sediments to be stirred up, spread, or scoured subsequently at flood discharges. The authors emphasized that the distribution of heavy metals in the river basin and the reservoir could not be satisfactorily described by analyzing the suspended sediment alone and that the analysis must be extended to bottom sediments.

123. Schnoor (1981) developed a mathematical model to describe the fate and transport of dieldrin through the Coralville Reservoir, Iowa. The pesticide data collected from 1968-1978 was used to test the validity of the model. The results of computations indicated that about 40 percent of the dieldrin that entered the reservoir from the agricultural watershed was adsorbed to the bottom sediments, and 50 percent was released through the dam gates of the reservoir, which has a short detention time. Uptake by fish accounted for 10 percent of the dieldrin input.

Reservoir releases

124. Downstream reservoir releases are generally regulated in accordance with the project objectives which may include hydroelectric power generation, low flow augmentation, water supply, discharge of flood waters, reservoir water quality control, and so on. The reservoirs designed for low level or bottom withdrawals result in the discharge of turbid and/or anoxic waters resulting in water quality problems downstream. Strain (1980) studied the environmental impact of bottom releases in a large CE reservoir operated for hydropower generation and found that an increase in the mortality rates at the downstream hatchery correlated with increases in total iron and manganese and a decrease in the dissolved oxygen concentrations in the reservoir hypolimnion.

125. Multilevel withdrawal outlets in CE reservoirs constructed in recent years have been used to regulate downstream as well as reservoir water quality. The use of a low-level outlet in Lost Creek Lake, Oregon, resulted in the discharge of turbid reservoir waters generated by winter storms, improving reservoir and Rogue River water quality. Rausch and Heinemann (1975) also advocated the use of bottom withdrawal to discharge the sediment-laden density currents caused by storm runoffs.

PART VI: DATA SUMMARY AND WATER QUALITY COMPARISONS

Comparison of Water Contaminant Data with the EPA Criteria for Water Quality

Basis of comparisons

126. The water quality criteria proposed by the EPA in 1979 for toxic substances pursuant to the Clean Water Act (Tables A1 and A2) were used as a primary basis for determining the magnitude of the chemical contaminants problem. The 1979 proposed criteria were used because the 1980 criteria did not become available until all comparisons had been conducted. The many sources of error in the contaminants data base which severely limit its usefulness for water quality evaluations and the general similarity of the proposed 1979 water quality criteria to the published 1980 EPA water quality criteria precluded investment of additional funds to update this part of the report. Differences between the 1980 criteria and the proposed 1979 criteria can be ascertained by comparing Tables A1 and A2 with Tables 1 and 2. The state standards for various contaminants were not used as a basis for comparison if the EPA criteria were available.

127. The principal reason for the use of the recently proposed EPA criteria was that these criteria were the product of the most up-to-date syntheses of the scientific data on contaminants behavior in the environment and their toxic effects on humans and aquatic organisms. For example, a criterion proposed for the protection and propagation of fish, shellfish, and wildlife reflects the best available estimate of the maximum concentration of a given contaminant that can be tolerated while still maintaining protection of aquatic life. Similarly, a criterion proposed for the protection of human health reflects the best available estimate of the concentration that can exist without posing an undue risk to humans who drink water without further treatment or eat fish or shellfish from the water. State standards are based not only on the scientific knowledge, but also on the economic and technical feasibility and thus may be different from the criteria EPA proposed.

128. In the case of certain contaminants for which no criteria were proposed in 1979, the EPA 1976 Red Book criteria were used as the basis for comparison. For a contaminant not covered in the 1979 criteria or the 1976 Red Book criteria, a state standard for that specific contaminant was used for comparison.

129. To determine if a reservoir exceeded the EPA criterion for human health protection for a specific contaminant, the maximum water contaminant concentration reported during the monitoring period was compared with the proposed or established maximum concentration ceiling. The reservoirs exceeding the EPA criterion at least once during the monitoring period for which data were available were considered to have a potential contaminant problem for the purpose of this report.

130. For freshwater aquatic life, water contaminant concentrations reported were compared with the criteria for maximum concentration ceiling (acute toxic effects) and the 24-hour average concentration (chronic toxic effects). To determine if a reservoir exceeded the criterion for acute toxic effects for a specific contaminant, the maximum water contaminant concentration reported during the monitoring period was compared with the maximum concentration proposed. However, to determine the reservoirs exceeding the 24-hour average concentration ceiling, a mean concentration value for the entire monitoring period was compared. (It was felt that a mean concentration value was a better approximation of the chronic effects than a maximum contaminant concentration that may occur less frequently or only once. In cases where mean concentration values were not available, the maximum concentration reported was used to determine the chronic toxicity problems.)

131. For beryllium, cadmium, trivalent chromium, copper, lead, nickel, and zinc, the criteria proposed for the protection of freshwater aquatic life were based on water hardness (Table A1; Table A8). Water hardness data (as calcium carbonate) of CE reservoirs surveyed were plugged into the proposed equations and allowable levels of metals for the 24-hour chronic and the maximum acute effects were calculated. These calculated metal concentrations were compared with the reported mean and maximum concentration values, respectively, to determine if a contaminant exceeded the proposed criteria (see paragraph 130). In a few of the CE

reservoirs for which no water hardness data were available, water hardness data from the surrounding reservoirs were substituted for computations. The results of the comparison of water contaminants data with the water quality criteria are discussed as follows.

Inorganic contaminants

132. The inorganic contaminants data for the 71 CE reservoirs that had one or more contaminants exceeding the criteria are given in Tables A9 and A10. The contaminant distribution in the various CE Divisions is presented in Tables A13 and A14. The overall comparisons of the contaminant reporting reservoirs with the criteria for human health protection and freshwater aquatic life are summarized in Tables A3 and A4, respectively. The results of these comparisons are discussed in the following paragraphs.

133. Arsenic. The ambient water concentration of arsenic is suggested to be zero to protect human health from the potential carcinogenic effects of arsenic exposure through ingestion of water and contaminated aquatic organisms (Federal Register, 1979a). Although in the National Drinking Water Standards the arsenic level was established at 50 $\mu\text{g}/\ell$ (Table 1), the EPA (1979) proposed an interim criterion of 0.02 $\mu\text{g}/\ell$ at a cancer risk level of 10^{-5} (Table A1). Data presented in Tables A3 and A13 indicate that all of the 27 reservoirs located in eight CE Divisions that reported arsenic data had water arsenic concentrations exceeding the proposed EPA water quality criterion for human health protection.

134. Arsenic concentrations found in reservoir waters were also compared with the EPA criteria for freshwater aquatic life protection. The EPA (1979) proposed that arsenic concentrations should not exceed a daily average of 57 $\mu\text{g}/\ell$ (referred to as 24-hour average) to protect freshwater organisms from the chronic toxic effects while arsenic concentrations should not exceed 130 $\mu\text{g}/\ell$ at any time to protect from the acute toxic effects. Data summarized in Table A4 show that of the 27 reservoirs that reported arsenic levels, only three exceeded the EPA criterion for maximum concentration, and four reservoirs exceeded 24-hour average concentrations.

135. The distribution of reservoirs with arsenic problems showed no regional patterns (Table A14).

136. Beryllium. The EPA proposed a water quality criterion of 0.087 μg beryllium/ ℓ at a cancer risk level of 10^{-5} , while ambient water concentration is suggested to be zero for the maximum protection of human health from the potential carcinogenic effects of beryllium (Table 1). No national drinking water standard has been established for beryllium. All of the nine reservoirs that reported beryllium levels exceeded the EPA criterion for human health protection (Table A3). These reservoirs were located in the North Atlantic, Ohio River, and Missouri River Divisions (Table A13).

137. Reservoir water hardness data were used in our study to calculate beryllium levels for comparison with the EPA criteria for freshwater aquatic life protection. None of the nine reservoirs reporting beryllium data exceeded the EPA criterion for maximum concentration (Table A4). Seven reservoirs reported beryllium concentrations that exceeded the criterion for 24-hour average concentration (Table A4).

138. Cadmium. To protect human health from the toxic properties of cadmium, the EPA has proposed ambient water criteria of 10 μg cadmium/ ℓ identical to the National Drinking Water Standards (Table A1). A survey of the reservoir water data indicated that 24 of the 38 reservoirs reporting cadmium data had concentrations exceeding the EPA criteria for human health protection (Table A3). North Atlantic, Southwestern, North Pacific, and South Pacific Divisions reported cadmium levels in reservoir waters and their tributaries lower than the criterion (Table A13). All reservoirs in the New England, South Atlantic, and North Central Divisions that reported cadmium data exceeded the criterion while in the Ohio River and Missouri River Divisions 86 and 57 percent of the reporting reservoirs, respectively, exceeded the criterion (Table A13).

139. The cadmium concentrations reported in CE reservoirs that may be potentially harmful to aquatic life were calculated using water hardness data and the equations proposed by the EPA (Table A8). A comparison of calculated cadmium values with the EPA criteria for freshwater aquatic life protection indicates that 20 CE reservoirs exceeded the criterion for maximum concentration and 35 reservoirs exceeded the criterion for 24-hour average concentration (Table A4). All CE Divisions that reported cadmium data had one or more reservoirs exceeding the freshwater aquatic

life criterion (Table A14). No data on contaminants in the Lower Mississippi Valley Division reservoirs were available.

140. Chromium. Trivalent chromium (Cr^{3+}) is reported to be toxic to humans as well as aquatic organisms, while hexavalent chromium (Cr^{6+}) is classified as a potential carcinogen. The EPA has proposed separate criterion for these two forms of chromium present in surface waters. The water quality criterion for the protection of human life from trivalent chromium has been proposed to be 50 $\mu\text{g}/\ell$ while for hexavalent chromium a criterion of 0.008 $\mu\text{g}/\ell$ is suggested for a cancer risk level of 10^{-5} (Federal Register, 1979c). The 1980 EPA water quality criteria recommended substantially higher concentrations for both forms of chromium. The maximum concentration of chromium (total) allowed in drinking water by the National Drinking Water Standards is set at 50 $\mu\text{g}/\ell$.

141. Inspection of data from CE reservoirs reporting chromium concentrations indicates that six CE Divisions had one or more reservoirs with chromium concentrations exceeding the EPA criterion for human health protection (Table A13). New England, South Atlantic, Ohio River, and Missouri River Divisions had proportionately more reservoirs with chromium concentrations higher than the EPA criterion. In all, 23 of 44 CE reservoirs reporting chromium data had exceeded the EPA criterion one or more times during the monitoring period recorded (Table A3).

142. The criteria proposed by the EPA for the protection of freshwater aquatic life from trivalent chromium are based on water hardness and two proposed equations were used for the calculation of both the 24-hour average concentration and the maximum concentration that should not be exceeded at any time (Table A8). For hexavalent chromium, the proposed EPA criterion to protect freshwater aquatic life is 10 $\mu\text{g}/\ell$ as a 24-hour average concentration and 110 $\mu\text{g}/\ell$ as a maximum concentration that should not be exceeded at any time. Of the 44 reservoirs reporting chromium data, one reservoir exceeded the criterion for maximum concentration and four reservoirs reported values higher than the 24-hour average concentration (Table A4). These reservoirs were located in the New England and North Atlantic Divisions (Table A14).

143. Copper. The EPA has proposed a water quality criterion of 1.0 mg copper/ ℓ for human health protection, the same as set for National

Drinking Water Standards (Table A1). A breakdown of CE reservoirs reporting copper levels indicates only two of 42 reservoirs had copper concentrations greater than the criterion. These reservoirs were located in the South Atlantic and Missouri River Divisions (Table A13).

144. The proposed EPA criteria for the protection of freshwater aquatic life from toxic effects of copper are based on water hardness, and the equations proposed for calculating critical copper levels are given in Table A8. The comparison of copper concentrations in reservoir waters with the EPA criteria indicated that one or more reservoirs in each of the eight CE Divisions reporting copper data had copper concentrations in or around reservoir waters which exceeded criterion for the daily average or the maximum concentration ceiling (Table A14). Of the 42 reservoirs that reported water copper data, 32 reservoirs exceeded the criterion for maximum concentration, and 38 reservoirs exceeded the criterion for 24-hour average concentration (Table A4).

145. The results of this study show that while copper is not hazardous for human health, the levels found in the majority of CE reservoir waters may be detrimental to freshwater aquatic organisms.

146. Lead. The ambient water criterion for the protection of human health from the toxic effects of lead proposed by the EPA is 50 $\mu\text{g}/\ell$ (Table 1). The National Drinking Water Standards also limit lead concentrations to 50 $\mu\text{g}/\ell$. A survey of reservoir water data shows that 29 of the 43 reporting reservoirs located in seven CE Divisions exceeded the EPA criterion for human health (Table A13). Twenty-two of these reservoirs were located in the New England, Ohio River, and Missouri River Divisions. Lead levels reported in reservoir waters located in the North Pacific and South Pacific Divisions were below the criterion proposed for human health protection.

147. The comparison of reservoir water lead concentrations with the proposed EPA criteria for freshwater aquatic life protection (based on water hardness, see Table A1) indicates that water lead concentrations in reservoirs located in six CE Divisions may be potentially harmful to freshwater aquatic life (Table A14). Of the 43 reservoirs reporting lead data, eight reservoirs exceeded the criterion for maximum concentration, while 20 reservoirs exceeded the criterion for 24-hour average concentration (Table A4).

148. Mercury. To protect human health from the toxic properties of mercury, the EPA has proposed the ambient water quality criterion of 0.2 µg mercury/ℓ (Federal Register, 1979c). The National Drinking Water Standard for mercury is set at 2 µg/ℓ - a value ten times higher than the proposed EPA criterion (Table 1). A survey of mercury data in reservoir waters indicated that mercury levels present in all of the 41 reservoirs located in nine CE Divisions that reported mercury data were higher than the EPA criterion (Tables A3, A13).

149. Divalent inorganic mercury and monomethylmercury are two principal mercury forms toxic to aquatic life, and the degree of toxicity varies with the mercury form. Based on the toxicological properties of these two mercury forms, the EPA proposed separate criteria for the protection of freshwater aquatic life. For inorganic mercury, the criterion proposed by the EPA to protect freshwater aquatic life is 0.064 µg mercury/ℓ as a 24-hour average concentration and 3.2 µg mercury/ℓ as a maximum concentration that should not be exceeded at any time. For methylmercury, the proposed criterion is 0.016 µg mercury/ℓ as a 24-hour average concentration and 8.8 µg mercury/ℓ as a maximum concentration. However, no methylmercury data were found in the reservoir data survey and the values discussed in this study are for the inorganic mercury only.

150. Each of the nine CE Divisions reporting mercury data had one or more reservoirs with mercury concentrations exceeding the proposed U. S. EPA criteria for the protection of freshwater aquatic life (Table A14). All of the 41 reservoirs that reported mercury exceeded the criterion for daily average concentration, suggesting the likelihood of chronic effects, while 15 reservoirs had mercury concentrations greater than the criterion for the maximum concentration that should not be exceeded at any time (Table A4).

151. Nickel. Very little information is available on the adverse effects of nickel intake by human beings. The criterion of 50 µg nickel/ℓ in the ambient water proposed by the EPA for the protection of human health has been extrapolated from studies on rats (U. S. EPA, 1979). No limit on nickel concentrations in the National Drinking Water Standards was established (Table 1). The survey of nickel concentrations in CE

reservoirs shows that one or more reservoirs located in each of six CE Divisions reporting nickel data contained nickel concentrations in excess of the proposed criterion for human health protection (Table A13). In the North Atlantic, North Pacific, and South Pacific Divisions nickel concentrations found were below the proposed criterion or no nickel data were reported (Table A13). Twenty-four of the 28 reporting reservoirs had water nickel concentrations higher than the proposed U. S. EPA criterion (Table A3).

