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Predicted Limnology of the Proposed Ridges Basin Reservoir

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PREDICTED LIMNOLOGY OF THE PROPOSED RIDGES BASIN RESERVOIR

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and
V. Dean Adams

PREDICTED LIMNOLOGY OF THE PROPOSED

RIDGES BASIN RESERVOIR

by

Lawrence A. Baker and V. Dean Adams

WATER QUALITY SERIES

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Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

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ABSTRACT

A limnological evaluation was conducted for the offstream Ridges Basin Reservoir proposed by the Bureau of Reclamation in southwest Colorado. The study required the determination of existing water quality in the source river and use of the information to predict the algal standing crop, hypolimnetic oxygen deficit, Secchi disk transparency, and retention of metals in the proposed reservoir.

A water quality study was conducted between May 1977 and August 1978. Samples were collected from the Animas River, which will provide the inflow to the proposed reservoir, and from the La Plata River, which will receive discharge from the reservoir. Samples were analyzed for 49 water quality constituents. The data were used to evaluate the quality of water in both rivers with respect to the proposed Colorado Water Quality Standards for raw water supply, agricultural use, and the protection of the aquatic biota.

A phosphorus loading model was evaluated and used to predict the summer standing crop of chlorophyll a that will occur in the reservoir. A computer model was used to simulate the rate of depletion of oxygen in the hypolimnion during the summer stratification period. The retention of iron, zinc, lead, and copper was predicted by using a simple mass balance model together with existing data on the retention of metals in lakes.

The standing crop of chlorophyll a in the reservoir will be between 5 and 13 mg/m^3 during the summer. The average Secchi disk transparency will be about 1.9 m. The oxygen concentration in the hypolimnion will probably drop to between 5 and 6 mg/l by the end of the stratification period. Between 92 and 99 percent of the iron, 30 to 85 percent of the zinc, 86 to 95 percent of the lead and 0 to 85 percent of the copper entering the reservoir will be retained. Many of the proposed standards for metals were exceeded in both rivers throughout most of the study period. The concentration of total metals was correlated with peak flows that occur during the period of spring runoff. The actual values of the limnological parameters will vary with changes in the hydrologic regime of the reservoir. These predictions do not apply to the period of initial filling and stabilization.

Control of the hydrologic regime by manipulating the inflow pumping strategy was suggested as a means of controlling the inflow of both nutrients and metals into the reservoir.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

INTRODUCTION

Background

The quality of water in a reservoir is determined by the quality of the inflow water and by biological and physical processes occurring within the reservoir. Both must be examined in order to predict the quality of water that will be stored in a proposed reservoir.

One of the most important processes that affect the quality of water stored in a reservoir is the production of algae. Since excessive algae production has a detrimental effect on the quality of stored water, it is generally desirable to have very little production of nuisance algae (i.e., blue-greens) in reservoirs. Undesirable consequences associated with increasing levels of algae production include: 1) a decrease in the concentration of dissolved oxygen in the hypolimnion, 2) a loss in community species diversity, accompanied by an increase in the predominance of populations of blue-green algae, 3) taste and odor problems associated with blooms of blue-green algae, 4) a change in the composition of fish populations from game fish (trout, bass) to rough fish (carp, bullheads), and 5) the occurrence of skin rashes among swimmers (Porcella and Bishop 1975).

The processes of sedimentation and chemical precipitation also affect the quality of water stored in reservoirs. Considerable clarification of the inflow water occurs in reservoirs as the result of a reduction in water velocity, and the water leaving a reservoir is usually much less turbid than the inflow water (Churchill 1957, Hannon and Young 1974). Chemical precipitation resulting from evaporation, or changes in temperature and biological activity, may decrease the loading of some dissolved substances between the inflow and the outflow of a reservoir. These processes may result in the accumulation of heavy metals, nutrients, and other constituents in the sediments.

Finally, during the early life of a reservoir, there is often a period of stabilization during which the decay of inundated organic material and the leaching of plant nutrients and other chemicals from soils and vegetation have a profound effect on the quality of stored water. The decay of inundated organic material may result in a larger oxygen demand in the hypolimnion during the period of initial filling and stabilization of a reservoir than in its later life. The leaching of materials from newly inundated soils and vegetation may result in an increase in the loading of dissolved constituents of a stream that has been recently impounded. Bolke and Waddell (1975) observed such a phenomenon in the Colorado River following the formation of Lake Powell. Gould (1954) and Howard (1954) (both cited in Neel 1963) observed a similar increase in the loading of dissolved solids in the Colorado River following the filling of Lake Mead. The release of plant nutrients from inundated soils and vegetation may be responsible for the peak in algae production observed in some newly formed reservoirs The extent and duration of the stabilization period is probably dependent on the nature of the bed material and the morphology and hydraulic characteristics of the reservoir. The stabilization period may last up to 10 years for some reservoirs (Table 1).

Objectives of Study

The objectives of this research were to conduct a detailed study of existing water quality in the Animas and the La Plata Rivers in the vicinity of the proposed Animas-La Plata project and to make a limnological evaluation of the proposed Ridges Basin Reservoir. The limnological evaluation was to predict: 1) the trophic status of the reservoir after stabilization, 2) the extent of oxygen depletion in its hypolimnion, and 3) the retention of heavy metals in the reservoir. The predictions made in this study are applicable to the Ridges Basin Reservoir following the stabilization period. Additional study would be necessary to evaluate the water quality of the reservoir during the period of initial filling and stabilization.

Project Description

The Animas-La Plata Project will be a multiple purpose water resource development located on the Upper Colorado River Basin in southwest Colorado and northwest New Mexico. The project will supply $1.48 \times 10^8 m^3$ (120,300 ac-ft) of water per year for irrigation and $9.7 \times 10^{-7} m^3$ (78,750 ac-ft) of water for municipal and industrial use in Durango, Colorado, Aztec and Farmington, New Mexico, and surrounding communities.

1

Table 1. Length of stabilization period for water quality parameters in new reservoirs.

Parameter	Time to Equilibrium (yrs.)	Type Reservoir	Source
Algae Production	8-10	Eastern Water Supply	*Whipple* (1933)
Hypolimnetic Dissolved O_2	9-10	Eastern Water Supply	*Purcell* (1939)
Taste and Odors H_2S	1	TVA Reservoirs	*Churchill* (1957)
Fe, Mn	3	Eastern Water Supply	*Purcell* (1939)
	8-9	Eastern Water Supply	*Purcell* (1939)
Biodegradable Substances	10-15	Unspecified	*Fair et al.* (1958)
TDS	0	Western Flood, Power and Irrigation	*Soltero et al.* (1973)
	0	Eastern Flood Control (Small)	*Williams* (1978)
Hardness and Alkalinity	2	Missouri River Flood Control	*Neel* (1963)

The central feature of this project and the object of this study is the Ridges Basin Reservoir, located southwest of Durango, Colorado (Figure 1). The reservoir will be operated as an offstream, pumped storage reservoir. Inflow to the reservoir will be supplied from the Animas River via the Durango pumping station. Stored water will be released back to the Animas River for municipal and industrial use in New Mexico ($4.6 \times 10^7 m^3$/yr) (37,400 ac-ft/year) and in Durango, Colorado ($1.1 \times 10^7 m^3$/yr or 8,850 ac-ft/year). An additional 152,800 ac-ft/ year will be released through the Dryside Canal to supply water for irrigation and for municipal and industrial use in the La Plata River Basin. A detailed flow schematic of the project is presented in Figure 2. The results of a USBR monthly hydrologic simulation of reservoir storage volumes, inflows, and outflows is presented in Appendix A.

The reservoir will be roughly triangular in shape (Figure 3) and will cover $9.0 \times 10^6 m^2$ (2,230 acres) at full capacity of $3.45 \times 10^8 m^3$ (280,000 acre-feet). The reservoir will have an average hydraulic residence time of about 1.6 years (based on total capacity and projected average supply).

The rockfill and earth dam forming the reservoir will rise 93.6 m (307 ft) above the streambed and will have a crestlength of 518 m (1700 ft). The inlet from the Animas River will enter the reservoir in the northwest corner at an elevation of 2117 m (6945 ft). The outlet for the New Mexico municipal and industrial supply will be located near the damsite at an elevation of 2035 m (6677
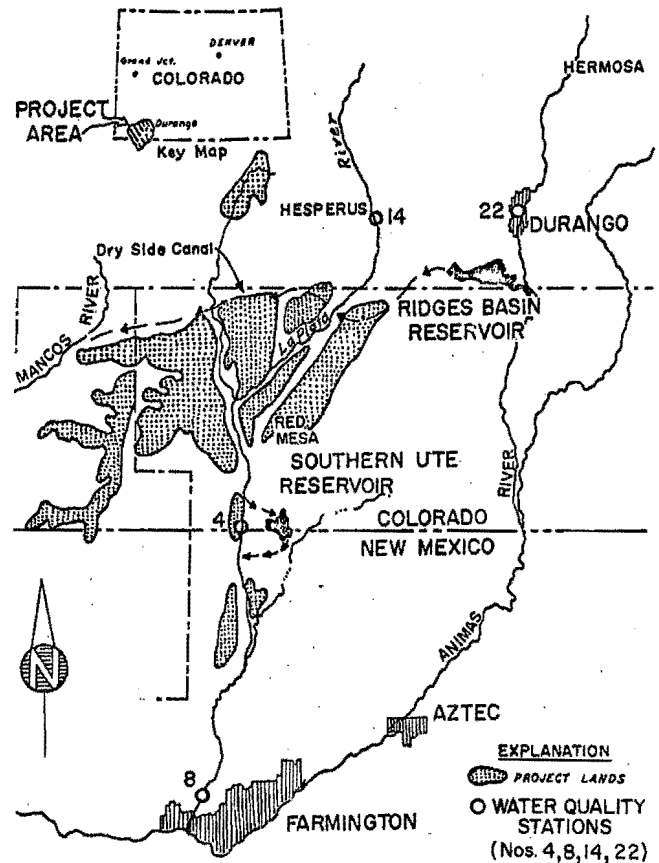
Figure 1. General map of Animas-La Plata project.

2
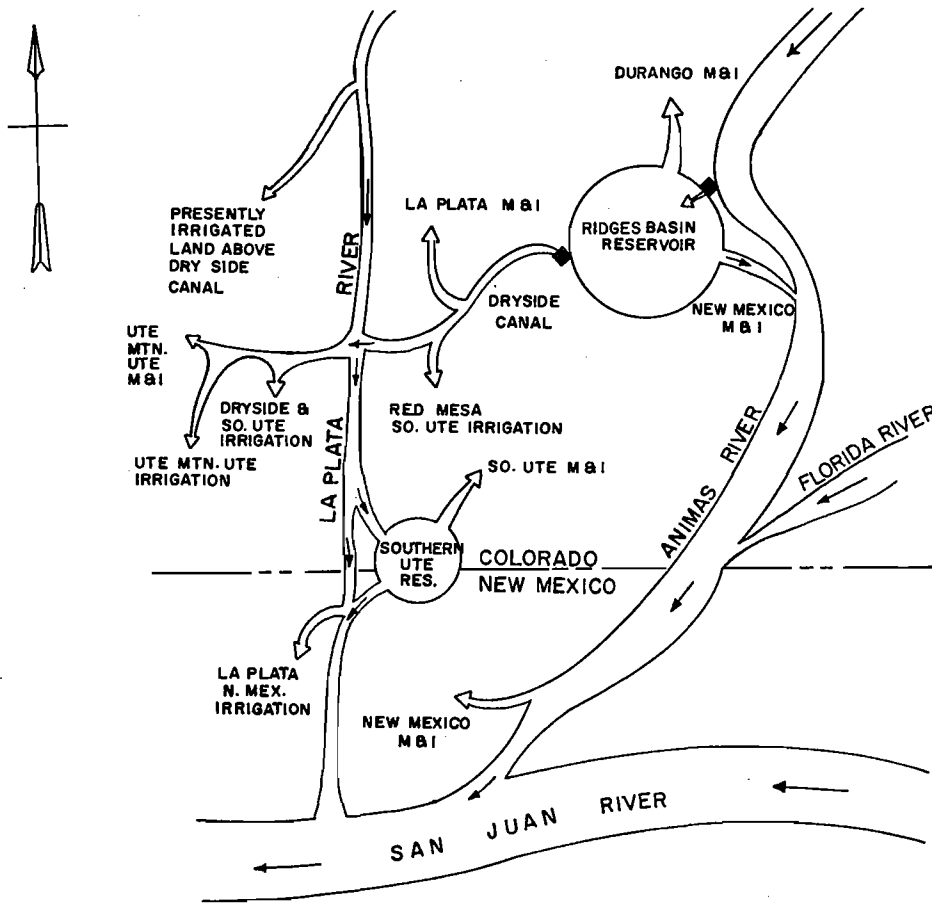
Figure 2. Flow schematic of Animas-La Plata project (USBR 1978).
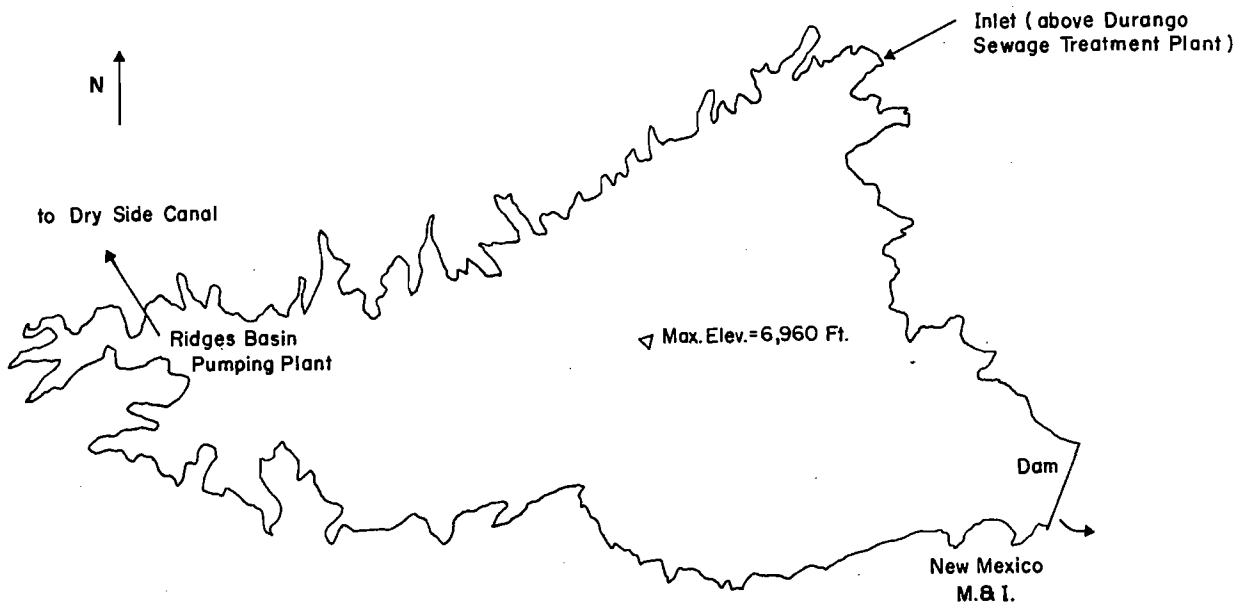
Figure 3. Detailed map of Ridges Basin Reservoir.

3

WATER QUALITY SURVEY

ANIMAS-LA PLATA PROJECT

During the period May 1977 to August 1978, an intensive program of water quality analysis was conducted on water samples obtained from stream segments associated with the proposed Animas-La Plata Project. The purposes of this survey were to 1) evaluate the current water quality of these stream segments with respect to the proposed Colorado Water Quality Standards, 2) provide information on the quality of waters that will be used to fill the Ridges Basin, and 3) provide a data base by which to assess the impacts of the project on the water quality downstream from the major project features.

The four sampling stations studied were:

Station #4: La Plata River at the Colorado-New Mexico Border

Station #8: La Plata River at Farmington, New Mexico

Station #14: La Plata River at Hesperus, Colorado

Station #22: Animas River at Durango, Colorado

The locations of these water quality stations are shown in Figure 1.

Samples were collected monthly by USBR personnel and shipped to the Utah Water Research Laboratory for analysis. Standard Methods (APHA 1975) and USEPA (USEPA 1976a) protocol were followed in the sample collection process and the analytical techniques for determining the constituents present. Forty-nine chemical parameters were determined for each of the 16 sampling periods. The raw data obtained in this survey are presented in Appendix B. The results of the water quality study were compared with the proposed Colorado Water Quality Standards for each of the four water quality stations. The results of the comparison study are on file at the UWRL Library.

PREDICTION OF TROPHIC STATUS FOR

THE PROPOSED RIDGES BASIN RESERVOIR

Introduction

Highly productive eutrophic waters are generally undesirable for most uses. Therefore, it is desirable to be able to predict the level of algal productivity that will occur in a newly formed body of water, and, if necessary, take measures to prevent excessively high levels of algal productivity.

A phosphorus loading model, developed by Vollenweider (1968, 1969, 1975, 1976), was used to predict algal production that will occur in the Ridges Basin Reservoir. The validity of predictions generated by this model was tested using data collected by the National Eutrophication Survey (USEPA 1977) for 40 lakes and reservoirs in the Intermountain West.