152. The criteria proposed by U. S. EPA for the protection of freshwater aquatic life from the toxic effects of nickel are based on water hardness (Table A1), and the equations proposed for calculating the 24-hour average chronic concentrations and the maximum acute concentrations are given in Table A8. The comparison of reservoir water nickel levels with the proposed criteria show that only one reservoir located in the Missouri River Division exceeded the proposed criterion for acute toxic effects (Table A4, A14). Eighteen reservoirs had nickel concentrations greater than the criterion for chronic toxic effects (Table A4).

153. Selenium. Selenium is toxic to humans and aquatic organisms and is known to produce tumors in animals (U. S. EPA, 1979). The ambient water quality criterion proposed by the EPA for the protection of human health is 10 $\mu\text{g selenium}/\ell$, which is identical to the National Drinking Water Standards (Table 1). Selenium has been reported in 13 CE reservoir waters and seven of these reservoirs had selenium levels higher than the proposed criterion (Table A3).

154. The proposed EPA criteria for the protection of freshwater aquatic life from the toxic effects of selenium are 9.7 $\mu\text{g}/\ell$ for a 24-hour average concentration and 22 $\mu\text{g}/\ell$ for a maximum concentration that should not be exceeded at any time (Table A1). A survey of selenium levels in the CE reservoirs indicated only two reservoirs located in the New England and Missouri River Divisions exceeded the criterion for the maximum concentration, while three reservoirs reported water selenium levels higher than the criterion proposed for the 24-hour average concentration (Tables A4, A14).

155. Silver. Silver is toxic to humans and aquatic organisms. Once absorbed by living tissues, silver is not readily removed and tends to

have cumulative toxic effects (U. S. EPA, 1979). The EPA criterion to protect human health from the toxic effects of silver present in ambient waters is proposed at a concentration of 10 $\mu\text{g}/\ell$ (Table A1). The maximum silver concentration allowed in drinking water by the National Drinking Water Standards is 50 $\mu\text{g}/\ell$, five times greater than the proposed EPA criterion (Table 1).

156. The results of the survey presented in Table A3 indicate that silver was reported in 22 reservoirs and 17 of these reservoirs had silver concentrations in reservoir or tributary waters greater than the proposed EPA criterion of 10 $\mu\text{g}/\ell$ for human health protection. These reservoirs were located in the New England, Ohio River, North Central, and Missouri River Divisions (Table A13). The North Atlantic, South Atlantic, Southwestern, North Pacific, and South Pacific Divisions either had no data reported for silver, or the reported concentrations were below the proposed criterion.

157. Although silver is very toxic to aquatic organisms at very low concentrations, little information is available to evaluate the effects of different forms of silver or water hardness on silver toxicity (U. S. EPA, 1979). Based on the available toxicity data, the EPA has proposed silver concentration of 0.009 $\mu\text{g}/\ell$ to protect freshwater aquatic organisms from the chronic effects and 1.9 $\mu\text{g}/\ell$ to protect from the acute toxicity effects (Table A1). The comparison of silver levels reported in CE reservoir waters with the proposed criteria for freshwater aquatic life shows that 20 reservoirs exceeded the criterion for maximum acute concentration, while all of the 22 reporting reservoirs had silver concentrations greater than the criterion for the 24-hour average chronic concentrations (Table A4).

158. Zinc. Zinc is an essential element for humans, animals, and plants. No toxic effects of zinc on human health have been reported for concentrations generally present in the environment. However, zinc is listed as a toxic pollutant, and an ambient water quality criterion of 5 mg/ℓ has been proposed for human health protection by the EPA. The National Drinking Water Standards also limit zinc to 5 mg/ℓ , essentially due to taste problems.

159. Out of 44 reservoirs that reported zinc data, four reservoirs exceeded the 5 mg/l criterion proposed for the protection of human health (Table A3). Three of these reservoirs were located in the New England and one in the Missouri River Divisions (Table A13).

160. The criteria proposed by the EPA for the protection of freshwater aquatic life are based on water hardness and the equations proposed for the calculation of toxic zinc levels for both the 24-hour average chronic concentration and the maximum acute concentration are given in Table A8. A comparison of reservoir water zinc data with the criteria proposed for freshwater aquatic life protection shows that 17 CE reservoirs had zinc levels that exceeded the concentration that should not be exceeded at any time (Table A4). Thirty reservoirs had zinc levels that exceeded the criterion for a daily average chronic concentration. All CE Divisions, except the North Pacific and the Lower Mississippi Valley, had reported zinc levels in one or more reservoirs that were potentially harmful to freshwater aquatic life (Table A14).

161. The results of this study suggest that the presence of zinc in reservoir waters was a greater problem for aquatic organisms than for humans and must be considered seriously when planning fisheries in the vicinity of contaminated reservoirs.

162. Iron. Iron is an essential trace element for humans, animals, and plants. No toxic effects of iron at levels generally present in the environment are reported. Iron is not included in the list of toxic pollutants and no criteria have been proposed by the EPA for the protection of human health and freshwater aquatic life. The EPA 1976 Red Book criteria had established a 0.3 mg iron/l concentration limit for domestic water supplies due to aesthetic considerations (Table 1). The National Drinking Water Standards also limit iron concentration to 0.3 mg/l due to aesthetic considerations. The EPA 1976 Red Book criteria are used in this study to compare iron concentrations reported in various CE reservoir waters.

163. A total of 66 CE reservoirs located all across the country reported iron data, and 55 of these reservoirs exceeded the 1976 EPA Red Book criterion (Table A3).

164. Iron present in excessive concentrations in water is toxic to freshwater aquatic life, but toxicity effects are modified by alkalinity, pH, hardness, temperature, dissolved oxygen, and the presence of ligands (U. S. EPA, 1976). The EPA 1976 Red Book criteria established a concentration limit of 1 mg iron/l to adequately protect freshwater aquatic life (Table 2). A survey of the reservoir water iron data shows that 47 of the 66 reporting reservoirs had iron concentrations greater than the criterion at least once during the monitoring period for which data were available (Tables A4, A14).

165. Manganese. Manganese, like iron, is essential for humans, animals, and plants. No toxic effects of manganese at levels generally present in water have been reported. Manganese is not included in the toxic pollutants list for which ambient water quality criteria are proposed by the EPA. The EPA 1976 Red Book criteria and the National Drinking Water Standards limited manganese concentration at 50 $\mu\text{g}/\text{l}$ for taste and aesthetic considerations.

166. The comparison of reservoir water manganese data with the EPA 1976 Red Book criteria indicates that 57 of the 64 reporting reservoirs had manganese concentrations in excess of the 50 $\mu\text{g}/\text{l}$ criterion (Table A3). Eight of the nine CE Divisions that reported manganese data had one or more reservoirs that exceeded the criterion (Table A13).

167. Manganese is not considered a problem for freshwater aquatic organisms and hence no criterion is established or proposed.

168. pH. The pH of water in natural systems is an indication of the acidity or alkalinity levels in water which may influence the dissolution or precipitation of toxic pollutants and other important compounds in the aquatic systems. The pH is not a toxic pollutant and therefore no criteria were proposed by the EPA in 1979. However, the 1976 EPA Red Book water quality criteria established a pH range of 5 to 9 for domestic water supplies (welfare) and 6.5 to 9 for freshwater aquatic life protection (Tables 1, 2).

169. In this study, the pH of reservoir waters was not treated as a toxic contaminant; therefore, if pH were the only parameter for which data were available, that reservoir was not included in the list with potential contaminant problems. For the reservoirs that had one of the

contaminants listed in Table 1 exceeding the criteria, pH values were recorded in Table A10. Of the 71 reservoirs with one or more contaminant problems, 65 reservoirs reported pH data (Table A3).

170. The pH of most of the lakes and reservoirs in the United States have been measured at one time or the other but no attempt was made in this study to collect these data. Walker (1979) has summarized pH data of 775 lakes and reservoirs nationwide that were recorded during the 1972-75 National Eutrophication Survey Program. Of these lakes and reservoirs, 107 are under CE jurisdiction. The pH data recorded in this study are therefore incomplete and do not adequately represent CE reservoirs. No comparisons of reservoir water pH values with the 1976 EPA Red Book criteria were therefore made.

171. Acidic pH levels (<5.0) are known to increase solubility of toxic heavy metals and thus may cause significant toxicity problems, especially in watersheds where acid mine discharge would flow into streams feeding the reservoirs. This excessive acidity and its associated toxicity problems are discussed later in this report.

Organic contaminants

172. Twenty reservoirs located in five CE Divisions were identified in this survey to contain one or more toxic organic contaminants (Table A11). The comparisons of the organic contaminants reported in reservoir waters with the proposed or established EPA criteria are discussed in the following paragraphs.

173. Aldrin/dieldrin.^{*} Aldrin and dieldrin have been two of the most widely used domestic pesticides. However, due to potential carcinogenic effects and adverse impact on the aquatic environment, the use and production of insecticides containing these two compounds have been restricted since 1974. Although aldrin has been used in greater quantities than dieldrin, aldrin in the environment readily transforms to dieldrin which is very slowly biodegradable and persistent in the environment.

174. For maximum protection of human health from the potential carcinogenic effects of exposure to aldrin or dieldrin, the ambient water

* Chemical names of the toxic organic contaminants reported in CE reservoirs are given in Table A15.

concentration is considered zero. The EPA has proposed a criteria of 4.6×10^{-5} $\mu\text{g}/\ell$ for aldrin and 4.4×10^{-5} $\mu\text{g}/\ell$ for dieldrin in water at additional lifetime cancer risk level of 10^{-5} (Federal Register, 1979c). A survey of CE reservoir data indicates that all of the nine CE reservoirs reporting aldrin/dieldrin data had concentrations greater than the proposed criterion (Table A5). However, it needs to be pointed out that the relatively small proportion of reservoirs reporting data does not accurately reflect the problem. Lack of analytical capabilities and high costs of contracted analysis for toxic organic pollutants may be a significant factor in the absence of data on organics in the majority of CE reservoirs.

175. The criteria proposed by the EPA in 1979 for the protection of freshwater aquatic life from the toxic effects of aldrin/dieldrin are based on only dieldrin data because aldrin is rapidly converted to dieldrin and there are insufficient data on aldrin toxicities. The proposed criterion for the 24-hour average concentration of aldrin/dieldrin is 0.0019 $\mu\text{g}/\ell$ and the maximum concentration that should not be exceeded at any time is 1.2 $\mu\text{g}/\ell$ (Table A2). The concentrations of aldrin and dieldrin reported in CE reservoir waters were added together for comparison with the proposed criterion. The results summarized in Table A5 show that concentration of aldrin/dieldrin in nine CE reservoir waters exceeded the criterion for a 24-hour average concentration, while no reservoir exceeded the maximum concentration ceiling.

176. Hexachlorocyclohexane (BHC). Hexachlorocyclohexane, an organochlorine insecticide commonly known as BHC, or benzene hexachloride, consists of five configurational isomers (alpha, beta, gamma, delta, and epsilon). Since 1976, BHC has been manufactured and registered under the gamma isomer configuration, called lindane, which is the most toxic of all the isomers. Hexachlorocyclohexanes are carcinogens and for maximum protection of human life their concentration criterion is considered zero. The EPA has proposed ambient water quality criterion of 0.016 $\mu\text{g}/\ell$ for alpha-BHC and 0.054 $\mu\text{g}/\ell$ for gamma-BHC (lindane) at an additional lifetime cancer risk level of 10^{-5} (Table A2). The maximum concentration of lindane allowed by the National Drinking Water Standards is 4 $\mu\text{g}/\ell$.

177. The survey of organic contaminants in CE reservoirs shows that of seven CE reservoirs that reported BHC, only one reservoir located in North Central Division exceeded the EPA criterion for γ BHC proposed for human health protection (Tables A5, A11).

178. The criterion proposed for the protection of freshwater aquatic life is based primarily on toxicity studies conducted with lindane since it is the most toxic isomer of BHC and is the least degradable (U. S. EPA, 1979). To protect freshwater aquatic life from the toxic effects of lindane, the EPA proposed a criteria of 0.21 $\mu\text{g}/\ell$ as a 24-hour average concentration and 2.9 $\mu\text{g}/\ell$ as maximum concentration (Table A2). The comparison of lindane concentrations reported for various CE reservoirs with the freshwater aquatic life criteria indicates that only one reservoir located in the North Central Division had lindane concentrations in the water samples equal to the criterion for a 24-hour average concentration, indicating the potential of chronic toxic effects (Tables A5, A11).

179. Chlordane. Chlordane is a broad spectrum insecticide of the group of polycyclic chlorinated hydrocarbons called cyclodiene insecticides. Chlordane is commercially used for termite control and as an insecticide for home and garden and food crops. Chlordane is a potential carcinogen, is highly toxic to aquatic organisms, and persists for a long period in the environment.

180. To protect human health from the potential carcinogenic effects of chlordane, the EPA proposed a criterion of 1.2 $\mu\text{g}/\ell$ in ambient water at a cancer risk level of 10^{-5} (Table A2). The proposed criteria to protect freshwater aquatic life from the toxic effects of chlordane are 0.024 $\mu\text{g}/\ell$ as a 24-hour average concentration and 0.36 $\mu\text{g}/\ell$ as a maximum concentration. In this study, only one reservoir located in the Missouri River Division reported chlordane data and these exceeded the criteria both for human health and freshwater aquatic life protection (Tables A5, A11).

181. DDT and metabolites. DDT, a chlorinated hydrocarbon, had been extensively used in the public health and agricultural programs in the United States and around the world for decades. In December 1972, agricultural use of DDT in the United States was banned by the EPA due to persistence and several harmful properties of the insecticide and its

metabolites. Since the 1972 ban, the use of DDT in the United States has been effectively discontinued. However, very slow biodegradability and past widespread use have resulted in the accumulation of DDT in the environment (U. S. EPA, 1979). For the maximum protection of human health from the potential carcinogenic effects of exposure to DDT, the ambient water quality criterion was proposed at 0.00098 $\mu\text{g}/\ell$, at a cancer risk level of 10^{-5} (Table A2).

182. The contaminants survey showed that eight reservoirs reported water DDT data and all of those reservoirs exceeded the EPA criterion for human health protection (Table A5). These reservoirs were located in the South Atlantic, North Central, Southwestern, and Missouri River Divisions (Table A11).

183. The criteria to protect freshwater aquatic life from the toxic effects of DDT and its metabolites proposed by the EPA are 0.00023 $\mu\text{g}/\ell$ as a 24-hour average concentration and 0.41 $\mu\text{g}/\ell$ as a maximum concentration that should not be exceeded at any time (Table A2). One of the eight CE reservoirs for which DDT data were available had DDT concentrations equal to the criterion for maximum concentration, while all of the eight reservoirs exceeded the criterion for a 24-hour average concentration, indicating potential for chronic toxicity (Table A5).

184. Endrin. Endrin, a cyclic chlorinated hydrocarbon, has been extensively used in cotton pest control in the southeastern and Mississippi Delta states. Endrin is highly toxic to humans, animals, and aquatic organisms and is highly persistent in the environment.

185. The ambient water quality criterion proposed by the EPA for the protection of human health from the toxic properties of endrin is 1.0 $\mu\text{g}/\ell$ (Table A2). The National Drinking Water Standards limit water endrin concentrations to a maximum of 0.2 $\mu\text{g}/\ell$. The criteria proposed to protect freshwater aquatic life from toxic effects of endrin are 0.002 $\mu\text{g}/\ell$ as a 24-hour average concentration and 0.10 $\mu\text{g}/\ell$ as maximum concentration which should not be exceeded at any time.

186. The contaminant survey indicated that two CE reservoirs located in the South Atlantic Division reported water endrin data and these levels were lower than the criteria for public health and freshwater aquatic

life maximum acute concentrations (Tables A5, A11). Endrin levels in these two reservoirs exceeded the criterion for chronic toxicity (Table A5).