Application of Vollenweider's Phosphorus Loading Model to Existing Lakes and Reservoirs

Vollenweider's (1976) phosphorus loading model can be used to predict the mean summer epilimnetic concentration of chlorophyll a (a common indicator of algal productivity) in a lake using variables that are independent of interactions occurring within the lake. According to this model, the mean summer epilimnetic concentration of chlorophyll a ([chl. a]) can be predicted from the equation:

$$\left[\text{chl. } \underline{a}\right] = 0.367 \left[\frac{L_p q_s}{\left[1 + \sqrt{\bar{z}/q_s}\right]}\right]^{0.91} \quad \ldots (1)$$

where

L_p = areal phosphorus loading, g/m^2/yr

q_s = water load, m/yr (m^3/yr/m^2)

z = mean depth, m

In order to test the claim by Vollenweider (1976) that this model can be used for lakes throughout the temperate zone to predict the mean summer epilimnetic chlorophyll a concentration, its predictions for 40 lakes and reservoirs in Colorado, New Mexico, Utah, and Wyoming were compared with data collected in the National Eutrophication Survey (NES) and reported in the National Eutrophication Working Papers (USEPA 1977). The methods used in the National Eutrophication Survey are presented in USEPA (1975a).

These working papers were used to compile data on mean depth ($\bar{z}$), areal phosphorus loading (L_p), areal water load (q_s), mean concentration of chlorophyll a (chl. a), and the ratio of total soluble inorganic nitrogen to orthophosphate (TSIN:OP) for each lake and reservoir (Table 3). The chlorophyll a data presented in column 8 of Table 3 are the average of all the epilimnetic zone sampling stations for the particular date. The chlorophyll a data in column 9 is the mean of all the sampling periods for each lake. The values in column 9 were considered to be the mean summer epilimnetic concentration of chlorophyll a for each lake.

Equation 1 is plotted in Figure 4 along with its 99 percent confidence intervals determined as suggested by Vollenweider (1976). The symbols used in plotting indicate the status of nutrient limitation for each reservoir. A completely shaded circle indicates that phosphorus was the limiting nutrient during all sampling periods, a half-filled circle indicates that nitrogen was limiting during some sampling period(s) and that phosphorus was limiting at other times, and an unshaded circle indicates that nitrogen was limiting during all sampling periods. Phosphorus was considered to be limiting whenever the ratio of TSIN:OP was greater than or equal to 11.3:1, based on a weight ratio (Greens et al. 1975). Data points for 6 of the 40 water bodies were omitted from Figure 4. Viva Naughton Reservoir (#26), Ute Reservoir (#34), Steinaker Reservoir (#13), and Blue Mesa Reservoir (#18) were omitted because the estimates of phosphorus loading for these water bodies were considered by the author(s) of the respective working papers to be unreliable. Lake DeSmet (#27) was omitted because two major tributaries that normally flow into the lake were being diverted at the time of sampling in order to allow construction of a dam that would increase the volume of the lake. Starvation Reservoir (#16) was omitted because it was still filling during the sampling period and therefore may not have reached equilibrium, a prerequisite for use of Vollenweider's model. Thus, 34 points actually appear in Figure 4.

Table 4 presents additional data for each of the 34 lakes and reservoirs plotted in Figure 4. These data were also taken from the National Eutrophication Survey Working Paper Series. Lakes and reservoirs in this table are separated into three groups.

Lake and Location	Lp (mg P/m²/yr) *10^{-3}	q_s (m/yr)	$\bar{z}$ (m)	$\dfrac{L_p/q_s}{(1 + \sqrt{\bar{z}/q_s})}$	Sampling Date	TSIN:OP	Chl. a[b] Concentration (mg/m³)	Mean Chl. a[c] Concentration (mg/m³)	Plotting Number
Minerville Res. Beaver Col, Ut.	1.45	7.71	5.6	102	5/8 8/12 9/25	0.5:1 0.5:1 2:1	4.7 19.8 76.3	33.6	1
Pelican L. Uninta Co., Ut.	0.13	0.76	3.0	57	5/13 8/7 9/23	4:1 16:1 20:1	1.4 4.7 13.3	6.5	2
Piute Res. Piute Co., Ut.	2.03	15.49	10.1	73	5/9 8/13 9/24	36:1 14:1 7:1	17.3 15.7 47.0	26.7	3
Sevier Bridge Res. Juab and Sanpete Co., Ut.	0.75	4.45	6.5	76	5/12 8/12 9/24	>44:1 >44:1 >44:1	7.5 20.5 26.7	18.2	4
Panguitch L. Garfield Co., Ut.	0.36	4.94	6.4	34	8/13 9/25	10:1 6:1	19.6 72.4	30.7	5
Otter Creek Res. Piute Co., Ut.	0.61	5.20	6.3	56	5/9 8/13 9/25	<7:1 <7:1	14.6 12.1 8.7	11.8	6
Utah L. Utah Co., Ut.	0.51	2.11	2.1	121	5/12 8/8 9/19	26:1 7:1 31:1	14.0 106.5 95.6	72.0	7
Willard Res. Box Elder Co., Ut.	0.21	2.79	5.9	31	5/14 8/6 9/23	6:1 4:1 11:1	10.4 7.1 5.3	7.6	8
Fish L. Sevier Co., Ut.	0.05	0.66	25.9	10	8/12 9/25	8:1 8:1	20.1 4.8	12.5	9
Tropic Res. Garfield Co., Ut.	0.40	20.21	3.0	14	5/8 8/14 9/25	18:1 5:1 13:1	17.0 9.4 1.2	9.2	10
Joe's Valley Res. Emery Co., Ut.	0.70	19.13	16.3	18	5/13 8/12 9/24	4:1 46:1 45:1	2.1 3.8 1.6	2.5	11
Pineview Res. Weber Co., Ut.	0.72	20.55	24.7	17	5/14 8/7 9/23	>17:1 >17:1 >17:1	9.0 3.7 4.4	5.8	12
Steinaker Res. Uintah Co., Ut.	0.11	7.82	14.0	6	5/13 8/7 9/22	4:1 12:1 17:1	4.1 2.4 1.7	2.6	13
Deer Creek Res. Wasatch Co., Ut.	2.47	36.08	19.9	39	5/12 8/11 9/19	>16:1 12:1 20:1	7.4 1.3 18.5	9.1	14
Moon Lake Duchesne Co., Ut.	0.52	37.07	14.1	9	8/11 9/23	>23:1 >23:1	2.8 2.6	2.7	15
Starvation Res. Duchesne Co., Ut.	2.70	16.65	19.9	78	5/13 8/11 9/24	8:1 13:1 8:1	4.0 9.3 3.7	5.7	16

8

Table 3. Continued.

Lake and Location	Lp (mg P/m²/yr) $*10^{-3}$	q_s (m/yr)	$\bar{z}$ (m)	$\dfrac{L_p/q_s}{(1+\sqrt{\bar{z}/q_s})}$	Sampling Date	TSIN:OP	Chl. a[b] Concentration (mg/m³)	Mean Chl. a[c] Concentration (mg/m³)	Plotting Number
Echo Reservoir Summit Co., Ut.	2.50	41.2	15.3	38	5/12	<10:1	10.9		
					8/7	18:1	4.5	7.0	17
					9/18	<10:1	5.5		
Blue Mesa Res. Gunnison Co., CO.	2.66	41.27	31.1	35	8/26	<10:1	4.9		
					9/29	<10:1	8.7	6.8	18
Dillon Res. Summit Co., CO.	0.61	24.06	24.6	13	8/25	>18:1	2.3		
					10/9	>18:1	4.0	3.2	19
Cherry Creek L. Arapahoe Co., CO.	1.53	2.44	5.2	26	8/22	<9:1	<8.7		
					10/9	<9:1	11.9	23.3	20
Barker Reservoir Boulder Co., CO.	0.59	30.15	8.3	13	5/7	16:1	4.8		
					8/26	10:1	3.7	5.3	21
					10/10	7:1	7.5		
Seminoe Reservoir Carbon Co., Wy.	2.91	28.00	25.6	53	5/19	19:1	2.2		
					8/27	11.1	2.2	2.5	22
					10/16	17:1	3.2		
Boyson Res. Fremont Co., Wy.	3.56	16.28	10.4	122	5/19	13:1	10.6		
					9/2	10:1	6.7	6.6	23
					10/17	8:1	2.4		
Big Sandy Res. Subletter and Sweetwater Co.'s, Wy.	1.20	7.99	5.8	81	5/	<4:1	5.3		
					9/2	<4:1	3.6	4.3	24
					10/16	<4:1	4.1		
Woodruff Narrows Reservoir Uinta Co., Wy.	6.02	31.68	4.9	136	5/16	3:1	6.1		
					8/7	7:1	3.3	13.0	25
					9/18	5:1	31.2		
					10/16	6:1	11.3		
Viva Naughton Res. Lincoln Co., Wy.	0.67	21.21	8.9	19	8/5	<8:1	18.6		
					9/18	<8:1	34.0	25.1	26
					10/16	<8:1	22.6		
Lake DeSmet Johnson Co., Wy.	0.07	0.94	12.8	16	5/22	5:1	4.7		
					8/29	5:1	10.0	11.1	27
					10/15	13:1	18.7		
Keyhole Res. Crook Co., Wy.	0.46	1.05	6.5	126	5/23	12:1	6.2		
					8/29	14:1	7.5	7.8	28
					10/15	13:1	9.6		
Ocean L. Fremont Co., Wy.	0.26	1.77	4.2	58	5/19	3:1	5.0		
					9/2	10:1	5.4	7.5	29
					10/16	14:1	12.1		
Boulder L. Sublette Co., Wy.	0.68	25.93	12.2	16	8/27	13:1	2.5		
					9/17	18:1	2.5	2.5	30
Freemont L. Sublette Co., Wy.	0.12	10.88	24.4	8	8/28	22:1	4.6		
					10/11	20:1	3.0	3.8	31
Navajo Reservoir Arculeta Co., Co. and San Juan and Rio Arriba Co., N.M.	2.50	25.20	33.3	46	4/30	15.1	2.3		
					8/18	10.1	1.6	2.2	32
					9/30	8:1	2.7		
Alamogordo Res. DeBaca and Guadalupe Co.'s, N.M.	1.52	5.03	8.1	133	5/1	6:1	2.1		
					8/20	18:1	7.3	5.9	33
					10/2	25:1	8.2		
Ute Reservoir Quay Co., N.M.	0.66	5.96	8.9	51	5/2	4:1	1.6		
					8/20	10:1	4.0	3.2	34
					10/2	15:1	4.1		

9

Table 3. Continued.

Lake and Location	Lp (mg P/m^2/yr) $*10^{-3}$	q_{s} (m/yr)	$\bar{z}$ (m)	$\dfrac{L_p/q_s}{(1+\sqrt{\bar{z}/q_s})}$	Sampling Date	TSIN:OP	Chl. a^{b} Concentration (mg/m³)	Mean Chl. a^{c} Concentration (mg/m³)	Plotting Number
L. McMillan Eddy Co., N.M.	1.05	9.77	2.1	73	5/1	17:1	10.8	14.1	35
					8/20	6:1	12.0		
					10/2	3:1	18.7		
Elephant Butte Res. Sierra and Socorro Co., N.M.	17.35	8.39	18.3	835	5/2	<3:1	7.4	6.8	36
					8/19	<3:1	9.5		
					10/3	<3:1	3.4		
El Vado Res. Rio Arriba Co., N.M	2.67	20.91	18.3	66	5/5	11:1	2.0	2.2	37
					8/19	5:1	2.0		
					10/1	5:1	2.6		
Eagle Nest Lake Colfax Co., N.M.	0.27	2.23	9.9	39	5/6	<1:1	15.8	13.9	38
					8/21	<1:1	4.0		
					10/7	<1:1	21.9		
Conchas Res. San Miguel Co., N.M.	0.29	4.15	11.8	26	5/1	6:1	1.5	3.3	39
					8/21	9:1	5.5		
					10/2	23:1	2.8		
Bluewater L. McKinley and Valencia Co.'s, N.M.	0.08	1.54	6.7	17	5/5	11:1	2.3	3.9	40
					8/19	12:1	5.1		
					10/1	19:1	4.2		

[a] Data from National Eutrophication Study Working Papers (*EPA*, 1977).
[b] Chl. a is mean for all stations for each date. (Chl. a) determined from 4.6 m integrated sample.
[c] Mean Chl. a data is mean of all sampling dates.
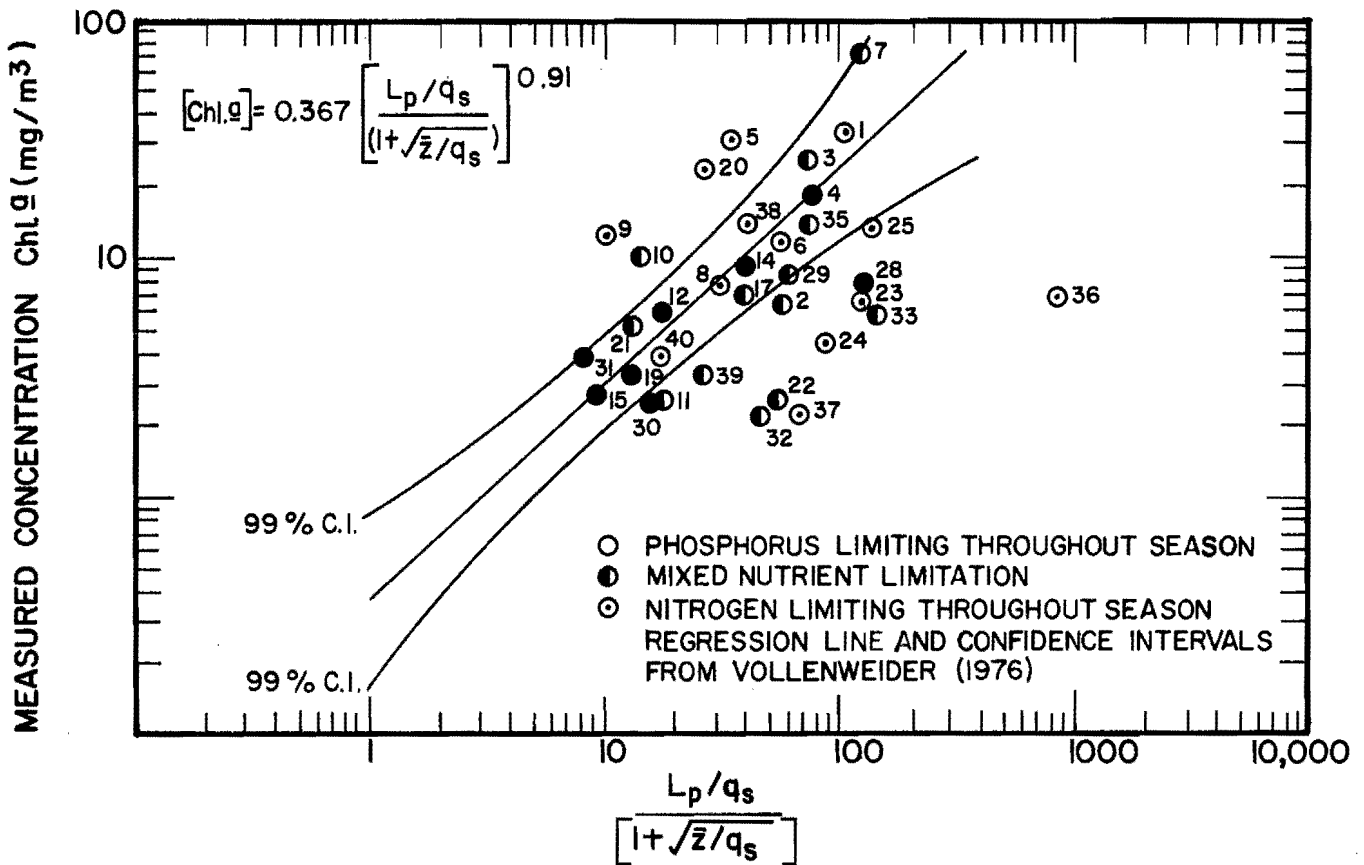
Figure 4. Mean chlorophyll a concentration vs. phosphorus loading for 34 intermountain lakes and reservoirs.

Table 4. Additional data for NES lakes and reservoirs.[a]

Lake or Reservoir and Plotting Number	Mean Depth (m)	θ_h [b] (yr.) (Based on Outflow)	Macrophytes x = noted xx = dense o = not noted	Turbidity x = noted xx = heavy o = not noted	Nutrient Limitation [c] N = nitrogen P = phosphorous N/P = mixed	S.D. [d] (m)	Volume (x10⁶ m³)	Comments
Reservoirs whose measured (chl. a) within 99% limits (n=17)								
Otter Creek (6)	6.3	1.4	o	o	N	1.2	64.8	Greyish water in May
Utah L. (7)	2.1	2.5	xx	o	N/P	0.2	832.6	Algal scums
Willard Res. (8)	5.9	3.3	o	o	N	1.1	240.5	
Ocean L. (29)	4.2	4.4	o	o	N/P	0.6	103.6	Milky green in Sept.
Bluewater L. (40)	6.7	5.8	o	o	N/P	(med) 0.5	47.4	
L. McMillan (35)	2.1	0.2	o	o	N/P	(med) 0.3	48.6	Water levels fluctuate; salinity problems
Eagle Nest L. (38)	9.9	5.3	o	o	N	(med) 1.1	97.9	blooms in Aug. & Oct.
Barker Res. (21)	8.3	0.3	o	o	N/P	2.1	14.2	
Pineview Res. (12)	13.4	0.7	x	o	P	1.7	135.6	
Echo Res. (17)	15.3	0.4	o	o	N/P	1.3	91.3	
Deer Creek (14)	19.9	0.6	x	o	P	1.7	192.3	Clumps of algae at surface in Sept.
Moon Lake (15)	14.1	0.4	o	o	P	3.1	44.1	
Dillon Res. (19)	24.6	1.3	o	o	P	8.1	313.6	
Fremont L. (31)	24.4	2.5	o	o	P	13.2	493.7	
Minersville Res. (1)	5.6	0.7	o	o	N	1.4	22.5	Algal blooms in Aug. and Sept.
Piute Res. (3)	10.1	0.7	o	o	N/P	0.4	101.5	
Sevier Bridge Res.(4)	6.5	1.6	x	o	P	1.3	291.1	Algal bloom in May
Lakes in which measured (chl. a) greater than upper limit of prediction (n=4)								
Panguitch L. (5)	6.4	2.2	xx	o	N	1.9	32.1	Algal blooms all three sampling periods
Tropic Res. (10)	3.0	0.2	xx	o	N/P	1.8	2.2	Algal bloom in August
Fish L. (9)	25.9	58.5	x	o	N	12.9	262.1	
Cherry Creek L. (20)	5.2	3.6	x	o	N	0.8	16.8	Possible bloom at station 2 in August

11

Table 4. Continued.