187. Heptachlor/heptachlor epoxide. Heptachlor, a polycyclic chlorinated hydrocarbon, has been extensively used to control soil insects in corn cultivation. Since 1976, the use of heptachlor for food crops has been banned by the EPA, and the insecticide is presently used for termite control or nonfood plants (U. S. EPA, 1979). Heptachlor epoxide is a principal metabolite of heptachlor. Heptachlor and heptachlor epoxide are potential carcinogens, are highly toxic to humans and aquatic organisms, and are highly persistent in the environment. The ambient water quality criterion proposed by the EPA for heptachlor/heptachlor epoxide is $0.00023 \mu\text{g}/\ell$ at a cancer risk level of 10^{-5} (Federal Register, 1979a). All of the four CE reservoirs reporting heptachlor data exceeded the public health criterion (Table A5).

188. The criteria proposed by U. S. EPA for the protection of freshwater aquatic life from toxic effects of heptachlor/heptachlor epoxide are $0.0015 \mu\text{g}/\ell$ as a 24-hour average concentration (to protect from chronic toxic effects) and $0.45 \mu\text{g}/\ell$ as a maximum concentration that should not be exceeded at any time (Table A2). Heptachlor/heptachlor epoxide concentration in one CE reservoir exceeded the criterion for a maximum concentration, while all of the reporting reservoirs had insecticide levels higher than the criterion for a 24-hour average concentration (Table A5). These reservoirs were located in the South Atlantic, North Central, and Missouri River Divisions (Table A11).

189. Toxaphene. Toxaphene, a polychlorinated hydrocarbon insecticide, is currently used on agricultural crops, mainly cotton, in the United States. Toxaphene is a potential carcinogen, is highly toxic to aquatic organisms, and can persist in the environment for prolonged periods (U. S. EPA, 1979).

190. The proposed EPA criterion for the protection of human health from toxaphene in ambient waters is $0.0005 \mu\text{g}/\ell$ at a cancer risk level of 10^{-5} (Table A2). The maximum concentration of toxaphene allowed in drinking water by the National Drinking Water Standards is $5 \mu\text{g}/\ell$ (Table A2). The criteria proposed by the EPA for freshwater aquatic

life are 0.007 $\mu\text{g}/\ell$ to protect from chronic effects and 0.47 $\mu\text{g}/\ell$ to protect from acute toxicity effects of toxaphene (Table A2). Two reservoirs located in the South Atlantic Division reported toxaphene data in this survey and both reservoirs exceeded the EPA criteria for the protection of human health and freshwater aquatic life protection from chronic toxicity (Table A5, A11). However, the water toxaphene concentrations were lower than the criterion proposed to protect aquatic life from the acute toxic effects (Table A5).

191. Polychlorinated biphenyls (PCB's). PCB's are chlorinated derivatives of biphenyls with compounds varying from monochlorobiphenyls to decachlorobiphenyls. The tetrachlorobiphenyls and higher chlorobiphenyls are more persistent and stay in the environment for a long period. The PCB's have been used in plasticizers, heat transfer fluids, hydraulic fluids, fluids in vacuum pumps and compressors, lubricants, wax attenders, capacitors, and transformers. Although the manufacture of PCB's in the United States was stopped in 1971 and its use restricted in 1974 to closed systems only, it presents a potential pollution problem in the future through discharge into the environment due to its widespread use and its persistence.

192. PCB's are potential carcinogens, are highly toxic to aquatic organisms, and are bioconcentrated in the food chain. The photodegradation products and metabolites of PCB's are also toxic. The allowable ambient water concentration of PCB's is considered zero to protect human health from potential carcinogenic effects of PCB's. The EPA has proposed a criterion of 0.0002 $\mu\text{g PCB's}/\ell$ at a cancer risk level of 10^{-5} (Table A2). The criteria proposed for the protection of freshwater aquatic life from the toxic effects of PCB's are 0.0015 $\mu\text{g}/\ell$ as a 24-hour average concentration and 6.2 $\mu\text{g}/\ell$ as maximum concentration that should not be exceeded at any time (Table A2).

193. The results of the contaminant survey showed that 11 CE reservoirs reported water PCB data (Table A5). Comparison with the proposed U. S. EPA criterion indicates that all reporting reservoirs exceeded the criterion for human health (Table A5). Ten reservoirs exceeded the 24-hour average concentration proposed to protect freshwater aquatic organisms from chronic toxic effects and none of the 11 reservoirs

exceeded the maximum concentration ceiling for acute effects (Table A5). The reporting reservoirs were located in the South Atlantic, Ohio River, North Central, Southwestern, Missouri River, and South Pacific Divisions (Table All).

194. Diazinon. Diazinon is an organophosphorus insecticide and degrades fairly rapidly in the environment, both under aerobic and anaerobic conditions. No criteria were established or proposed by the EPA for the protection of public health or aquatic organisms from diazinon. Diazinon is also not regulated in the National Drinking Water Standards. However, several states established a maximum limit of zero to 0.009 g diazinon/l in state water quality standards to protect human health and aquatic organisms from toxic effects of diazinon (Table A5, A6).

195. The survey of CE reservoirs contaminant data indicated that four CE reservoirs located in Iowa, South Carolina, and Colorado reported diazinon data (Table All). However, these states had no specific standards for diazinon and no comparisons were made.

196. Guthion. Guthion is an organophosphorus insecticide which replaced endrin over ten years ago for the control of the sugarcane borer. Like other organophosphorus insecticides, guthion is readily degradable and does not persist in the environment for long periods. The insecticide is toxic to humans, animals, and aquatic organisms. Guthion was not included in the 65 toxic substances for which the criteria were proposed by the EPA in 1979. The 1976 EPA Red Book criteria set a maximum concentration of 0.01 µg/l to protect freshwater and marine aquatic life from toxic effects of guthion (Table 2). No limit on guthion concentration has been proposed in the National Drinking Water Standards.

197. The results of the contaminant survey indicated that the concentration of guthion in the three reservoirs reporting data exceeded the 1976 EPA Red Book criteria to protect aquatic life (Table A5). The reservoirs were located in the South Atlantic and South Pacific Divisions (Table All).

198. Parathion. Parathion is an organophosphorus insecticide used in crop pest control. It is readily biodegradable and does not persist in the environment for long periods. Parathion is highly toxic to aquatic organisms, but, if taken up by the organisms, persists only for a short

time. The EPA criteria published in 1976 (Red Book criteria) established 0.04 µg/l as a maximum concentration of parathion to protect aquatic life. No criterion for public health protection is proposed or in effect. The results of this study indicated that parathion was reported only in two reservoirs located in the South Atlantic Division and the levels were higher than the 1976 Red Book criterion for freshwater aquatic life protection (Tables A5, A11).

199. Malathion. Malathion is an organophosphorus insecticide with properties similar to parathion but comparatively less toxic to aquatic organisms. In the 1976 EPA Red Book criteria, a maximum of 0.1 µg/l of malathion was established as a safe concentration for the protection of freshwater aquatic life. The results of the CE reservoirs contaminant survey showed that only two reservoirs located in the South Atlantic Division reported malathion data and the concentrations were higher than the 1976 criterion (Tables A5, A11).

200. Chlorophenoxy herbicides (2,4-D; 2,4,5-TP). The compounds 2,4-D, and 2,4,5-TP (silvex) are two widely used herbicides in aquatic weed control programs. These herbicides are easily degradable through photo, chemical, and biological decompositions and are not bioconcentrated to any significant degree. These chlorophenoxy herbicides are toxic to humans and animals, but concentrations that may be harmful if ingested rarely build up in the potable water supplies (Frank, 1972). The water quality criteria published by the EPA in 1976 had established 100 µg/l for 2,4-D and 10 µg/l for 2,4,5-TP as a maximum safe concentration for human health protection (Table 1). Similar limits were fixed in the National Drinking Water Standards (Table 1). These two herbicides were not included in the criteria proposed for 65 toxic substances by the EPA in 1979. Nine CE reservoirs reported 2,4-D values and six reported 2,4,5-TP values, and the levels were below the 1976 EPA Red Book criteria and the National Drinking Water Standards (Table A5). These two herbicides were not considered potentially toxic to aquatic organisms at concentrations used for weed control; hence, no criteria were established.

201. Alachlor. Alachlor is a chloracetamide herbicide largely used in the United States for preemergence control of grasses in corn, soybeans, cotton, peanuts, and other legume crops. In addition to its use

in major field crops, alachlor is also used for weed control in fruits and ornamentals. Alachlor is a nonpersistent herbicide and degrades rapidly in the environment. Alachlor toxicity to mammals and aquatic organisms is low (McEwen and Stephenson, 1979). No criteria for alachlor in water and fish have been developed for the protection of human health and aquatic life. Alachlor was reported in two CE reservoirs located in the North Central Division in the contaminants survey (Tables A5, A11).

202. Atrazine. Atrazine is a heterocyclic nitrogen herbicide largely used for weed control in corn and several other crops. Atrazine is slightly toxic to animals and is moderately persistent in the environment. No criteria or state standards were reported for the protection of human health and aquatic life from the toxic effects of atrazine. Five CE reservoirs reported atrazine concentrations in reservoir waters in the contaminants survey conducted (Table A5).

203. Bladex. Bladex, also cited in literature as cynazine, is a triazine herbicide and is moderately persistent in the environment, lasting in soils up to 12 months. No criteria or state standards were reported for this herbicide. Two CE reservoirs located in the North Central Division reported bladex concentrations in reservoir waters in the survey conducted (Tables A5, A11).

Comparison of Fish and Shellfish Data with FDA Allowable Limits

204. The data for various chemical contaminants reported in fish and shellfish in various CE reservoirs are presented in Table A12. Eleven CE reservoirs reported one or more contaminants present in fish samples. The allowable limits of those contaminants in food set by the FDA for the protection of human health, where applicable, are given in Table 7. A breakdown of the numbers of reservoirs reporting each contaminant is recorded in Table A6.

205. DDT and its metabolites were reported in fish samples in ten reservoirs, heptachlor/heptachlor epoxide in seven reservoirs, aldrin/dieldrin in eight reservoirs, PCB's in six reservoirs, BHC isomers in five reservoirs, and chlordane, endrin, and mirex in two reservoirs each

(Table A6). Methoxychlor, toxaphene, diazinon, 2,4-D, and HCB were reported in fish samples in one reservoir each. A comparison of the contaminant concentrations in fish with the FDA limits indicated that one reservoir each for aldrin/dieldrin and two reservoirs for PCB's had exceeded the FDA limits, respectively (Table A6). No FDA limits were established for BHC isomers, methoxychlor, diazinon, 2,4-D, and HCB found in reservoir fish samples and therefore no comparisons can be made.

206. Of the inorganic contaminants, mercury concentrations were reported in three reservoir fish samples and cadmium in one reservoir only (Table A6). Fish mercury concentrations in one reservoir exceeded the FDA limit of 1 mg/l (Table A6). No FDA limits were established for cadmium in fish and therefore no comparison can be made. No other inorganic contaminants were reported in reservoirs fish samples in the survey.

Regional Contaminant Problems

207. The data presented in Tables A9 through A14 and discussed earlier will be reevaluated in this section to determine any trends in the regional distribution of chemical contaminants identified in the CE reservoirs. In addition to the CE reservoir contaminant data, information on acid mine drainage, salinity, the contaminant surveys conducted in various parts of the country, accidental spills of toxic chemicals, and discharges of contaminants from manufacturing plants should also be considered in evaluating potential regional contaminant problems. Significant data available on these problems are discussed in the following paragraphs.

CE reservoirs regional contaminant distribution

208. The CE is operating over 500 Civil Works reservoir projects (Office, Chief of Engineers, U. S. Army, 1975) either under planning, construction, or operation, but information on the toxic contaminant problems was available for only 109 of these reservoirs. Seventy-one of these reservoirs had one or more contaminants in the water or fish samples that exceeded the EPA or the FDA criteria. The data presented in

Table A9 indicated that the Ohio River Division had the maximum number of reservoirs reporting contaminants (19) followed by the Missouri River Division (14), the South Pacific Division (11), the New England Division (9), and the Southwestern Division (7). Only four reservoirs in the South Atlantic, three in the North Central, and two reservoirs each in the North Atlantic and North Pacific Divisions reported contaminant data. No information on the contaminant problems in reservoirs located in the Lower Mississippi Valley Division was available.

209. It is apparent that the reporting of reservoir contaminant data was not uniform in all the CE Divisions. This indicates that the contaminant monitoring activities were very Division-specific and may depend on the Division priorities or the availability of water quality personnel and the contaminant monitoring and analytical facilities in the Division or District offices. It needs to be pointed out that if a CE Division had contaminant data available for the majority of their reservoirs, it does not necessarily imply that the CE Division had more contaminant problems than the CE Divisions reporting data for only a few of the reservoirs. Due to lack of reservoir contaminant data availability from all CE Divisions, it is not feasible to extrapolate with much confidence the regional patterns of reservoir contamination. However, based on the available data, some broad generalizations about the regional contaminant patterns are made in the following paragraphs.

210. Inorganic contaminants. Mercury, arsenic, iron, and manganese were reported in most of the reservoir waters in concentrations potentially toxic to human health all across the country. In general, reservoirs located in the New England, Ohio River, and Missouri River Divisions had other toxic metal concentrations exceeding the EPA criteria for human health or aquatic life protection. The South Pacific and North Pacific Divisions appeared to have fewer reservoirs with toxic metals contamination problems. Toxic metals data for reservoir waters in the North Atlantic, South Atlantic, North Central, and Southwestern Divisions were reported for only a few reservoirs; hence, no generalizations can be made.

211. Concentrations of toxic metals in CE reservoir fish samples were available for mercury in only three reservoirs and for cadmium in

one reservoir. No data were available for other metals and therefore no geographic trends can be speculated.

212. Organic contaminants. Only 20 reservoirs located in five CE Divisions reported data on one or more organic contaminants in reservoir waters. Eleven reservoirs reported data on PCB's while other contaminants were reported in less than ten reservoirs each. These data are too few to determine any significant regional patterns. It may be pointed out that no data on the persistent chlorinated hydrocarbon pesticides were reported in the South Pacific Division except for a single DDT analysis in one reservoir. The phenoxy herbicides (2,4-D, 2,4,5-TP) were reported only in the Missouri River and South Pacific Division reservoirs. The PCB's were more widely distributed than other organic contaminants. The occurrence of pesticides may follow certain regional use patterns due to agricultural or forestry use but these cannot be determined from the available data.

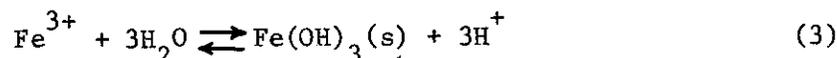
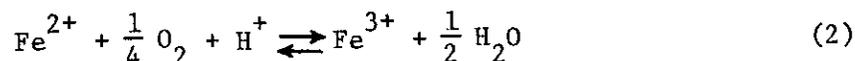
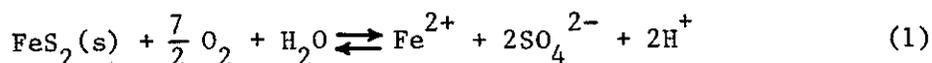
213. The presence of one or more organic contaminants in reservoir fish samples was reported in 11 CE reservoirs. The DDT metabolites were reported in ten CE reservoirs while other contaminants were reported in one to eight reservoirs each. No geographical distribution can be predicted from the scanty data available.

Acid mine drainage
and precipitation

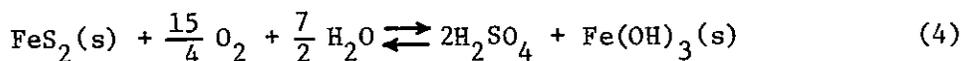
214. In recent years, much concern has arisen over the harmful effects of metal and coal mining in the southeast, east, and midwest on the environment. The deterioration of surface water quality as a result of low pH and a high concentration of toxic metals that occur in drainage originating from mining and milling operations adversely affects the propagation of aquatic life; curtails recreational uses of water such as boating, swimming, and fishing; and contaminates domestic and industrial water supplies. Over 5000 miles (8000 km) of streams and many reservoirs on these streams in ten states are reported to be affected by acid mine drainage with Pennsylvania, the Virginias, and Colorado facing major problems (ReVelle and ReVelle, 1974; Wentz, 1974a, b; Schrader and Furbish, 1978).