Lake or Reservoir and Plotting Number	Mean Depth (m)	θ_h [b] (yr.) (Based on Outflow)	Macrophytes x = noted xx = dense o = not noted	Turbidity x = noted xx = heavy o = not noted	Nutrient Limitation [c] N = nitrogen P = phosphorous N/P = mixed	S.D. [d] (m)	Volume (x10^6 m^3)	Comments
Lakes in which measured (chl. *a*) below lower limits of prediciton (*n*=13)								
Boulder L. (30)	12.2	0.5	o	o	P	3.5	85.8	
Joe's Valley Res. (11)	16.3	0.9	o	o	N/P	2.5	77.1	Some algae in August
Boysen Res. (23)	10.4	0.7	o	o	N/P	0.8	934.3	Clumps of Algae noted in Sept. and Oct.
Big Sandy Res. (24)	5.8	0.7	o	xx	N	0.3	48.4	Silt affects trout pop.
Woodruff Narrows Res. (25)	4.9	0.2	o	o	N	0.8	34.6	
Conchas Res. (39)	11.8	3.0	o	o	N/P	(med) 1.2	456.6	
El Vado Res. (37)	18.3	0.9	o	xx	N	(med) 0.9	239.9	Algal bloom in Oct.
Elephant Butte Res. (36)	18.3	2.2	o	xx	N	(med) 0.6	2,707.5	S.D. transparencie low
Alamogordo (33)	8.1	1.7	o	x	N/P	(med) 0.9	150.6	
Navajo Res. (32)	33.3	1.4	o	o	N/P	1.5	2,108	
Keyhole Res. (28)	6.5	15.2	o	o	P	1.2	246.5	Algal bloom in Oct.
Seminoe Res. (22)	25.6	0.9	o	xx	N/P	1.3	1,248.5	
Pelican L. (2)	3.0	36.8	xx	o	N/P	1.6	20.9	Bloom in Sept.

[a] Source: NES Working Papers (*EPA*, 1977).

[b] θ_h = hydraulic residence time (V/Q).

[c] P considered to be limiting when TSIN:OP $\geq$ 11.3:1 (by weight).

[d] "med" indicates median secchi disc reading (not a true mean).

Group 1: Lakes and reservoirs whose plotting position in Figure 4 lies above the upper 99 percent confidence limit calculated by Vollenweider (1976) (n = 4).

Group 2: Lakes and reservoirs whose plotting position lies within the 99 percent confidence interval calculated by Vollenweider (1976) (n = 17).

Group 3: Lakes and reservoirs whose plotting position lies below the lower 99 percent confidence limit calculated by Vollenweider (1976) (n = 13).

Data on the presence of macrophytes were taken from the text of the appropriate working papers and are qualitative assessments. The presence of macrophytes is recorded as follows.

o = the presence of macrophytes was either not mentioned or noted as the "absence of macrophytes."

x = the presence of macrophytes was noted in the working paper but was not described as being dense or covering large areas of the lake.

xx = the presence of macrophytes was noted in the working paper as being "dense" or "covering large areas of the lake."

Similarly, a qualitative assessment of the turbidity in each water body was noted in the text of each working paper. In Table 4 turbidity for each lake is noted as follows:

o = turbidity not noted.

x = "heavy" turbidity.

xx = "very heavy" turbidity.

In some cases the text of the working paper suggested that turbidity may limit algae growth.

The type of nutrient limitation for each lake is noted in Table 4 as follows.

N = nitrogen was limiting during all three sampling periods (i.e., TSIN:OP always less than 11.3:1).

N/P = nitrogen was limiting during some sampling periods and phosphorus was limting during other periods.

P = phosphorus was limiting during all three sampling periods (i.e., TSIN:OP always greater than 11.3:1).

The mean or the mean of the medians of the Secchi disc readings for each lake is presented in column 7 of Table 4. In most cases the mean Secchi disc reading for each sampling period was presented in the appropriate working paper for each sampling period. For these lakes the number in column 7 is the mean for all sampling periods. In a few cases, only the median Secchi disc reading was recorded for each sampling period. In these cases, the number in column 7 is the average of the medians and is indicated as such.

Figure 4 reveals that for many of these lakes the measured values for chlorophyll a is not within the confidence intervals established by Vollenweider. The measured concentration of chlorophyll a for these lakes fell within the 99 percent confidence interval for prediction values only half (50 percent) of the time. Thirty eight percent (n = 13) had measured chlorophyll a concentrations less than the lower 99 percent confidence limit for predicted values, and 12 percent (n = 4) had measured chlorophyll a concentrations higher than the upper 99 percent confidence limit for predicted values.

Some of the discrepancy between the actual and predicted concentrations of chlorophyll a for these water bodies can be attributed to data error. The value used for "measured mean epilimnetic chlorophyll a concentration" was the average for all stations and sampling dates for each body of water. The number of sampling periods ranged from two to four for each water body. Since the chlorophyll a concentration of a lake may vary by an order of magnitude or more throughout the growing season, an estimate based on relatively few observations is likely to be in error. Although error due to insufficient sampling should be random, there may be some negative bias in the measured chlorophyll a means since the earliest sampling data in the NES study was in May. Temperate zone lakes typically have maxima in chlorophyll a concentrations in the spring (following turnover) and in the late summer: the earlier peak may have been missed for many of these lakes, resulting in a negative bias in the mean chlorophyll a data. If a negative bias was real the fit of the survey lakes to Vollenweider's model would probably be improved if more complete data were available.

Further inspection of Figure 4 and Table 5 reveals several possible reasons for the discrepancy between the observed and predicted values for chlorophyll a concentration. For the water bodies whose measured chlorophyll a concentration fell within Vollenweider's 99 percent confidence limit (Group 2), 76.4 percent were phosphorus limited (i.e., TSIN:OP > 11.3:1) for at least one sampling period, and 35.2 percent were phosphorus limited throughout the sampling period. For the lakes in Group 1 (measured values of chl. a above Vollenweider's 99 percent confidence limit) only 25 percent were phosphorus limited at any time and none were phosphorus limited throughout the entire season. For water bodies in Group 3 (measured chl. a concentration below Vollenweider's 99 percent confidence limit) 69.2 percent were phosphorus limited for at least

Table 5. Comparison of characteristics of lakes and reservoirs falling above, within, and below confidence intervals of Vollenweider's model.

Lake Group[a]	P Always Limiting	N Always Limiting	Mixed Nut. Limitation	Measured (chl. a) in mg/m^3 (mean)	S.D.[b] in m (mean)	Depth in m (mean)	Volume in m^3 x 10^6	θ_h (yr.)	Macrophytes Noted	Turbidity Noted
Group 1 (n = 4)	0.0	75.0%	25.0%	18.9	4.4	10.1	78.3	16.1	100%	0.0
Group 2 (n = 17)	35.2%	23.5%	41.2%	15.5	2.2	10.6	184.4	1.9	21.0%	0.0
Group 3 (n = 13)	15.4%	30.8%	53.8%	5.1	1.3	13.4	658.4	5.0	8%	38.5%

[a]Group 1: Lakes in which mean chl. a concentration for sampling period above upper 99% confidence limit of Vollenweider's model.

Group 2: Lakes in which mean chl. a concentration for sampling period within 99% C.I.'s of Vollenweider's model.

Group 3: Lakes in which mean chl. a concentration for sampling period less than lower 99% confidence limit for Vollenweider's model.