215. Coal mine drainage. Coal deposits contain a number of minerals including pyrite, marcasite, clays, quartz, and carbonates. Acid

production is associated with the oxidation of pyrite and marcasite, a ferrous sulfide compound of the formula FeS_2 , in the presence of water and occurs during mining, milling, and disposal operations. The oxidation mechanism of pyrite associated with coal mining is well documented in the literature (Stumm and Morgan, 1970; Ahmad, 1974; Wentz, 1974b) and can be summarized in the following reactions:



216. The sum of Reactions 1 through 3 gives the overall stoichiometric relationship:

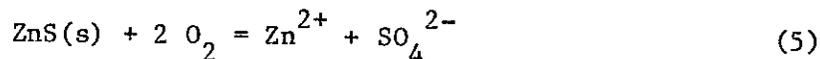


217. Reaction 1 represents the oxidation of pyrite, releasing sulfate, acidity (H^+), and ferrous iron (Fe^{2+}) to water. The dissolved iron is subsequently oxidized to ferric iron (Fe^{3+}) and is hydrolyzed to form insoluble ferric hydroxide, depositing pale yellow to orange coatings in the streams (Reactions 2 and 3, respectively). Reactions 2 and 3 do not necessarily occur at the same location as Reaction 1 and thus have little or no bearing on pyrite oxidation. Reaction 1, the pyrite oxidation, a critical reaction in the model, is a function of the oxygen concentration, temperature, degree of surface saturation by water, and pH of the solution in contact with the pyrite. Reaction 4, which represents the overall process, indicates that a net of 4 moles of H^+ are liberated for each mole of pyrite (FeS_2) oxidized, making this reaction one of the most acidic weathering reactions known (Wentz, 1974b).

218. The acid waters produced during the mining operation dissolve toxic metals present in the mining deposits and add to downstream pollution loadings when discharged. Acid mine discharge in the Appalachian region of the eastern United States has been a major source of surface water pollution and a cause of great concern. Coal-mine drainage in the

Colorado mining areas has not been a major problem because of the low sulfur content of Colorado's coal (Wentz, 1974a).

219. The metal ores of copper, zinc, lead, silver, and gold associated with metal mine drainage are usually present as metal sulfides and do not contribute to the formation of acid waters. For example, the oxidation of sphalerite (ZnS) by molecular oxygen in an aqueous solution (Reaction 5) does not contribute to the liberation of free acidity during the weathering process, as does the weathering of pyrite (Reaction 4).



Also, the metal ions Cu^{2+} , Pb^{2+} , Zn^{2+} , and Ag^+ do not hydrolyze to the extent Fe^{3+} hydrolyzes. However, acid production does result from the oxidation of pyrite associated with the metal ores and enhances the hydrolysis of associated metals. As a consequence, large quantities of metals can be brought into solution.

220. High concentrations of cadmium, cobalt, copper, iron, manganese, zinc, lead, and nickel have been reported in the metal-mining areas of Colorado compared to the control sites (Wentz, 1974b). Schrader and Furbish (1978) reported excessive levels of iron, manganese, cadmium, and lead in a tailings pond and downstream originating from a sulfide mineral mining site in Georgia; the concentrations exceeded safety standards for human consumption.

221. Considerable research has been conducted to determine effective ways to reduce the acid mine discharges into streams, neutralize active acidity, and rehabilitate mined areas to minimize continued discharges from the abandoned mining sites. Management alternatives to minimize the acid mine drainage and related toxic metal loadings downstream are discussed elsewhere.

222. In addition to the acid mine drainage, acid precipitation resulting from an increased use of coal and other sulfur-containing fuels in the eastern and northeastern United States has caused local and regional water pollution problems (American Chemical Society, 1978). Dissolution of sulfur and nitrogen compounds during rain and snowfall

produces acids that lower the pH of receiving streams, lakes, and reservoirs, and threatens aquatic life.

223. New England Division and Baltimore District. The problems of acid precipitation and acid mine discharge have been reported for a number of reservoirs. Buelow^{*} indicated that acid rainfall prevalent in the New England Division is probably aggravating low pH conditions in 20 of 31 reservoirs and influencing the solubility of metals in the reservoir waters. Juhle^{**} indicated that five reservoirs located in the Baltimore District had potential for acid mine drainage problems.

224. Pittsburgh District. Acid mine discharge from the bituminous coal-mining activities in southwestern Pennsylvania and northern West Virginia has been a serious water quality problem in CE reservoirs located in the Pittsburgh District. Cingle[†] indicated that CE reservoirs in the Allegheny and Monongahela river basins frequently experienced acid mine discharge problems. The Clarion, Kriskiminetas, and Tygart rivers receive most of the acid mine discharges and cause water quality problems downstream from the discharging streams. The U. S. Army Engineer District, Pittsburgh (1976), reported that highly acidic conditions generally existed in the Tygart Reservoir during low flow periods of the winter and early spring. Interflow of acid slugs through the reservoir also occurred during the months of July and August, due to thermal stratification, and could be detected 10 miles (16 km) downstream of the inflow approximately 35 days after first entering the reservoir. Iron and manganese were found in high concentrations in the reservoirs and downstream waters.

225. Koryak et al. (1979) observed a slug of acid mine discharge entering the Tygart Reservoir in late February and early March of 1978. The pH of the lake remained below 5.5 for over a month, and a pH of 3.9 was recorded in the reservoir outflow. A significant fish kill also occurred at the reservoir.

* D. P. Buelow, U. S. Army Engineer Division, New England, personal communication, 1980.

** P. Juhle, U. S. Army Engineer District, Baltimore, personal communication, 1980.

† G. Cingle, U. S. Army Engineer District, Pittsburgh, personal communication, 1980.

226. Acid mine discharges into East Branch Clarion River Reservoir have also caused occasional water quality problems (U. S. Army Engineer District, Pittsburgh, 1975).

227. Montana and Colorado. Acid mine discharges containing high concentrations of heavy metals are reported to cause water quality problems in Montana and Colorado mining areas (Johnston et al., 1975; Boyles et al., 1974; Wentz, 1974a, b). Field surveys of 995 stream sites in Colorado conducted during 1971-1972 indicated that cadmium concentrations in surface waters exceeded drinking water standards in more than 12 percent of the samples, while arsenic and lead exceeded their limits in 1-3 percent of the samples (Wentz, 1974a). Copper and zinc were reported to present the greatest danger of toxicity to the resident aquatic life. Wentz concluded from his studies (Wentz, 1974a, b) that acid production was a bigger problem in coal-mining areas than metal-mining areas.

228. Missouri. Metal-mine discharges from the lead and zinc mining areas in the new lead belt of Missouri generally result in the precipitation of heavy metals in the stream waters due to high carbonate contents and slightly basic pH; levels of dissolved metals are generally low (Hardie et al., 1974; Wixson, 1978). However, finely divided particulate matter bearing toxic heavy metals released from mining and milling operations is transported as suspended matter for considerable distances downstream. Transport of heavy metals from the mining areas to deep sections of Clearwater Lake has been documented in the literature (Hardie et al., 1974). Bioaccumulation of heavy metals at high concentrations by the aquatic organisms in the receiving streams has also been reported (Wixson, 1978).

Salinity

229. High salinity levels in reservoirs and rivers are generally caused by naturally saline surface or groundwater discharges or salt-laden agricultural, industrial, or municipal wastewater discharges. Excessive buildup of soluble salts in reservoirs with long retention time can occur in Texas, New Mexico, Utah, Arizona, and California where

high summer temperatures accelerate surface evaporation. Excessive concentrations of chlorides, sulfates, and total salts in waters is injurious to aquatic life and agricultural crops and makes the water unfit for drinking (McKee and Wolf, 1963).

230. The gradual buildup of chloride concentration in Hordes Creek Lake, Texas, was attributed to the discharge of brine from the oil wells and disposal wells in the Glen Cove area (U. S. Army Engineer District, Fort Worth, 1978b). The high chloride concentrations, although lasting for a short period, exceeded the limits recommended by the Texas Department of Water Resources, and caused detrimental effects on the fish and invertebrates of the lake.

231. Alamo Reservoir and Painted Rock Reservoir, operated by the Los Angeles District, indicated buildup of high salinity in the reservoir waters in warm summer months (U. S. Army Engineer District, Los Angeles, 1979). An increase in salinity in the Alamo Reservoir was a result of low water levels in the reservoirs and high evaporation rates. Although no state water quality standards were violated in the reservoir or its release waters, releases were restricted to low discharges to minimize downstream impacts.

232. The Painted Rock Reservoir receives inflow from eight major dams upstream on the Gila River. Long-term impoundments coupled with high evaporation rates increase salinity concentrations in the upstream dams. Their inflow in turn causes salinity changes in the Painted Rock Reservoir. Water releases from the Painted Rock and other reservoirs in the Los Angeles District are regulated to minimize downstream impacts (U. S. Army Engineer District, Los Angeles, 1979).

Toxic contaminants in the waters
of the U. S. and aquatic organisms

233. The results of contaminant surveys of the CE reservoirs presented earlier in this section indicated that while inorganic contaminants were reported in many CE reservoir waters, organic contaminants were reported in very few reservoirs (Table A3 vs. Table A5). These results also indicated that only 11 CE reservoirs reported data on one or more inorganic or organic contaminants in the reservoir fish samples (Table A12). The comparison of these data with the contaminant surveys

conducted for the Great Lakes and several major U. S. watersheds and river streams (described in the following paragraphs) may suggest an underestimation of the magnitude of organic contaminant problems in the CE reservoirs.

234. Great Lakes. A survey of Lake Ontario for DDT, aldrin/dieldrin, and PCB's conducted during the International Field Year of the Great Lakes indicated the presence of these toxic contaminants in fish collected from all sampling stations (Waller and Lee, 1979). The concentration of PCB's in whole fish samples ranged from 0.1 to 9.2 $\mu\text{g/g}$ and was equal to or greater than the International Joint Commission (IJC) limit of 0.1 $\mu\text{g/g}$ suggested for whole fish. DDT concentrations in 76 percent of the fish samples exceeded the IJC limits of 1 $\mu\text{g/g}$ for whole fish in Lake Ontario suggested for the protection of fish-consuming birds (Waller and Lee, 1979). Concentrations of PCB's, DDT, dieldrin, cadmium, and copper in lake waters far exceeded the IJC and the EPA 1976 Red Book water quality criteria.

235. Other surveys indicated concentrations of arsenic (Lake Michigan), mercury (Lake Erie), and PCB's (all Great Lakes) in the Great Lakes that exceeded both EPA and IJC water quality criteria (Delfino, 1979). Mercury concentrations in fish in Lake Erie and concentrations of PCB's in fish in Lakes Michigan, Superior, Huron, Erie, and Ontario exceeded the FDA limits for human consumption. Delfino (1979) concluded from studies on the Great Lakes that toxic substances were transported to the Great Lakes Basin from sources well removed from the basin through atmospheric processes and other nonpoint sources, making control very difficult.

236. Major watersheds. Veith et al. (1979) reported analysis of 58 composite fish samples collected in 1976 from major U. S. watersheds located in EPA Regions I, IV, V, and VI and in California and New Mexico for toxic organics. PCB's were found in 93 percent of the fish samples, and the concentrations ranged from less than 0.3 ppm to 130 ppm in the composite samples. About 91 percent of the composite fish samples contained DDT, while 59 percent of these samples had DDT concentrations less than 1 ppm. The study indicated that residues of DDT had decreased significantly since its use was banned in the United States in 1972.

Hexachlorobenzene (HCB) was confirmed in 19 percent of the watershed samples, and chlordane and nonachlor isomers were identified in 36 percent of the samples. In addition to these persistent chlorinated hydrocarbons, the organic contaminants identified (but not quantified) included chlorinated benzenes, styrenes, anisoles, phenols, anilines, propanes, and butadienes, as well as mixtures of petroleum hydrocarbons.

237. Results of extensive annual monitoring of agricultural pesticides conducted from 1968 to 1973 and published recently (Carey, 1979) indicated that urban soils generally had higher pesticide residues than did agricultural soils in the same region. Annual monitoring of aldrin, dieldrin, toxaphene, and DDT indicated the levels decreased with time as the use of these pesticides decreased. In addition to the organochlorine pesticides, high concentrations of mercury, lead, and cadmium were also observed in urban soils.

238. The National Academy of Sciences (NAS, 1979) indicated in a recent report that the Appalachian Mountains - Atlantic Coast regions - and the St. Lawrence drainage basin consistently had the highest levels of PCB's in various components of the aquatic system, while the Pacific Coast to the Continental Divide and the Gulf of Mexico drainage basin had the lowest concentrations of PCB's. The study concluded that freshwater sediments were the most important continental sink for PCB's, and recommended monitoring programs and studies of PCB's cycling from sediments through human food chains.

Accidental spills

239. Accidental spills of toxic contaminants during transportation or from storage facilities may contaminate nearby streams or reservoirs through storm sewers or surface runoff if a rainstorm followed the spill. The potential contamination of Berlin Reservoir, Ohio, in 1974, is a good example (U. S. Army Engineer District, Pittsburgh, 1974).

240. On July 14, 1974, a fire and subsequent explosion destroyed the Universal Cooperatives Agricultural Chemical Plant located in Alliance, Ohio. The Universal Cooperatives Plant was reported to store over 157,000 kg of 26 toxic chemicals that included wood preservatives, herbicides, and insecticides. The chemicals included 12 persistent chlorinated

hydrocarbons, 7 organophosphorus compounds, 6 other organic compounds, and copper sulfate.

241. An official consensus was that most of the chemicals were destroyed in the fire and that very little contamination would reach the Berlin Reservoir by way of the Alliance storm sewers and the Mahoning River. Analysis by the Ohio EPA and the U. S. EPA for suspected chemicals in the water and fish samples taken from various locations near the site of the spill and in the upper 6 miles (10 km) of Berlin Reservoir within 24 hours of the spill confirmed that the Berlin lake was not contaminated by the toxic chemicals. The lake was reported to meet the established water quality standards for recreation, public water supply, and aquatic life (U. S. Army Engineer District, Pittsburgh, 1974). The reservoir was declared suitable for fishing and recreation. The Berlin Reservoir experience indicates the value of immediate and follow-up monitoring efforts to establish the extent of the contamination if such an accident involving toxic chemicals occurs in the drainage basin of a reservoir.

Discharge of toxic chemicals
from manufacturing plants

242. Routine losses of toxic substances from chemical plants through washing, volatilization, and other manufacturing processes are reported to add significant quantities of chemicals into the environment. Contamination of the James River by kepone, and of Indian Creek, the Tennessee River, and Wheeler Reservoir, Alabama, by DDT are two examples of such industrial contamination.

243. Kepone. Allied Chemicals, Hopewell, Va., manufactured kepone from 1966 until 1975 when the plant was closed due to discovery of neurological disorders in the plant workers. Concentrations of kepone as high as 2.1 $\mu\text{g/g}$ in finfish and 0.48 $\mu\text{g/g}$ in oysters from the James River were found in the 1975 monitoring (U. S. EPA, 1975). Follow-up studies of the residues in soils surrounding the plant indicated kepone concentrations of 2 to 6 $\mu\text{g/g}$ present (NAS, 1978; Huggett and Bender, 1980).

244. Extensive data on kepone levels in water, sediments, and aquatic organisms in the James River and other affected areas have been reported in the recent years (NAS, 1978; U. S. EPA, 1978; Huggett and Bender, 1980). These studies indicate that the highest concentrations

of kepone were reported 15-50 km downstream of the chemical plant, and the transport was primarily related to movement of suspended solids in the river. Huggett and Bender (1980) concluded from the studies reported on kepone behavior in the James River that it may take from one to ten decades for the natural cleansing process to remove this persistent pesticide from the system.