[b]Mean of S.D. readings is actually mean of means and/or medians. For some lakes only the median S.D. readings were calculated in the original working papers--these medians are used as means.
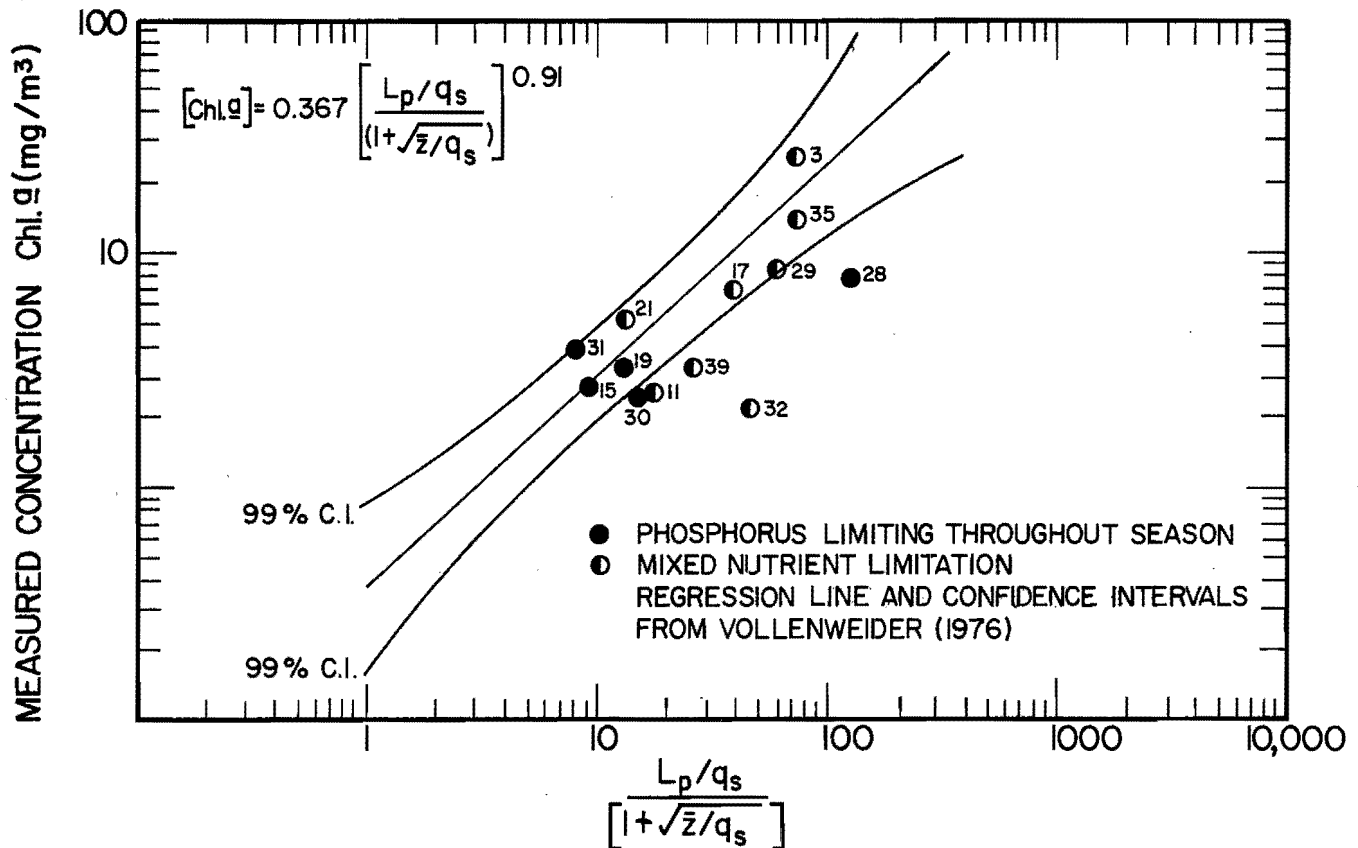
Figure 5. Mean concentration of chl. a vs. P-loading term for 13 lakes that are phosphorus limited and free of macrophytes and turbidity.

part of the year and only 15.4 percent were phosphorus limited throughout the entire sampling period. Furthermore, 75 percent of the survey lakes for which phosphorus was limiting throughout the sampling period (n = 8) fell within Vollenweider's 99 percent confidence interval. These data suggest that Vollenweider's model may be applicable only to lakes that are phosphorus limited for at least part of the growing season.

In addition, the information in Table 5 also suggests that Vollenweider's model may not be applicable to water bodies whose water is highly turbid and whose phytoplankton production is limited by light penetration. For survey lakes whose measured chlorophyll a concentrations were below Vollenweider's lower 99 percent confidence limit, 38.5 percent (n = 5) were described in the respective working papers as being "turbid" or "highly turbid" (vs. 0 percent for both Group 1 and Group 2 lakes). Furthermore, the Secchi disc data for Group 3 lakes ($\bar{x}$ = 1.3 m) is less than that for Group 1 lakes ($\bar{x}$ = 2.2 m) or Group 2 lakes ($\bar{x}$ = 4.4 m), even though the mean chlorophyll a concentration is lower for this group (5.1 mg/m^3 vs. 18.9 mg/m^3 and 15.5 mg/m^3, respectively, for Groups 1 and 2). This limitation to Vollenweider's model is probably because light penetration limits algae growth in lakes with high turbidity. Unfortunately, since quantitative data on the concentration of inorganic suspended solids is not available for the NES lakes, it is impossible to determine the upper limit of suspended solids that would preclude the use of Vollenweider's model.

Finally, the data in Table 5 suggest that Vollenweider's model may not be applicable to lakes that support macrophyte populations. All of the lakes in Group 1 had growths of macrophytes during the sampling period of the National Eutrophication Survey, while only 21 percent of those in Group 2 and 8 percent of those in Group 3 were observed to have macrophyte growths. Thus, Vollenweider's model seems to underestimate chlorophyll a when macrophytes are present. This observation is surprising in view of the fact that macrophytes are commonly considered to inhibit phytoplankton growth through light limitation and possibly by the secretion of antibiotic compounds (Wetzel 1975). On the other hand, rooted macrophytes can act as a nutrient "pump" by adsorbing phosphorus from the sediments and releasing it to the overlying waters (Wetzel 1975). If this occurs, macrophytes would act to increase the phosphorus concentration in the overlying water by increasing the residence time of phosphorus in the water column. Since Vollenweider's model assumes that the relative residence time of phosphorus is a function of the areal water load (Vollenweider 1976), any mechanisms that acts to increase the relative residence time would cause Vollenweider's model to underestimate the total phosphorus concentration in the lake. It is possible that by increasing the concentration of

phosphorus in the water, macrophytes may, in some cases, actually promote algal growth. The position of the lakes in which macrophytes occur in Figure 4 suggests that this phenomenon may be occurring.

From this section it can be concluded that the application of Vollenweider's 1976 model to phosphorus-limited lakes in the intermountain west is valid unless: 1) the lake is highly turbid and algal productivity is limited by light penetration; 2) phosphorus is not the limiting nutrient for at least part of the year; 3) the lake supports dense growth of macrophytes.

When water bodies having growths of macrophytes, high turbidity, or nitrogen limitation throughout the sampling period were omitted from this analysis, the fit between observed and predicted values of mean summer epilimnetic chlorophyll a concentration was improved considerably (Figure 5). For the remaining 13 water bodies, 61 percent of the observed mean chlorophyll a concentrations were within Vollenweider's 99 percent confidence intervals (r^2 = 0.49).

Application of Vollenweider's Phosphorus Loading Model to the Ridges Basin Reservoir

Vollenweider's phosphorus loading model (Vollenweider 1976) as described above, was used to predict the average summer epilimnetic concentration of chlorophyll a in the Ridges Basin Reservoir.

Calculation of the annual phosphorus loading into the reservoir was based on data of total phosphorus concentration determined on a monthy basis by the Utah Water Research Laboratory (Appendix B) and data of inflows into the reservoir were obtained from the USBR hydrologic simulation (Appendix A).

The annual period used for this analysis began in September 1977 and ended in August 1978. The phosphorus loading analysis was performed using phosphorus data for the Animas River since nearly all of the inflow into the reservoir will be obtained from the Animas River. The inflow data used for this analysis are based on the average simulated monthly inflow for a 48-year period (1929-1977). Actual monthly data on inflows for the study period were not available because the USBR did not simulate the hydrologic regime for 1978. Data on phosphorus concentrations and flow rate for the inflow water, together with calculations of the monthly phosphorus loading into the reservoir are presented in Table 6.

Data on average surface area and average volume for the Ridges Basin Reservoir were obtained directly from the USBR planning study for the reservoir (USBR 1978). The overflow rate, q_s, was based on the average annual inflow as determined by the USBR hydrologic model and the average annual precipitation at the Durango Weather Station (USBR 1978).

Table 6. Phosphorus loading for the proposed Ridges Basin Reservoir.

	Total P[a] (mg/ℓ)	Inflow[b] (1000 A.F.)	Loading of P[c] (1000 Kg)
Sept., 1977	0.010	8.0	98.4
Oct.	0.014	10.6	182.5
Nov.	0.008	7.1	69.9
Dec.	0.004	4.5	22.1
Jan., 1978	0.017	3.6	75.3
Feb.	0.011	3.3	44.6
March	0.008	6.1	60.0
April	0.039	13.4	642.7
May	0.338	20.4	8,481.1
June	0.037	24.4	1,110.4
July	0.028	19.0	654.4
August	0.024	12.7	374.9
ANNUAL TOTAL		133.1	10,816.2

[a] UWRL data

[b] From USBR hydrologic simulation for average year.