245. DDT. Contamination of Huntsville Spring Branch, Indian Creek and the adjacent lands, and Wheeler Reservoir on the Tennessee River by DDT residues (DDT, DDD, DDE) discharged from a DDT manufacturing plant that was operated by the Calabama Chemical Company from 1947 to 1954 and by the Olin Mathieson Chemical Company from 1954 to 1970 has been reported in a recent study (Water and Air Research, Inc., 1980). The investigation was initiated by the CE and was conducted in cooperation with the Tennessee Valley Authority in the summer of 1979. The possible adverse effects of the consumption of DDT-contaminated fish by the human population living in the area prompted the study. The study included extensive field and laboratory work to collect data on fish, sediment, water, microinvertebrates, aquatic plants, mammals, birds, and reptiles in the area.

246. The report indicated that an estimated 760,000 kg of DDT residues was present in the sediments of the Huntsville Spring Branch-Indian Creek-Wheeler Reservoir System. Fish samples taken in the study area showed DDT residues above the FDA limit of 5 ppm. Based on the results of this study, the authors concluded that 68 to 137 million dollars would be required to remove and decontaminate DDT residues from the affected areas, with a 95 percent removal efficiency. The suggested alternatives included dredging and disposal, by-pass channels, and isolation of the material in situ.

PART VII: MANAGEMENT CONSIDERATIONS FOR RESERVOIR CONTAMINANT PROBLEMS

Water Quality versus Project Purposes

247. Reservoirs are authorized, planned, constructed, and operated to achieve specific project purposes. The most common purposes include flood control, municipal and industrial water supply, fish and wildlife conservation and enhancement, recreation, irrigation, flow augmentation during low flow periods, navigation, and hydroelectric power generation. The intended reservoir function may be singular, as for flood control or municipal water supply. Single-purpose projects are often small or perhaps are not designed to have a permanent pool, such as temporary impoundment of a river or stream during high flow periods to control the release of flood waters downstream. More often, a reservoir is authorized to serve a number of specific purposes. Such projects are commonly called multi-purpose reservoirs.

248. Federal and state criteria require that a high water quality must be maintained for both pool and release waters for many of the specific project purposes. Water quality management is often complicated in multi-purpose projects because management to achieve water quality objectives for one designated function may require compromise of some other water quality parameter for other project purposes (Strain, 1980). For example, release of hypolimnetic waters to maintain suitable temperatures for a downstream coldwater fishery during summer months may compromise other desirable or mandated water quality parameters such as dissolved oxygen or iron levels. In many projects, chemical contaminant levels may have to be controlled in the future as well as the more common reservoir water quality parameters. Because of the few water quality management options available for reservoirs, maintaining pool and release waters that meet water quality criteria is going to be increasingly difficult in the future as criteria become more stringent and project purposes more complex.

249. Earlier, priorities in managing reservoirs focused on controlling pool levels within prescribed limits in order to maintain a given reserve storage capacity, often for flood control or water supply. Maintaining appropriate pool elevations for the various designated functions of a reservoir is still a primary goal in managing reservoirs.

250. In recent decades, maintaining temperature and dissolved oxygen levels of release waters within satisfactory ranges for downstream purposes has also received a high priority in managing reservoirs. The high priorities given to maintaining seasonal pool elevations (guide curve) appropriate for project purposes and the temperature and dissolved oxygen conditions of release waters will not change. However, reservoir management to maintain or improve the quality of pool and release waters in terms of potentially toxic contaminants may also be assigned a high priority in the future in reservoirs where chemical contaminant problems are identified. Reservoir management to minimize adverse environmental impacts associated with the presence of contaminants is going to add another level of complexity to the operation of reservoirs to meet authorized purposes. Thus, more and more operational restrictions must be addressed with the relatively few reservoir management practices available. These interactions will be more thoroughly discussed elsewhere.

General Considerations

Reservoir specificity

251. From the conception of this project, it was known that there was insufficient information available on reservoir contaminants with which to prepare a comprehensive, scientifically based guidelines manual providing optimum reservoir management methods for controlling levels of the various contaminants that would be applicable to most reservoirs. Initially, it was hoped that sufficient information would be available on the chemistry of contaminants in reservoirs for qualitative prediction of the effect of a particular management practice on the levels of a contaminant in pool and release waters and possibly in fish populations. Even these modest initial objectives were not feasible because of the

very limited information available on the behavior of chemical contaminants in reservoirs and the fact that every reservoir is unique, such that an effective procedure for dealing with a chemical contaminant in one reservoir will very likely not be effective for another. Thus, reservoir specificity is an important and essential consideration in any plan to control the levels and impacts of chemical contaminants. Any plan for managing a reservoir to minimize potential adverse impacts associated with contaminants present should include input from those persons most knowledgeable about the reservoir.

252. Every reservoir project is unique (Eiker, 1977). Therefore, the assessment of water quality problems associated with reservoir contaminants and the implementation of reservoir management practices to control contaminants must be done on a reservoir-specific basis. Management plans to mitigate reservoir contaminant problems must be reservoir-specific because of the large number of physical, chemical, biological, climatological, and hydrological properties affecting the levels, transport, and fate of contaminants; the wide range of these properties encountered in different reservoirs; the differences in the use of pool and release waters of the different projects; and the limited operational reservoir management practices available to control contaminants.

253. For example, experience with two existing reservoirs in California resulted in the incorrect decision that multiple-level power outlets would not be necessary to maintain suitable temperatures for fish spawning in the fall in the American River below the planned Folsom Dam. This experience with the unique properties of reservoirs concurs with the judgment of those planning and evaluating the effectiveness of river water quality monitoring programs for which it is concluded that each basin is different and specific monitoring programs must be developed accordingly (Goslin, 1977).

254. Factors contributing to reservoir specificity in considering contaminant management include: the nature of the contaminant problem; basin characteristics; designated function(s) of pool and release waters; climate; hydrological and chemical characteristics of inflowing water; the interaction of physical, chemical, and biological characteristics of the reservoir with the preceding factors; reservoir morphology/hydrology

affecting contaminant movement and stratification; and the available operational management practices that will affect reservoir contaminants.

255. Because of the limited data available specifically pertaining to the chemistry of contaminants in reservoirs and because of the uniqueness of individual reservoirs when considering their physical, chemical, and biological properties, and their designated purposes, it is risky to generalize on how various factors will affect the mobility and fate of reservoir contaminants. For example, Larson reported on the mercury content of fish from two Oregon lakes that were within a few hundred yards of an old mercury mine.* One lake was eutrophic and one was oligotrophic. A higher mercury concentration in fish from the eutrophic lake was attributed to differences between the lakes related to vertical physicochemical gradients. It was believed that the eutrophic lake developed thermal, pH, and dissolved oxygen conditions that contributed to higher methylmercury uptake by the fish. A key point Larson made in this communication was that the findings were opposite those of Jernelov in a 1975 paper on the effects of eutrophication on mercury availability. Thus, specific reservoir conditions are important in regulating the environmental chemistry of some contaminants and predictions of the environmental chemistry of a contaminant based on one reservoir may not be valid when applied to another.

Watershed pollution control

256. Chemical contamination of reservoirs is a result of watershed contamination. Reservoir contaminants are derived from either point-source discharge into the reservoir or inflowing streams, or from non-point sources (land runoff). Problems with chemical contaminants in streams and reservoirs are often indicative of the need for better pollution management in the watershed (Meier, 1975). For example, the PCB problem in portions of Hartwell Reservoir, located on the Savannah River between South Carolina and Georgia, is a result of point-source discharge from an electrical component manufacturer located near the upper reaches

* D. W. Larson, U. S. Army Engineer District, Portland, personal communication, 1980.

of the reservoir in South Carolina.* Measurable levels of several pesticides in some Iowa reservoirs reflect the intensive agricultural activity of the watersheds (Baumann et al., 1979). It has been estimated that 72 to 89 percent of the heavy metal load of the Chattahoochee River in the vicinity of Atlanta, Georgia (downstream from Lake Lanier), is derived from nonpoint sources (Cherry et al., 1977). These are just three specific examples from among a large number of documented cases that could be cited to demonstrate the relationship between reservoir contamination and pollution sources in the watershed. Thus, the point cannot be overstated that reservoir contaminant problems are inseparable from contaminant problems or pollution in watersheds. Therefore, since reservoir water quality is a function of inflow water quality, watershed pollution management can be an important component in managing reservoir contaminant problems.

257. The feasibility of implementing watershed pollution control practices as a component in addressing reservoir contaminant problems will, of course, depend on the specific circumstances of the reservoir and watershed problems. For example, if unauthorized point-source discharge of a chemical pollutant is adversely affecting the quality of a stream feeding a reservoir, there are probably appropriate agencies and statutes available to control the source. The point-source PCB problem in Hartwell Reservoir (South Carolina-Georgia) is a case in point. On the other hand, the movement of excess herbicide residues into Lake Rathburn, Iowa, from nonpoint sources (Kennedy, 1978) may be a more difficult watershed problem to manage. Certainly, practicing the best available soil and water conservation measures will be helpful, but control of the aggregate effect of many smaller actions (i.e., herbicide application by individual farmers) on reservoir water quality may be difficult to accomplish.

Contaminants from natural sources

258. There is a need for comprehensive evaluation of the environmental conditions at each project instead of pursuing water quality

* J. Inabinet, South Carolina Department of Health and Environment Control, personal communication, 1980.

standards for standard's sake (Strain, 1980). Just one aspect of this includes the question of how to consider apparent excessive concentrations of potentially toxic elemental constituents (i.e., heavy metals) that are derived from natural sources. All across the country, there are reservoirs and rivers in which elemental constituents commonly associated with pollution are present at levels exceeding state and Federal water quality criteria, but which are derived from natural sources. For example, arsenic levels are elevated in certain reservoirs in the northwest from naturally high concentrations of the element that can be found in the soils and sediments of that region. Reservoirs with levels of dissolved mercury and mercury in fish tissue that exceed many criteria are found in most sections of the country. In many of these reservoirs, the mercury is apparently derived from natural sources. Similar examples of other potentially toxic elemental substances are found in the literature. Though human health considerations should always receive highest priority, there seems to be some justification for not enforcing compliance with criteria simply for water quality criteria's sake in many of these cases.

Contaminant monitoring

259. Monitoring for the presence of toxic materials in reservoirs and reservoir releases is necessary to identify problems and demonstrate compliance with applicable Federal and state water quality criteria. Monitoring is also a necessary component in managing reservoirs to minimize adverse environmental effects from contaminants. An adequate contaminant monitoring or survey program is an essential first step to identifying reservoir contaminant problems and establishing the nature and magnitude of the problem. If the monitoring or survey indicates the need for ameliorative management practices, then continued monitoring is useful for measuring the benefits derived from the management action.

260. There are several problems with existing CE reservoir monitoring programs that are evident from reading Division water quality reports and various published papers of CE reservoir personnel. These problems include:

- a. Inadequate monitoring for chemical contaminants.

- b. Lack of adequate monitoring capabilities to measure most contaminants.
- c. Lack of quality control for contaminant analyses.
- d. Lack of guidelines for planning good reservoir monitoring programs.
- e. Lack of quick-response capability to monitor instances of chemical spills.

261. Some of the monitoring concepts discussed in the following paragraphs were developed from a series of articles published as the proceedings of a water quality conference for obtaining good river water quality data (Greeson, 1977). They were summarized here because it is believed many of these same monitoring considerations should be applied to reservoirs as well.

262. Monitoring programs. Reservoir water quality monitoring programs generally include parameters such as temperature, turbidity, dissolved oxygen, nutrient levels, and secchi depth. For most reservoirs, toxic and potentially toxic inorganic and synthetic organic materials are not included in either monitoring or periodic surveys of water quality. Thus, all too often there is either inadequate or no characterization of contaminants in reservoirs. For example, the Walla Walla District acknowledges ". . . the present deficiency of information with regard to toxic substances . . ." (U. S. Army Engineer Division, North Pacific, 1980).

263. At present, there is a wide range in the thoroughness of contaminant monitoring between CE Divisions, between Districts within a Division, and even between reservoirs within a District. A few of the recognized reservoir contaminant problems with synthetic organics have been identified almost by accident. Many other contaminant problems have been confirmed following lengthy delays in implementing contaminant testing after a problem is suspected.

264. Because of a lack of uniformity in contaminant monitoring efforts, any evaluation of the available CE reservoir contaminant data to identify Divisions, Districts, and reservoirs with potential problems must be interpreted very carefully. Reservoir managers, Districts, and

Divisions that have done a good job of contaminant monitoring may appear to have more potential problems than CE units that have not adequately surveyed or monitored for contaminants.

265. Monitoring capabilities. The availability of trained personnel and satisfactory laboratory facilities to adequately monitor contaminants in most CE reservoirs of the U. S. may be lacking. Water quality criteria for most metallic and synthetic organic contaminants require measurement techniques with sensitivities in the range of parts per billion. Compared to commonly measured water quality parameters such as temperature, dissolved oxygen, conductivity, turbidity, and nutrient content, the sampling, sample processing, and analyses of water samples for most substances considered as contaminants at the parts per billion level require more highly trained laboratory and field personnel, more difficult and time-consuming laboratory procedures for sample processing, and much more sophisticated and expensive instrumentation.

266. Many CE Districts and apparently some Divisions do not have this capability in-house. Some reservoir managers, particularly in the Southwestern Division, point out that one of their monitoring problems is the great distances between projects and available laboratory facilities (U. S. Army Engineer Division, Southwestern, 1980). Some project managers and Districts are contracting with either private laboratories or USGS laboratories for analyses of toxic metal and organic contaminants. Also, from reports and publications of CE personnel, concern over quality control of contaminant analyses is evident.

267. Quality control. At present, there is a pressing need for project managers to have ready access to sampling and analytical services capable of doing quality work for contaminants. This analytical capability need not be in-house, as satisfactory contaminant monitoring or survey work on rivers, harbors, and reservoirs of many Districts is being done by USGS and some private labs. As pointed out by CE water quality specialists, however, quality control must be exercised at sample collection, preservation, processing, and analysis stages.

268. Planning guidelines. Reservoir water quality monitoring for contaminants should be done on a reservoir-specific basis. The following statement from Goslin (1977) concerning rivers applies equally well

to reservoirs: "Because each river basin presents a set of physical, chemical, and biological conditions unique to itself, it is highly essential, even mandatory, that each river basin be subjected to intensive overall assessment in order to lay the foundation for scientific and cost-effective solutions to pollution control and water management problems."

269. Each reservoir is also unique in terms of its physical, chemical, and biological conditions, and in terms of the designated functions of pool and release waters. These differences must be considered by individuals knowledgeable about the reservoir in producing the most effective monitoring program. A blanket monitoring scheme applied on a national scale in many cases will not result in the best utilization of monitoring resources (Velz, 1977). For example, intensive contaminant characterization studies specifically designed for a particular reservoir should be conducted in the most pollution-prone areas of the reservoir and during the most critical periods such as during low flow. Present water quality data for reservoirs that are routinely monitored for chemical contaminants (compared to most, which are not) too often involve routine monitoring approaches that do not provide the necessary sensitivity, capability, and confidence levels to separate water quality variations of natural changes from deleterious water quality changes resulting from pollution (Hines and Rickert, 1977).

270. In summarizing a reservoir water quality seminar, Eiker (1977) pointed out the need to consider each reservoir independently: "I think it was evident from the presentations that every project is unique. The study at Libby is different from the study at Stockton, even though they are both reservoir projects. Each investigation requires a different approach to evaluation. It requires looking at the problem, defining objectives properly, and determining on a case-by-case basis the type of sampling, the parameters to be measured, frequency of sampling, and location of sampling stations. These questions can't be answered in training courses. They can only be answered by having knowledgeable people with a dedication to getting the job done."