[c]
Loading = Total P $(\frac{mg}{\ell})$ x Inflow (1000 A.F.) x 1230 $\frac{m^3}{A.F.}$.

Based on these data (Table 7) and Vollenweider's (1976) model the mean summer epilimnetic concentration of chlorophyll a in the Ridges Basin Reservoir was calculated to be 7.9 mg/m^3 (99 percent C.I. 5-13 mg/m^3). This prediction indicates that the Ridges Basin Reservoir will be mesotrophic, according to the trophic status classification outlined by Wetzel (1975). This predicted value for mean epilimnetic chlorophyll a concentration was used to predict the average Secchi disc transparency. Carlson (1977) has found that Secchi disc transparency can be predicted from the relationship:

$$\ln S.D. = 2.04 - 0.68 \ln (chl. \underline{a}) \quad \ldots\ldots(2)$$

where S.D. = Secchi disc reading, in m

and (chl. a) is in mg/m^3, taken near the surface.

Carlson (1977) found the regression coefficient (r^2) for this relationship to be 0.93 (n = 147). Using the predicted value for the mean chlorophyll a concentration and Equation 2, the mean Secchi disc transparency

in the Ridges Basin Reservoir was calculated to be 1.9 m (6.2 ft). The chlorophyll a concentration used in this calculation was the mean value for the entire epilimnion and may be somewhat different (probably lower) than the concentration of chlorophyll a "near the surface."

Table 7. Calculation of the mean summer epilimnetic chlorophyll a concentration in the proposed Ridges Basin Reservoir.

Annual loading of phosphorus[a] 1000 Kg	10,816.2
Ave. area, $10^6 m^3$ [b]	7.8695
Ave. volume, $10^8 m^3$ [c]	2.5815
Mean depth, in m (Z)[d]	32.8
Average annual inflow $10^8 m^3$ [e]	1.637
Areal loading of phosphorus[f] mg/m^2/yr (L_p)	1,370
Areal water loading m/yr (q_s)[g]	21.27
$\dfrac{L_p/q_s}{(1 + \sqrt{Z/q_s})}$	28.73
Predicted mean summer epilimnetic[h] concentration of chlorophyll a, mg/m^3	7.79 (5-13)[i]

[a] See Table 5.

[b] From Animas-La Plata project description, USBR, January, 1978, ("ave. pool. area").

[c] Calculated using ave. pool area and area-volume output from USBR computer simulation.

[d] Mean depth = mean volume ÷ mean area.

[e] From Appendix A, Table 23 .

[f] L_p = Total P loading ÷ ave. surface area.

[g] $q_s = \dfrac{\text{ave. inflow + ave. precipitation}}{\text{ave. area}}$

[h] $(Chl. \underline{a}) = 0.367 \left[\dfrac{L_p/q_s}{(1 + \sqrt{Z/q_s})} \right]^{0.91}$

[i] 99 percent C.I.

The accuracy of the predicted concentration of chlorophyll a in the proposed Ridges Basin Reservoir depends on the validity of several assumptions that were made in using Vollenweider's (1976) model:

1. Vollenweider's model is based on the assumption that a lake is a continuously stirred tank reactor (CSTR) in which the effective hydraulic retention time is equal to the theoretical hydraulic retention time. While this assumption is never entirely true, the demonstrated reliability of this model (Vollenweider 1976) indicates that departures from this assumption are not seriously violated for most lakes. If serious short circuiting occurs in a lake, the model may not produce accurate estimates of the epilimnetic chlorophyll a concentration. In the Ridges Basin Reservoir some short circuiting may occur as a result of the fact that the position of the outlet to the Dryside Canal (70.1 m from the bottom) is located at approximately the same elevation as the inlet (82.3 m from the bottom). However, considering that the outlet and inlet are located at opposite ends of the reservoir and that the reservoir will be dimictic and have a hydraulic residence time of 1.6 years, it seems reasonable that its effective hydraulic residence time will be close to its theoretical residence time. Thus, the use of Vollenweider's model seems valid with respect to hydraulic considerations.

2. In developing this model, Vollenweider found that the relative residence time of phosphorus with respect to water could be predicted from the hydraulic residence time and was independent of trophic status. However, as pointed out in the previous section, the relative residence time of phosphorus, and hence algae growth, may be increased when macrophytes are present since rooted macrophytes may act as a nutrient pump. It was demonstrated that when macrophytes are present, Vollenweider's model may underestimate the actual chlorophyll a concentration in the epilimnion. In the Ridges Basin Reservoir, the growth of rooted macrophytes should be minimal due to the large drawdown 21.3 m (70 ft) and an increase in phytoplankton growth as the result of nutrient release by macrophytes is not expected.

3. The slope of the line that describes the relationship between the phosphorus loading term and the concentration of chlorophyll a (Figure 4) was determined in Vollenweider's model on the basis of an empirically determined relationship between the spring (turnover) concentration of total phosphorus and the mean summer concentrations of chlorophyll a in the epilimnion. Predictions of chlorophyll a using Vollenweider's model are thus based on the assumption that phosphorus is the limiting factor in determining the standing crop of phytoplankton. Although the strength of the relationship between total phosphorus concentration at turnover and the summer standing crop of chlorophyll a has been demonstrated by Sakamoto (1966) and Dillon and Rigler (1974a), other factors, such as other nutrients, turbidity or toxic materials, may limit phytoplankton production in lakes. In particular, the relationship between total phosphorus concentration at turnover and summer phytoplankton production may not be valid when other nutrients, particularly nitrogen, are limiting. In the previous section it was concluded that for water bodies that are nitrogen limited throughout the growing season, Vollenweider's model does not produce accurate estimates of the mean chlorophyll a concentration. Although the ratio of total soluble inorganic nitrogen to orthophosphate in the Ridges Basin Reservoir is not known, the ratio of TSIN:OP in the Animas River was found to be very high during four out of five sampling periods in which bioassays were conducted (Table 8). These data indicate that phosphorus is likely to be the limiting nutrient in the Ridges Basin Reservoir and thus support the validity of using Vollenweider's model to predict the chlorophyll a concentration in the reservoir.

Table 8. Nitrogen: phosphorus ratios for the Animas River at Durango.

Date	Orthophosphate (mg/ℓ P)	Ammonia (mg/ℓ N)	Nitrate + Nitrite (mg/ℓ N)	TSIN:OP[a]
September 8, 1977	26	56	122	7
November 29, 1977	<1	26	190	>216
January 9, 1978	2	99	150	125
March 8, 1978	2	48	182	115
May 10, 1978	1	24	100	124

[a] $TSIN = NO_3 + NO_2 + NH_3$

OP = Orthophosphorus

Ratio of TSIN:OP on wt:wt basis

In water bodies that are highly turbid, light may limit the growth of phytoplankton, and Vollenweider's model may overestimate the actual concentration of chlorophyll a in the epilimnion, as demonstrated earlier. Although suspended solids were not measured in this study, the water from the Animas River generally appeared to be fairly clear except during the period of spring runoff. This observation, plus the fact that the hydraulic retention time of the reservoir (1.6 years) should be long enough to allow clarification of the inflow water, support the contention that phytoplankton growth in the Ridges Basin Reservoir will not be limited by allochthonous turbidity.

17

Finally, the presence of toxic materials may limit phytoplankton growth. Algal bioassays conducted using water from the Animas River showed that growth without the addition of EDTA was only 10 to 40 percent of that expected on the basis of the nutrient composition of the water. The addition of EDTA, a known metal chelator, resulted in 80 to 100 percent of the expected growth. These data indicate that heavy metal toxicity was limiting the growth of algae in bioassays. The heavy metal most likely responsible for this toxicity is dissolved zinc, which was present at concentrations up to 150 µg/l in the Animas River. Greene et al. (1975) have demonstrated that dissolved zinc in the range of 3-121 µg/l were toxic to algae in Long Lake, Washington. It is likely that dissolved zinc will inhibit the growth of algae in the Ridges Basin Reservoir and the reservoir may have a lower standing crop of chlorophyll a than predicted by Vollenweider's model. To some extent the toxicity of zinc may be mitigated by the development of resistant strains of algae (Hutchinson and Stokes 1975) and by the precipitation of zinc in the reservoir.

4. The validity of predictions made using Vollenweider's model requires that the lake be in equilibrium with respect to the movement of phosphorus. During the period of initial filling and stabilization, this assumption is probably not valid, since phosphorus may be released from the inundated soils and vegetation. Several authors (Neel 1963, Purcell 1939) have asserted that the algal productivity of reservoirs declines following initial filling. Data to support the hypothesis of an early peak in algal productivity can be found in Purcell (1939), Whippel (1933), Barton and Johnson (1978) and Lake Tahoe Area Council (1971). They show various measures of algal productivity (microscopic cell counts, ^{14}C fixation, Secchi disc transparency, etc.) to decrease with time after the initial filling. On the other hand, some reservoirs apparently do not have a period of high initial productivity. Wright and Soltero (1973) found an increase in chlorophyll a concentration in Yellowtail Reservoir between 1968 and 1969 (filling began in 1965), Williams (1978) found no obvious trend of increase or decrease in algae standing crop or Secchi disc transparency for Raystown Reservoir, Pa., between 1974 and 1976 (filling began in October 1973). Thus, some reservoirs do not appear to go through an initial period of relatively high algal productivity. As suggested by Whipple (1933), the nature of the reservoir bottom is probably an important factor in determining whether there will be an initial period of high productivity following the initial filling.