271. Quick-response capability. Most reservoir contaminant problems are the result of chronic low level releases from point and nonpoint

sources. For this type of chronic contamination, reservoir-specific monitoring programs based on the considerations given above should be adequate to identify contaminant problems, to determine appropriate ameliorative management practices, and to evaluate the effectiveness of the management practices implemented. However, potentially the most acute condition of reservoir contamination could be a situation in which the reservoir was seriously contaminated by a chemical spill. Reservoir managers should be prepared to move rapidly to implement an intensive reservoir water quality survey in response to a chemical spill that may occur in the reservoir or the upstream basin (U. S. Army Engineer Division, Ohio River, 1979).

272. To respond to an acute condition of reservoir contamination would require advanced preparedness. Trained sampling personnel, supplies, and equipment needed for sampling would have to be readily available as well as laboratory facilities that could conduct the necessary sophisticated analyses in a timely fashion. Such an emergency response capability could be developed at the project level, but CE District or Division levels seem to be more appropriate bases for a chemical-spill emergency monitoring capability. This capability would prove very valuable in quickly and accurately assessing the magnitude of an acute contaminant problem and implementing available reservoir operational management procedures to best protect reservoir and release water quality while preserving the reservoir's authorized functions.

273. In July of 1974, a fire and subsequent explosions destroyed an agricultural chemical plant in Alliance, Ohio (U. S. Army Engineer District, Pittsburgh, 1974). It was believed for a time that fire-fighting efforts might have washed a substantial portion of the more than 157,000 kg of wood preservatives, herbicides, and insecticides into the Berlin Reservoir by way of the Mahoning River and city storm sewers. Testing later revealed that most of the unaccounted for chemicals must have been consumed by the fire, as contamination of the reservoir was far less than initially expected. Nevertheless, this event does indicate the type of chemical spills that may occur and the importance of a rapid contaminant testing capability.

Reservoir stratification
and mobility of contaminants

274. Most of the deep CE reservoirs develop a stratified water column during some portion of the year resulting in two or more distinct layers within the water column. Stratification is known to have an important effect on a number of physical and chemical properties of the water column. These properties include temperature, density, dissolved oxygen levels, iron and manganese levels, as well as a number of other interacting parameters. Because of the substantial effect of reservoir stratification on major water quality parameters, it is believed that stratification will also have an important influence on the mobility and fate of reservoir contaminants. However, there are very few data that deal specifically with the chemistry of contaminants in reservoirs. Because of the unique physical, chemical, and biological properties of reservoirs, it is risky to generalize.

275. In recent years, much has been learned about the chemistry and fate of potentially toxic metals and synthetic organics in soils and sediment-water systems. A considerable amount of information is available on the effects of different physicochemical conditions (i.e., pH, salinity, and oxidation-reduction conditions), such as may exist in a stratified water column, on the environmental chemistry of contaminants. Much of the information suggests that one should be cautious in making generalizations about how different physicochemical conditions such as those found in a stratified water column will affect the chemistry of contaminants.

276. Specific information on the chemical, physical, and biological properties of a system are needed before predictions on the fate of a contaminant can be made. For example, a number of research reports have shown that more trace and toxic metals (other than iron and manganese) are released into a water column or made available to plants when the sediment or sediment-water interface is oxidized than when it is reduced (Chen et al., 1976; Gambrell et al., 1977b). However, other studies have found higher levels of the potentially toxic metals released during elutriate tests or to a simulated water column when the sediment-water

systems are anaerobic or reducing. This is because a number of interacting chemical processes play a role in regulating the mobility of metals and the processes dominating may depend on the particular sediment-water system being considered (Gambrell et al., 1976).

New reservoirs

277. It should be recognized that the aquatic chemistry of new reservoirs will often differ from older reservoirs and that changes in many water quality parameters in new reservoirs will occur with time. This is often attributed to the flush of microbial activity acting on a readily available energy source consisting of organic detritus at the soil/sediment-water interface (Larson* ; Fan, 1976). During the early years of a reservoir's life, this may cause more intense reducing conditions that will contribute to excessive levels of constituents such as iron, manganese, hydrogen sulfide, and sometimes dissolved humic materials in the hypolimnion. These excessive levels may decrease somewhat with time when the flush of organic matter decomposition is over.

278. It is interesting to note that some personal communications to the authors of this report by persons familiar with mercury in reservoirs suggested that elevated levels from background sources often persist during the first few years after establishing a new reservoir. The environmental chemistry contributing to this observation is unknown in most cases, but the more intense anaerobic conditions at the sediment-water interface during the first few years may be a contributing factor. Perhaps chemical speciation (redox changes) is affected, or else the kind and amount of soluble humic materials available for complexing the mercury is altered in some way.

Examples of Management Actions

279. Reservoir management to control water quality is not new. However, most reservoir water quality management practices in the past have focused on dissolved oxygen content and temperature. With limited

* D. H. Larson, *ibid.*

exceptions, this is true today. At present, there is very little effort expended to manage the quality of pool and release waters in terms of potentially toxic contaminants. There are several reasons for this. One is that the status of reservoir contamination and the potential environmental impact associated with contaminated reservoirs is just becoming known. Another reason is that not enough is known about the physical, chemical, and biological behavior of contaminants in reservoirs on which to base effective reservoir contaminant-management procedures. Given the greater awareness of the distribution and potential impacts of environmental contaminants in surface waters, it is anticipated that management of contaminants associated with reservoirs will receive a higher priority in the next few years.

280. Specific examples of reservoir management practices are given below that have been or are currently being applied to improve water quality of reservoir pools or releases. The presentation of these examples is not to be construed as suggestions of general reservoir management practices that can be applied to solve reservoir contaminant problems. One point that the authors of this report wish to make clear is that the development and implementation of reservoir management practices to mitigate contaminant problems should be done on a reservoir-specific basis with the heavy involvement of those persons most knowledgeable about the reservoir. Thus, the purpose of presenting these specific examples is to illustrate the variety of techniques being used, and to indicate how consideration of specific characteristics of the system must be incorporated into effective management procedures, i.e., what works in one reservoir may not control the same problems in another.

281. As stated earlier, relatively little reservoir management specifically designed to control contaminants is currently being practiced. Therefore, most of the examples presented in this section will be for managing water quality parameters other than those normally considered as contaminants. However, the type of management practice and the specific conditions under which the practice is feasible will have important implications for contaminant management as well.

Point-source pollution

282. The J. Percy Priest Reservoir in Tennessee is contaminated with sewage, has a sediment bedrock rich in phosphate, and is affected

by urban runoff and point-source discharges from eight major industries upstream and downstream from the reservoir (U. S. Army Engineer District, Nashville, 1978). Operation for power generation in the summer and fall resulted in a decline in downstream fisheries and occasional unexplained fish kills. Diluting the J. Percy Priest outflows with releases of better quality water from the Old Hickory Dam Reservoir improved the downstream water quality.

Acid mine drainage

283. In the mid to northern Appalachian Mountain region, many streams and reservoirs are adversely impacted by acid mine drainage that results from acidic waters, often with elevated levels of trace and potentially toxic metals, draining from the mines, slag heaps, soils, and sediments affected by the acidic waters. Though the acidity and toxic metals are derived from natural sources, the fact that the problems arise as a result of anthropogenic activities (mining) makes this a contamination problem where water quality of pool and release waters may violate applicable criteria. In this part of the nation, rainfall is abundant; streams, rivers, and reservoirs are numerous; and low flow is not normally a problem. Thus, dilution with high quality water from nearby reservoirs or tributaries is often possible and is being practiced now in some cases. In other regions, excess surface waters from nearby reservoirs or downstream tributaries are not available for dilution of poor quality water. While acid mine drainage is a problem in several regions of the United States, the problem is basin-specific. Individual problems and affected subbasins are somewhat localized within regions.

284. There are numerous cases where basin monitoring and stream and reservoir management practices are such that high quality reservoir water can be used to dilute acid streams and/or high quality stream water is used to dilute acid reservoir releases in downstream waters (U. S. Army Engineer District, Nashville, 1978; U. S. Army Engineer District, Pittsburgh, 1976; Flippo, 1971). A good water quality monitoring program is essential for this type of management, since potentially harmful acid-drainage conditions are closely related to meteorological events and rapid changes in water quality can be expected. Again, trade-offs on

reservoir function sometimes occur as some reservoirs used for this type of water quality management are not designed for this purpose and may either temporarily use a portion of flood-control storage capacity in retaining poor quality water or release some of the conservation pool to dilute other poor quality streams. It is less likely that poor water quality streams or reservoirs will be sufficiently close to reservoirs and streams with high water quality for dilution to be an effective contaminant management practice in midwestern and many western regions affected by acid mine drainage because of the lesser rainfall, greater distances between streams and reservoirs, and the usual lack of high volume flows.

285. Foster Joseph Sayers Reservoir in Pennsylvania is an extremely alkaline, nutrient-rich lake. Controlled releases are made to neutralize Beech Creek and the West Branch Susquehanna, both of which are severely polluted by acid mine drainage (U. S. Army Engineer Division, North Atlantic, 1979). This lake management practice has been very successful. Similar examples exist where high quality reservoir water is useful in mitigating thermal and domestic pollution in rivers downstream of a reservoir. This is reported to be one benefit of the Tygart River Lake project in West Virginia on the Monongahela River (U. S. Army Engineer District, Pittsburgh, 1976).

286. Another variation of the dilution effect is to take advantage of stratification that occurs in most deep reservoirs. Stratification causes acid slugs to move through certain reservoirs as distinct acid density currents which travel as a band some distance beneath the reservoir surface. Following a period of high runoff, the acid slug from the stream feeding the reservoir can be detained, and higher quality water released from a different level, diluting the acid drainage from watersheds into streams below the reservoir. The acid slug can then be released from the reservoir after downstream waters return to normal. This prevents acid slugs from an upper reservoir basin being released from the reservoir at a time when other acid slugs are entering the main channel below the reservoir.

287. In the East Branch Clarion River project in Pennsylvania, during summer months an acid density current 10 to 30 feet (3 to 9 meters) below the surface often moves through the reservoir to the outlet without substantial dilution and neutralization (U. S. Army Engineer District, Pittsburgh, 1975). The East Branch Clarion River project has a multi-level withdrawal capability, which "presents an opportunity to reduce effects of acid mine drainage . . ." and increase productivity. However, bottom withdrawal produces discharge water that is too cold for downstream recreation and fisheries.

288. The same type of acid density current occurs at a depth of 25 to 40 feet (8 to 12 meters) in the Tygart River project, West Virginia, where acid interflows, which have travelled from about 10 miles (16 km) upstream of the dam, have been detected. Water quality regulation is difficult for the Tygart River project because of design features (selective withdrawal unavailable) and downstream commitments. The discharge of water with high iron and manganese concentrations could be mitigated if selective withdrawal were available (U. S. Army Engineer District, Pittsburgh, 1976).

289. Waters from a few streams affected by acid mine drainage are being treated by lime neutralization facilities to improve the quality of the water before it impacts reservoirs or other sensitive downstream waters (U. S. Army Engineer District, Pittsburgh, 1975).

Sedimentation and sediment traps

290. Burial of contaminants by sedimentation may be an important factor and an effective process in isolating potentially toxic substances from surface waters and important biological populations. Sedimentation, though an undesirable process in reservoirs as it reduces the pool capacity, is nevertheless an active and inevitable process occurring in all reservoirs. Though soil conservation and other basin erosion control methods should be practiced to minimize sedimentation, there should be a better understanding of the role of sedimentation in burying sediment-bound reservoir contaminants.

291. For example, the partial success of efforts to reduce PCB contamination of the Sheboygan Harbor is reflected by PCB concentration profiles of the sediment (U. S. Army Engineer Division, North Central, 1980). Considerably less contaminated sediment layers from recent

deposits are found overlying harbor sediments containing as much as 75 ppm of PCB. Although the effects of mixing and resuspension processes associated with high flows, wind-induced currents, and bioturbation can reduce the effectiveness of sediment burial, more needs to be known about this process such that its role in a comprehensive reservoir contaminant-management scheme can be properly evaluated.

292. Traps or basins to remove sediment from inflowing waters are reported to be used for some reservoirs in California (Moser and Sears, 1976). Since most contaminants, whether organic or metallic, enter reservoirs adsorbed to particulates, sedimentation traps or basins that effectively remove particulates (especially fines) from inflowing water should also effectively remove most inflowing contaminants. As for all other potential reservoir contaminant management procedures, the feasibility and effectiveness of such a sediment/contaminant trap would be highly dependent on the reservoir, the contaminant source, and properties of the inflowing stream. It is doubtful that the use of subimpoundments placed across inflowing streams would be economically feasible or especially effective for most reservoirs.*

293. Kanapolis Lake, Kansas, is reported to improve the quality of the Smoky Hill River in the Kansas City District. The downstream water quality is thought to be improved due to natural entrapment of sediment and nutrients in the lake. Also, the lake acts as a final treatment stage for all inflowing sewage in the basin (U. S. Army Engineer District, Kansas City, 1976a). Contaminants such as toxic metals and synthetic organics would also tend to be accumulated by the lake and result in an improvement of downstream water quality. Although reservoirs should not have to serve as physical, chemical, and biological traps to clean rivers, this example of a reservoir serving this function indicates the potential for contaminant accumulation in reservoirs.

Natural pollutants

294. Salinity and chloride (two related water quality parameters) are naturally elevated in streams in many low rainfall regions, especially

* D. L. Robey and K. W. Thornton, 1980. "Subimpoundments as Nutrient Traps Above Water Supply Reservoirs," unpublished M.S., U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

in the Southwestern Division. They may be considered contaminants if anthropogenic activities result in their presence in excessive levels in surface and ground waters. One such case is Hords Creek Lake in Texas, where chloride levels often exceed criteria and concentrations are increasing (U. S. Army Engineer District, Fort Worth, 1978a). The source of elevated chlorides is believed to be brine discharge associated with oil and gas production in the basin.

295. Another example is the Painted Rock project in Arizona. Elevated salinity concentrations in the Gila River flowing into the reservoir are concentrated to even higher levels by evaporation in the reservoir (U. S. Army Engineer District, Los Angeles, 1979). The concentration of salt by evaporation in reservoirs upstream from Painted Rock also contributes to the increased salinity; thus, a series of reservoirs compounds the salinity problem. Reservoir releases from Painted Rock resulted in deleterious effects from increased height of the saline water table downstream. This particular adverse impact is being managed at present by prohibiting water release from the Painted Rock Reservoir, though salinity levels of the pool water continue to increase.

296. Long-term storage of conservation water in the Alamo Lake project in Arizona will result in increased salinity levels because of high evaporation (U. S. Army Engineer District, Los Angeles, 1979). It is reported that release rates will be established that will avoid increasing salinity concentrations downstream in Lake Havasu (Arizona-California). During dry periods when reservoir levels are low and salinity concentrations have built up, releases will be restricted to low discharges that should have minimal impact. Because of treaty requirements with Mexico, salinity must be controlled in the Colorado River.

Municipal water supply

297. Some hypolimnetic releases from many reservoirs operated by the Louisville District are high in dissolved organics, manganese, and/or other substances that affect downstream water quality and make the waters unsuitable for municipal supply. Ideally, the release waters should meet applicable criteria for downstream requirements as well as be free of undesirable characteristics not specified by criteria. In

this case, the second best option was to time releases such that the downstream intake structures would be closed when the bad water passed. This has been attempted at one location (U. S. Army Engineer Division, Ohio River, 1979), though the high levels of manganese in release waters did not behave quite as expected in moving downstream. Similar problems exist at Cave Run Lake, Kentucky, and structural modifications to force epilimnetic water to the bottom are being considered (U. S. Army Engineer Division, Ohio River, 1979).

Flow-related problems

298. Most chemical water quality problems in rivers are flow related such that problems are greatest under low flow conditions (Hines and Rickert, 1977). Thus, there is the potential for ameliorating certain flow-related water quality problems downstream from a reservoir (i.e. industrial, thermal, or domestic pollution) by modifying the reservoir guide curve to increase release rates during low-flow periods. In practice, it may be difficult to modify releases substantially due to requirements to maintain pool elevations within prescribed limits so that the reservoir meets other project purposes. Also, certain regions, such as the Southwestern Division, have difficulty in meeting minimum flow requirements on most of their reservoirs (U. S. Army Engineer Division, Southwestern, 1980).

Stratification

299. It is expected that iron, manganese, hydrogen sulfide, and copper levels will be elevated in the hypolimnetic waters of the Foster Joseph Sayers Reservoir in Pennsylvania (U. S. Army Engineer Division, North Atlantic, 1979). This may cause problems in late summer as much of the water released will be from the metalimnion and the hypolimnion. Though a stilling basin below the dam will be used to reaerate the water, an adverse impact is still expected for miles downstream. Drainage of the reservoir to its winter pool level just prior to the fall turnover has been mentioned as a management practice to improve the water quality of the impoundment. However, it is obvious that such action will improve the water quality of the impoundment at the expense of downstream water quality during the pool adjustment (Flipppo, 1970). This again indicates

most actions to improve reservoir water quality may have important interactions, and often adverse interactions, on some other aspect of water quality within the pool or downstream of the reservoir.

Chemical contaminants

300. Another water quality related aspect of the Foster Joseph Sayers Reservoir is that uncontaminated water from this reservoir is expected to dilute mirex- and kepone-contaminated water in Spring and Bald Eagle Creeks (Flipppo, 1970).

301. A ban on the use of chlorinated hydrocarbon insecticides has resulted in decreased dieldrin levels in sediment, water, and fish of the Coralville Lake in Iowa (Kennedy, 1978). Reservoir contamination may be only a small part of the total chlorinated hydrocarbon problem and the ban was not made specifically to protect reservoirs. However, this is a case in which environmental regulations resulted in long-term improvement of reservoir water quality and should be considered a management tool, though not directly under the control of reservoir managers.

302. In some reservoirs where elevated concentrations of chlorinated hydrocarbon insecticides are found in fish tissue, it has been noted that bottom-feeding fish exhibited the highest levels, presumably because sediments are sinks for the compounds and the greater lipid content of the species of bottom fish studied (Kennedy, 1978). If this relationship exists for other reservoirs, a potential management practice would be to warn fishermen of the species that are found to be most contaminated instead of banning all fishing in contaminated reservoirs. Closing reservoirs or sections of reservoirs to commercial and/or sports fishing, though an unsatisfactory, after-the-fact approach, is a management practice that has been implemented in some cases (U. S. Army Engineer Division, Southwestern, 1979).

303. Indian Rock Reservoir in Pennsylvania is downstream from a number of industries. Though the reservoir has never been used for this purpose, it has been suggested that the reservoir may be useful in containing hazardous chemical spills from the upstream industry (U. S. Army Engineer Division, North Atlantic, 1979).

304. In the Sacramento District, PCB's and heavy metals are potential problems in some reservoirs. These problems are compounded by

drought conditions that reduce dilution and flushing. Maintaining adequate flow to dilute and flush contaminated systems obviously is not always possible, but there will be some situations in which this approach will be useful.

305. Certain reservoirs in the midwest are having problems with elevated levels of agricultural herbicides and banned chlorinated hydrocarbon insecticides, as well as with some nonchlorinated hydrocarbons generally considered nonpersistent. Implementation of recommended soil conservation practices for the basin will minimize reservoir contamination with pesticides from agricultural land, but will not completely prevent such transport since total erosion control is not feasible. As stated elsewhere in this report, reservoir pollution problems are often the result of poor pollution control in the watershed. Normally, this is beyond the control of a reservoir manager, but action by other appropriate agencies may be necessary in some cases to reduce basin pollution contributing to reservoir contamination.

Power generation

306. At Lost Creek Lake in Oregon, the use of a turbine outflow to power a generator resulted in lower dissolved oxygen over normal outflow procedures. Because of a fish hatchery downstream, power generation was discontinued for part of the year (U. S. Army Engineer District, Portland, 1978). This example again reinforces the fact that interactions between management to achieve reservoir purposes and management for water quality considerations are frequently going to conflict.

Algal blooms

307. West Thompson Lake in Connecticut is a relatively small reservoir with nuisance algal blooms. A possible alternate operating scheme being considered is to increase the permanent pool level prior to the low-flow season such that a higher release rate can be used to discharge nutrient- and algae-laden water at the onset of a bloom.* Such a plan would probably not be feasible for a large reservoir.

* U. S. Army Engineer Division, New England, 1977. "Algae Blooms at West Thompson Lake, Connecticut," Internal communication NEDED-W, Waltham, Mass.

Multilevel withdrawal

308. In practice, there are very few operational management options available to a reservoir manager to control water quality. Multilevel withdrawal capability may be a powerful management tool to control contaminant problems in reservoir pools and release waters. This is due to reservoir stratification and the important effects of stratification on numerous water quality parameters.

309. The beneficial use of a multilevel withdrawal capability in maintaining selected water quality conditions of release waters is well documented. At present, however, dissolved oxygen and temperature are the two principal water quality criteria used to gauge the need for multiple-level releases at an impoundment project. At this time, there is simply not enough research information available on the use of multilevel withdrawal structures for the purpose of controlling contaminants to estimate the benefits expected or to offer operational guidelines to manage specific contaminants. Based on the available information on the environmental chemistry of many contaminants and the properties of reservoirs, it is logical to assume that multilevel withdrawal structures would be useful in controlling contaminants, but there is need for much reservoir-specific research on this topic.

310. Though very limited information is available on managing reservoir contaminants with multilevel release structures, it is believed such structures will be useful in minimizing potential adverse impacts of contaminants in pool and release waters of most large reservoirs. The value of a multilevel withdrawal capability for managing the important water quality parameters of temperature and dissolved oxygen and sometimes turbidity, hydrogen sulfide, and iron/manganese levels in release waters is well documented. There is a much greater interest in equipping new reservoirs with this capability. Water quality personnel working with single-level withdrawal projects frequently comment in the published literature and CE reports that a multilevel withdrawal capability would enhance water quality management. Perhaps a more important indication of the value of multilevel withdrawal capability is the fact that many Divisions and Districts are modifying old projects to equip them with a multilevel outlet capability.

311. The water quality is reported to be good for the B. A. Steinhagen Reservoir in Texas (U. S. Army Engineer District, Fort Worth, 1978a), but the water quality management is limited due to the dam having no multiple-level release. In the cited report, there is no specific mention of contaminants. The Rock Island District of the North Central Division reports* that "NCD is at an early stage of development for management of reservoirs for water quality purposes. One limitation we are faced with is the absence of selective withdrawal structures at our dams. Other management alternatives being considered include in-reservoir aeration and raising conservation pool levels." Again, it is not evident from this report that chemical contaminants are being considered. The design of selective withdrawal structures is very important. Some selective withdrawal facilities are so difficult to operate that they discourage proper use (U. S. Army Engineer Division, Southwestern, 1980).

312. At Lake Lanier, Georgia, it is believed that selective withdrawal of surface water may alleviate downstream toxicity to fish due to a suspected, but unconfirmed, toxic substance(s) in the hypolimnetic waters. Mortality increases were associated with increases in total manganese and iron concentrations and a decrease in oxidation-reduction conditions (Strain, 1980). Copper has also been implicated as a toxicity factor, and the possibility of reduced humic materials has not been ruled out. If a selective withdrawal structure were installed, release water temperature might then become a problem for the particular fisheries involved.

313. In a recent report on impoundment projects (U. S. EPA, Office of Federal Activities, 1976), it was stated that selective withdrawal facilities are most commonly used for regulating temperature and chemical quality of reservoir water withdrawn for municipal or industrial supply. "The most frequently noted water quality problems that can sometimes be ameliorated by selectively withdrawing water from an impoundment" were listed as: tastes and odors, iron and manganese, turbidity, salinity,

* Z. M. Goodwin, U. S. Army Engineer Division, North Central, personal communication, 1980.

radioactivity and toxic substances, and temperature. In the brief discussion of radioactivity and toxic substances, it was mentioned that "accidental spills of toxic or radioactive substances upstream from a stratified reservoir are likely to be confined to a narrow depth band as the inflow seeks its density level. In the summer stratification period, the pollutant may enter as an overflow or interflow and remain confined to a well defined layer."

314. Under a discussion entitled "Impoundment Releases for Downstream Quality Control, Regulation of Physical and Chemical Quality," in the same report mentioned above, it was stated: "Any physical or chemical constituents exhibiting vertical gradients, or affected by inflow density currents, may be controlled to some extent by use of multilevel outlets."

315. Two other important points concerning water quality management by use of selective withdrawal facilities were made in this impoundment's project report. Both points have been stressed elsewhere in this report. One concerned the interactions between water quality parameters as well as various reservoir functions which may result in selective withdrawal to enhance one water quality parameter being detrimental to other quality parameters. Also, the importance of project-specific considerations of a reservoir's water quality problems and possible ameliorative management actions is stressed.

316. In addition to selective withdrawal structures, this report also discusses other techniques for regulating release water quality. These include turbine aeration for projects including hydroelectric power generating capabilities, discharge aeration using Howell-Bunger valves, and destratification and hypolimnetic aeration.

317. Of the aeration techniques discussed, selective withdrawal and destratification/hypolimnetic aeration probably offer the greatest potential for managing reservoir contaminants.

General Guidance

318. Based on the current state of knowledge about the control of contaminants in reservoirs, only a few very general points can be made concerning management guidelines:

- a. In most instances of reservoir contamination, only two options exist for managing the problem parameter: either contain it within the reservoir to protect downstream water quality or encourage it to pass through the reservoir to enhance water quality of the pool. One can quickly reach the conclusion that what to do depends on the water quality requirements of pool versus release waters, applicable water quality regulations, the interaction of contaminant management on other important water quality parameters desirable for pool and release waters, and perhaps other factors. This reasoning leads to the additional conclusion that management to meet certain reservoir operational restraints often compromises other objectives.
- b. The operation of multiple-purpose reservoirs to serve authorized functions has always involved priorities; e.g., management for flood control usually takes precedence over other project purposes. Managing several water quality parameters (of a noncontaminant nature) such as temperature and dissolved oxygen of release waters has received a high priority in recent decades. Managing reservoirs for contaminants will involve expanding the reservoir water quality concept to include toxic-substances control.
- c. There is a need for better monitoring of contaminants in most reservoirs. At present, reservoir water quality data requirements too often exclude measurements for chemical contaminants. An adequate monitoring effort is essential for determining the nature and magnitude of reservoir contaminant problems and the level of improvement resulting from ameliorative actions.
- d. There is a need for comprehensive evaluation of the environmental conditions at each project instead of pursuing water quality standards for standard's sake (Strain, 1977). Just one aspect of this includes the question of how to consider apparent excessive concentrations of potentially toxic elemental constituents that are derived from natural sources (i.e., heavy metals).
- e. It should be recognized that the aquatic chemistry of new reservoirs will often differ from older reservoirs and that a change in many water quality parameters will occur with time in new reservoirs.

PART VIII: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

319. This study was initiated to review, analyze, and interpret the existing data on the nature and magnitude of chemical contaminants in CE reservoirs, and suggest interim guidelines, if possible, for operational and management techniques to minimize contaminant problems based on contaminant behavior in reservoir ecosystems.

320. The three phases of the project included: information acquisition; evaluation and interpretation of the literature; and consideration of management practices to minimize reservoir contaminant problems. The information synthesized in these three phases was reorganized and presented in the report as outlined in the following paragraphs.

Inventory of water quality criteria and standards

321. Information on the water quality criteria proposed by the EPA in 1979 for 65 toxic pollutants and published in 1980 for the protection of human health and freshwater aquatic life was summarized. Information on the EPA 1976 Red Book criteria established to protect human health and aquatic life from toxic effects of pollutants was also collected for use on contaminants not included in the 1980 EPA criteria. In addition to the two EPA water quality criteria, information on the states' water quality standards, National Drinking Water Standards, and the FDA limits on toxic contaminants in aquatic food species was summarized.

Contaminant data base

322. The data base for contaminants in CE reservoirs was very limited and subject to many significant sources of error, especially the data retrieved from STORET. The sources of error included, but were not limited to, use of whole water analysis, varying detection limits, differing sampling and analytical methods, and the apparent entering of detection limits into the STORET data base. In addition, the frequency of sampling and contaminant analysis has been very limited in the past for inorganic contaminants. The existing data for organic contaminants

was even more limited. The paucity and quality of existing data precluded, for the most part, any meaningful conclusions on the magnitude of contaminant problems in CE reservoirs.

Survey of toxic chemical contaminants
in CE reservoirs and their tributaries

323. Inorganic contaminants. The inorganic contaminants reported in the CE reservoirs survey included arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, zinc, iron, and manganese. In the survey, over 60 reservoirs reported water data for iron and manganese; between 40 and 46 for cadmium, chromium, copper, lead, mercury, and zinc; between 24 and 30 for arsenic, nickel, and silver; 13 for selenium; and 9 for beryllium. With the exception of copper and zinc, a majority of CE reservoirs that reported toxic metal concentrations exceeded the EPA water quality criteria for human health protection. Only two of 44 reservoirs reporting copper data and four of 46 reservoirs reporting zinc data had exceeded the EPA criteria for human health protection.

324. A majority of reservoirs that reported water data for beryllium, cadmium, copper, mercury, nickel, silver, zinc, and iron had exceeded the EPA water quality criteria for the protection of freshwater aquatic life from the chronic or acute toxic effects. About 44 percent of lead reported in reservoirs exceeded the EPA water quality criterion for freshwater aquatic life protection from the acute toxic effects. Less than 25 percent of reservoirs that reported arsenic, chromium, and selenium data exceeded the EPA water quality criteria for freshwater aquatic life protection.

325. The data available for inorganic contaminants present in CE reservoir fish samples were essentially nonexistent. Only two reservoirs reported mercury data in fish samples and one reported data for cadmium. Of the inorganic contaminants, the FDA has established a maximum concentration limit in fish samples only for mercury, and the reservoirs reporting mercury data did not exceed this limit.

326. It is apparent from the survey that the number of reservoirs for which water data for specific contaminants were available (9 to 66 reservoirs) is only a small fraction of over 500 CE reservoirs in

operation, construction, and planning. Although a substantial number of reporting reservoirs exceeded the EPA water quality criteria for several toxic metals, the quality of the data leaves any conclusion of widespread metals contamination largely unresolved.

327. Organic contaminants. PCB's were reported in 11 reservoir waters in the survey, aldrin/dieldrin and 2,4-D in nine reservoirs each, DDT metabolites in eight reservoirs, and 2,4,5-TP in six reservoirs. The number of reservoirs that reported chlordane, endrin, heptachlor/heptachlor epoxide, toxaphene, diazinon, guthion, parathion, malathion, alachlor, atrazine, and bladex in reservoir waters ranged from 1 to 5. The organic contaminants that exceeded the EPA water quality criteria for human health and/or freshwater aquatic life protection one or more times during the monitoring period included aldrin/dieldrin, BHC isomers, chlordane, DDT metabolites, endrin, heptachlor/heptachlor epoxide, toxaphene, PCB's, guthion, parathion, and malathion. Although concentrations were reported in CE reservoirs, no criteria or standards were established for diazinon, alachlor, atrazine, and bladex.

328. Organic contaminants in fish samples were reported in ten reservoirs. DDT metabolites ranked the highest (10) followed by aldrin/dieldrin (8), heptachlor/heptachlor epoxide (7), PCB (6), and others (5 and less). Only two CE reservoirs exceeded the FDA limits on PCB concentrations in fish samples, and aldrin/dieldrin and endrin concentrations exceeded in one reservoir each.

CE reservoirs regional
contaminant distribution

329. Toxic contaminants. The results of the survey showed that the Ohio River Division had the maximum number of reservoirs reporting toxic contaminants (19), followed by the Missouri River Division (14), the South Pacific Division (11), the New England Division (9), and the Southwestern Division (7). Only four reservoirs in the South Atlantic, three in the North Central, and two reservoirs each in the North Atlantic and North Pacific Divisions reported contaminant data. No information on the contaminant problems in reservoirs located in the Lower Mississippi Valley Division was available. The reporting of reservoir contaminant data was not uniform and suggests that contaminant monitoring was very Division-specific. It is important to point out that if a CE

Division had contaminant data available for the majority of their reservoirs, it does not necessarily imply that the CE Division had more contaminant problems than the CE Divisions reporting data for only a few of the reservoirs. Due to a lack of reservoir contaminant data availability from all CE Divisions, it is not feasible to extrapolate with much confidence the regional patterns of reservoir contamination.

330. Acid mine drainage and acid precipitation. The problems of acid precipitation and acid mine discharges were reported to create low pH conditions in many reservoirs in the New England Division and Baltimore District. Acid mine discharges from the coal- or metal-mining activities in southwestern Pennsylvania, northern West Virginia, Montana, Colorado, and Missouri were reported to cause low pH and high toxic metal concentrations in the upstream, reservoir, and downstream waters.

331. Salinity. Excessive concentrations of chlorides, sulfates, and total salts in reservoirs with long retention times and high summer temperatures were reported to cause water quality problems in reservoirs and their tributaries in Arizona, New Mexico, and California.

332. Discharges of toxic chemicals from accidental spills and manufacturing plants were reported to cause localized water quality problems in the receiving streams and reservoirs.

Toxic chemical contaminants
behavior in aquatic systems

333. To understand the behavior of toxic contaminants in reservoir systems, information on the sources, transport, persistence, and bioaccumulation of contaminants was summarized. The significant sources of toxic contaminants include: geological weathering, industrial processing and use of ores and metal compounds, agricultural use of inorganic and organic pesticides, and industrial and municipal waste discharges of inorganic and organic contaminants. The toxic chemical contaminants discharged from various sources are transported to reservoirs through the atmosphere, surface waters, and suspended and bottom sediments. The roles of contaminant properties, climatic conditions, soil and sediment properties, stream flow conditions, and sediment depositional patterns in transporting contaminants to reservoirs were summarized.

334. Persistence of contaminants. While toxic metals cannot be destroyed, toxic organics are degradable and range from very persistent to nonpersistent. Photo, chemical, and microbial degradation are important mechanisms of organics breakdown. The effects of various environmental factors on the degradation of toxic organic contaminants in the aquatic systems were summarized. The chlorinated hydrocarbon pesticides and PCB's were reported to degrade slowly and persist for long periods. Organophosphorus pesticides, and triazine and phenoxy herbicides ranged from nonpersistent to moderately persistent.

335. Bioconcentration of contaminants. The published literature indicated that arsenic, copper, cadmium, lead, mercury, and zinc showed a high degree of bioconcentration while beryllium, chromium, nickel, selenium, and silver did not bioconcentrate to any appreciable degree. DDT and its metabolites, aldrin, dieldrin, toxaphene, chlordane, endrin, heptachlor/heptachlor epoxide, mirex, and PCB's were reported to be highly accumulative. BHC, which included all isomers except gamma isomer (lindane), was reported to be moderately accumulative. Lindane and methoxychlor were the only chlorinated hydrocarbons that were slightly accumulative. Herbicides and organophosphorus insecticides were reported to be easily biodegradable and not to bioconcentrate in aquatic organisms to any significant degree.

Sediment transport in
the reservoir systems

336. The published literature indicates that the transport of suspended and bottom sediments containing contaminants from watersheds to reservoirs is generally very limited during low flow conditions such as occur during summer months. Because of the long detention time and high water temperatures which speed up biochemical processes and metabolic rates, summer low flow periods are the most likely times for occurrence of localized water quality problems. However, accelerated erosion resulting from land-use activities during snow melt and rainy seasons, commonly spring and winter months, may result in considerable transport of sediments from the watershed to streams and rivers and into the reservoirs. The reservoirs generally act as depositories for the sediments because of their high sediment trap efficiency. Due to high adsorption capacity, sediments act as sinks for contaminants in the reservoirs and

may also cause water quality problems downstream through reservoir releases. Since toxic inorganic and organic contaminants associated with the sediments can be bioconcentrated by the aquatic organisms present in the reservoirs and downstream waters, a knowledge of sediment transport would be helpful in understanding the contaminant problems.

337. However, a review of research studies indicated that limited information was available on the loss of sediments from watersheds, their transport in streams and rivers, their accumulation in reservoirs, and their discharge in reservoir release waters. Research studies on the pollutant loadings of reservoirs and release waters were also lacking.

Management considerations

338. Water quality versus project priorities. Reservoir management to control water quality is not new. However, most reservoir water quality management practices in the past have focused on dissolved oxygen and temperature. With limited exceptions, this is true today. At present, there is very little effort expended to manage the quality of pool and release waters in terms of potentially toxic contaminants. There are several reasons for this. One is that the status of reservoir contamination and the potential environmental impact associated with contaminated reservoirs is just becoming known. Another reason is that not enough is known about the physical, chemical, and biological behavior of contaminants in reservoirs on which to base effective reservoir contaminant management procedures. Given the greater awareness of the distribution and potential impacts of environmental contaminants in surface waters, it is anticipated that management of contaminants associated with reservoirs will receive a higher priority in the next few years.

339. High water quality must be maintained in both pool and release waters for many designated project purposes. Water quality management is often complicated in multiple-purpose projects because management to achieve water quality objectives for one designated function often requires compromise of some other water quality parameter. For example, release of hypolimnetic waters to maintain suitable temperatures for a downstream coldwater fishery during summer months may compromise other desirable or mandated water quality parameters such as dissolved oxygen or iron levels.

In many projects, chemical contaminant levels will have to be controlled as well as the more common reservoir water quality parameters. Because of the few water quality management options available for reservoirs, maintaining pool and release waters to meet criteria is going to be increasingly difficult in the future.

340. Early priorities in managing reservoirs focused on controlling pool levels within prescribed limits in order to maintain a given reserve storage capacity, often for flood control or water supply purposes. In recent decades, maintaining temperature and dissolved oxygen levels of release waters within satisfactory ranges for downstream purposes has also received high priority in managing reservoirs. The high priorities given to maintaining seasonal pool elevations (guide curve) appropriate for project purposes and the temperature and dissolved oxygen conditions of release waters will not change. However, reservoir management to maintain or improve the quality of pool and release waters in terms of potentially toxic contaminants is also going to be assigned a high priority in the future in reservoirs where chemical contaminant problems are identified. Reservoir management to minimize adverse environmental impacts associated with the presence of contaminants is going to add another level of complexity to the operation of reservoirs to meet authorized purposes. Thus, more and more operational restrictions must be addressed with the relatively few reservoir management practices available.

341. Watershed contamination. Chemical contamination of reservoirs is most often a result of watershed contamination. Reservoir contaminants are derived from either point-source discharge into the reservoir or inflowing streams or from nonpoint sources (land runoff). Problems with chemical contaminants in streams and reservoirs are often indicative of the need for better pollution management in the watershed. Therefore, since reservoir water quality is a function of inflow water quality, watershed pollution management can be an important component in managing reservoir contaminant problems. The feasibility of implementing watershed pollution control practices as a component in addressing reservoir contaminant problems will, of course, depend on the specific circumstances of the reservoir and watershed problems.

342. Contaminant monitoring. Monitoring for the presence of toxic materials in reservoirs and releases may be necessary to identify problems and to demonstrate compliance with applicable Federal and state water quality criteria. Monitoring is also a necessary component in managing reservoirs where contaminant problems exist to minimize adverse environmental effects from contaminants. An adequate contaminant monitoring or survey program is an essential first step to identifying reservoir contaminant problems and establishing the nature and magnitude of the problem. If the monitoring or surveying indicates the need for ameliorative management practices, then contaminant monitoring is useful for measuring the benefits derived from the management action.

343. There are several problems with existing CE reservoir monitoring programs that are evident from reading Division water quality reports and various published papers of CE reservoir personnel. These problems include inadequate monitoring for chemical contaminants, lack of adequate monitoring capabilities to measure most contaminants, lack of quality control, lack of guidelines for planning good reservoir monitoring programs, and lack of a quick-response capability to monitor instances of chemical spills.

344. Reservoir monitoring programs generally include parameters such as temperature, turbidity, dissolved oxygen, nutrient levels, and secchi depth. For most reservoirs, toxic and potentially toxic inorganic and synthetic organic materials are not included in either monitoring or periodic surveys of water quality. Thus, all too often, there is either inadequate or no characterization of contaminants in reservoirs.

345. At present, there is a wide range in thoroughness of contaminant monitoring between CE Divisions, between Districts within a Division, and even between reservoirs within a District. Because of a lack of uniformity in contaminant monitoring efforts, an evaluation of the available CE reservoir contaminant data to identify Divisions, Districts, and reservoirs with potential problems must be interpreted very carefully. Reservoir projects in which a good job of contaminant monitoring has been done may appear to have more potential problems than projects that have not adequately surveyed or monitored for contaminants.

346. Reservoir stratification. Most of the deep CE reservoirs develop a stratified water column during some portion of the year resulting in two or more distinct layers within the water column. Stratification is known to have an important effect on a number of physical and chemical properties of the water column. These properties include temperature, density, dissolved oxygen levels, iron and manganese levels, as well as a number of other interacting parameters. Because of the substantial effect of reservoir stratification on major water quality parameters, it is believed that stratification will also have an important influence on the mobility and fate of reservoir contaminants. However, there is very little data which deal specifically with the chemistry of contaminants in reservoirs. Because of the unique physical, chemical, and biological properties of reservoirs, it is risky to generalize.

347. In recent years, much has been learned about the chemistry and fate of potentially toxic metals and synthetic organics in soils and sediment-water systems. A considerable amount of information is available on the effects of different physicochemical conditions (i.e. pH, salinity, and oxidation-reduction conditions), such as may exist in a stratified water column, on the environmental chemistry of contaminants. Much of the information suggests that one should be cautious in making generalizations about how different physicochemical conditions such as those found in a stratified water column will affect the chemistry of contaminants. Specific information on the chemical, physical, and biological properties of a system are needed before predictions on the fate of a contaminant can be made. This is because a number of interacting chemical processes play a role in regulating the mobility of metals and the processes dominating may depend on the particular sediment-water system being considered (Gambrell et al., 1976).

348. Because of the limited data available specifically pertaining to the chemistry of contaminants in reservoirs, and the uniqueness of individual reservoirs when considering their physical, chemical, and biological properties in addition to their designated purposes, it is risky to generalize on how various factors will affect the mobility and fate of reservoir contaminants.

General guidance

349. In most instances of reservoir contamination, only two options exist for managing the problem parameter: either contain it within the reservoir to protect downstream water quality or encourage it to pass through the reservoir to enhance water quality of the pool. Relatively little reservoir management specifically designed to control contaminants is currently being practiced. Thus, there is very limited experience upon which to base management guidelines. Therefore, many of the examples presented in this report were for managing water quality parameters other than those normally considered contaminants.

350. In practice, there are very few operational management options available to a reservoir manager to control water quality. Multilevel withdrawal capability may be a powerful management tool to control contaminant problems in reservoir pools and release waters. This is due to reservoir stratification and the important effects of stratification on numerous water quality parameters. The beneficial use of a multilevel withdrawal capability in maintaining selected water quality conditions of release waters is well documented.

351. At present, however, dissolved oxygen and temperature are the two principal water quality criteria used to gauge the need for multiple level releases at an impoundment project. At this time, there is simply not enough research information available on the use of multilevel withdrawal structures for the purpose of controlling contaminants to estimate the benefits expected or to offer operational guidelines to manage specific contaminants. Based on the available information on the environmental chemistry of many contaminants and the properties of reservoirs, it is logical to assume that multilevel withdrawal structures would be useful in controlling contaminants, but there is a need for much reservoir-specific research on this topic.

352. There is considerable interest in equipping new reservoirs with this capability. Water quality personnel working with single-level withdrawal projects frequently comment in the published literature and CE reports that a multilevel withdrawal capability would enhance water quality management. Perhaps a more important indication of the value of multilevel withdrawal capability is the fact that many Divisions and

Districts are modifying old projects to equip them with a multilevel outlet capability.

Conclusions and Recommendations

353. Based on the findings of this report, the following conclusions and recommendations are considered warranted:

- a. One of the primary findings of this project was that there is insufficient information available to accurately determine the nature and magnitude of contaminant problems in Corps reservoirs. Some exceptions exist where intensive, quality monitoring has been conducted on a few selected reservoirs. For the majority of reservoirs, however, there has been inadequate monitoring, and much of the limited information available is of doubtful reliability or is in a format that makes the data difficult to evaluate. Within the data limitations previously indicated, a data evaluation approach was developed for identifying potential contaminant problems. Data evaluation, however, served chiefly to illustrate the sources and types of data available, but could not establish the nature and magnitude of CE reservoir contaminant problems with an acceptable degree of confidence because of data limitations. Due to data quality and quantity, alternative data evaluation procedures would be expected to produce similar results.
- b. The chemical contaminants data presented in the main body of this report and the appendices were collected from various sources and lack uniformity in sampling techniques, sampling depth, sample pretreatment, and accuracy and precision of analytical methods used. Due to these and numerous other limitations, the authors feel that these data may not be reliable and may only be used for general qualitative interpretations of the potential contaminant problems existent in CE reservoirs.
- c. Comparison of the contaminants data collected in the survey with the applicable Federal and state criteria indicated that 109 of over 500 CE reservoirs reported data for one or more contaminants listed as toxic in the EPA or FDA criteria. By the approach used to identify potential contaminant problems, 71 of the CE reservoirs surveyed had one or more chemical contaminants exceeding the criteria during certain periods when monitoring was conducted. Data utilized in identifying these potential contaminant problems were subject to all previously discussed limitations.

- d. The results of the survey indicated that while data on inorganic contaminants were reported in a small fraction of CE reservoirs, data on the organic contaminants were essentially nonexistent.
- e. Due to a lack of reservoir toxic chemical contaminant data availability in all CE Divisions, it is not feasible to extrapolate the regional patterns of reservoir contamination.
- f. Very little information is available on pollutant and sediment transport to CE reservoirs and their discharge in release waters.
- g. There is a need for a greater contaminant monitoring effort and more uniform emphasis on monitoring in CE reservoirs.
- h. Reservoir water quality monitoring for contaminants should be done on a reservoir-specific basis.
- i. Where reservoir contamination is a problem, the need for better pollution control in the watershed must be examined.
- j. Reservoir managers should be prepared for rapid implementation of intensive reservoir water quality surveys in response to a chemical spill that might occur in the reservoir or the upstream basin.
- k. Every reservoir project is unique. Therefore, the assessment of water quality problems associated with reservoir contaminants and the implementation of reservoir management practices to control contaminants must be done on a reservoir-specific basis. This requires the involvement of those persons most knowledgeable about the reservoir.
- l. Because of increasing operational restrictions placed on reservoirs, reservoir management priorities for each project need to be carefully evaluated or reevaluated considering authorized reservoir functions, traditional water quality parameters, and contaminant problems.
- m. Although a considerable amount of information is available on the environmental chemistry of most classes of contaminants in sediment-water systems (much of which is probably applicable to reservoirs), there remains a need for basic reservoir-specific research on the chemistry and fate of toxic substances in reservoir systems.
- n. At present, there is relatively little experience on which to base guidelines for managing reservoir contaminants. This points to the need for reservoir-specific

research to provide the needed information for contaminant management.

- o. Multilevel outlet capabilities for reservoirs will undoubtedly prove to be valuable in managing reservoir contaminant problems, but much additional research is needed on this topic.

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