If the Ridges Basin Reservoir has an early peak in algal productivity due to potential release of nutrients from inundated soil and vegetation, it may develop eutrophic characteristics prior to the establishment of equilibrium conditions. Inhibition of algal growth by heavy metals may prevent an early peak in algal productivity.

Finally, this prediction of trophic status was based on specified conditions for the loading of phosphorus and the hydraulic regime. The actual chlorophyll a concentration in the epilimnion may vary with changes in the phosphorus loading or pumping strategy from year to year.

If it becomes necessary to control the growth of phytoplankton in the Ridges Basin Reservoir, the most reasonable management strategy may be to take advantage of the fact that this reservoir is an off-stream reservoir whose inflows can be controlled by simply altering the pumping regime. For example, if the current average hydrologic regime were altered by interchanging the inflow for April with that of May, the phosphorus loading for the two-month period would be decreased from 9123 kg to 6550 kg, a decrease of 2573 kg. This reduction of phosphorus loading would result in a decrease in the mean summer chlorophyll a concentration in the epilimnion from 7.9 mg/m^3 to 6.0 mg/m^3. A management strategy to reduce algal productivity could be based on an attempt to pump water into the reservoir when the phosphorus concentration in the Animas River is relatively low and to avoid pumping during periods of very high phosphorus concentration.

DEPLETION OF HYPOLIMNETIC DISSOLVED OXYGEN

Introduction

The extent to which oxygen is depleted in the hypolimnion during the period of summer stratification is an important aspect of the environmental quality of lakes. During this period, the thermocline forms a diffusion barrier that limits the vertical movement of dissolved substances, including oxygen. The oxygen pool in the hypolimnion is utilized during the stratification period by biological respiration, nitrification, and other inorganic oxidation reactions. A decrease in the concentration of hypolimnetic dissolved oxygen throughout the summer usually occurs. When the stratification is distinct and the inputs of oxidizable materials are sufficiently large, the hypolimnion may become anoxic.

Most beneficial uses of stored water are adversely affected by this decline in oxygen concentration. Populations of fish and fish food organisms are especially susceptible to decreases in oxygen concentrations. For this reason the proposed Colorado Water Quality Standards specify a minimum dissolved oxygen concentration of 6.0 mg/l (7.0 mg/l for spawning) for the protection of a cold water biota and 5.0 mg/l for the protection of a warm water biota. In addition to the direct impact on fisheries, large decreases in the concentration of dissolved oxygen in the hypolimnion may result in the accumulation of anaerobic decomposition products including methane, ammonia, hydrogen sulfide and organic acids in the hypolimnetic water. The presence of these compounds is particularly undesirable with respect to municipal water supply and recreational water use. Finally, low concentrations of dissolved oxygen in the hypolimnion may cause the resolubilization of metal precipitates. The resolubilization of manganese and iron is highly undesirable with respect to municipal water supply since the presence of these metals gives drinking water an unpleasant taste and causes staining of sinks and clothing. The resolubilization of heavy metals such as lead, cadmium, and zinc may be more important. These metals may be toxic to both humans and the aquatic biota. The resolubilization of heavy metals is a potential problem in the Ridges Basin Reservoir due to the high concentrations of heavy metals in the Animas River.

In view of the severity of problems that may result due to an oxygen depletion in the hypolimnion, a prediction of the dissolved oxygen concentrations that will occur in the Ridges Basin Reservoir would be useful. This section is an attempt to model the behavior of oxygen in the hypolimnion of the Ridges Basin Reservoir. Since much of the input data used in this model was obtained from a thermal simulation of the reservoir performed by the USBR, a brief description of the USBR thermal simulation precedes the section on model development.

USBR Temperature Simulation

The USBR Durango Field Station simulated the thermal regime of the Ridges Basin Reservoir using a modified version of the U. S. Corps of Engineer/Water Resources Engineers temperature simulation model for the period May 1 - August 28, 1977. The development of this model is discussed in the U. S. Corps of Engineers (1975) and by Burdick and Parker (1971).

The hydrologic data used in this simulation were obtained from the USBR operational study of Ridges Basin Reservoir and USGS flow data for the Animas River. Data on water temperature in the Animas River were obtained by the U. S. Fish and Wildlife Service. Meteorological data were obtained from the USBR Kroeger Demo. Farm located 4.5 miles southwest of the reservoir site. Since only total radiation data were available, data on short wave radiation were generated using the data on total radiation and data on cloud cover (Reg. Leech, USBR Durango Field Office).

The results of the USBR temperature simulation are presented in Appendix F. Their diffusion coefficients are largest in the area of the thermocline, although this is exactly the oposite of what should occur. Sartoris (1978) shows that minimum effective diffusion occurs at the thermocline and the maxima occur in the hypolimnion and near the surface. Furthermore, calculation of gravitational stability, E, using the density data from this model as described by Sartoris (1978) do not give the same values as those found in the column titled "stability" in the USBR temperature simulation.

These observations suggest that an error was made in running this model. Conversations with Jim Sartoris (USBR Engineering and Research Center) and Reg. Leech (USBR Durango Field Office) support this contention. The simulation of hypolimnetic dissolved oxygen described in the following pages utilized the output from the USBR thermal simulation.

Model Development

In order to predict the concentrations of dissolved oxygen in the hypolimnion of the Ridges Basin Reservoir during the period of stratification, a simple model of hypolimnetic oxygen depletion was developed. In the development of this model several assumptions were made concerning the behavior of dissolved oxygen in lakes.

First, both the epilimnion and the hypolimnion were considered to be continuously stirred tank reactors (CSTR's) and thus verticially homogeneous with respect to dissolved oxygen concentration. The entire gradient of oxygen concentrations between the surface and the bottom was thereby compressed in the model into a single depth interval at the thermocline. The entire epilimnion was considered to be saturated at a concentration corresponding to that of the surface temperature of the reservoir (corrected for altitude). At the onset of stratification the reservoir was considered to be saturated with dissolved oxygen throughout its depth.

Three processes were considered to affect the oxygen concentration of the hypolimnion: diffusion across the thermocline, benthic utilization, and loss by advection through hypolimnetic outflow. The rate of change in the mass of hypolimnetic dissolved oxygen was calculated as a function of these three processes:

$$\frac{dM_h}{dt} = \frac{dM_d}{dt} + \frac{dM_b}{dt} + \frac{dM_o}{dt} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where

M_h = mass of hypolimnetic dissolved oxygen

M_d = mass of oxygen gained (or lost) by diffusion across the thermocline

M_o = mass of oxygen lost to the hypolimnetic outflow

M_b = mass of oxygen utilized by benthic demand

Oxygen concentration was related to mass by the relationship

$$\frac{dC_h}{dt} = \frac{dM_h}{V_h dt} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

where

C_h = concentration of oxygen in the hypolimnion

V_h = volume of hypolimnion

The development of each segment of the model is discussed below.

Diffusion

The rate of oxygen diffusion across the thermocline for Equation 3 was estimated with the relationship:

$$\frac{dM_d}{dt} = D_c \, (C_o - C_h) \, \frac{A_h}{\Delta z} \quad \ldots\ldots\ldots\ldots (5)$$

where

C_o = concentration of oxygen in the epilimnion

C_h = concentration of oxygen in the hypolimnion

A_h = the surface area of the thermocline

ΔZ = the thickness of the layer being considered

D_c = effective diffusion coefficient

A positive value of dM_d/dt indicates a gain of oxygen by the hypolimnion and a negative sign indicates a loss of oxygen from the hypolimnion.

In this model the term D_c is an "effective diffusion coefficient" that is composed of both true molecular diffusion and convection mixing (U. S. Corps of Engineers 1975). The use of a general effective diffusion coefficient for dissolved substances can be defended since molecular diffusion itself is very small in magnitude (U. S. Corps of Engineers 1975). Hutchinson (1957) presents data on Lake Mendota to support this contention. Values for D_c across the thermocline were based on the stability of the thermocline, where the stability, E, is calculated:

$$E = \frac{1}{\rho} \frac{d\rho}{dz} \quad \ldots\ldots\ldots\ldots (6)$$

where

$d\rho/dz$ = density gradient

$\bar{\rho}$ = average density of interval

In this model values of E were calculated for intervals immediately above the thermocline plane as defined by the USBR thermal regime model. The value of E for each time interval was used to determine values for D_c from a plot of D_c vs. E (U. S. Corps of Engineers 1975, Figure II-2). Three values of D_c were used for each time interval as defined by the three curves depicted in U. S. Corps of Engineers (1975) Figure II-2 in order to assess the range of reasonable values for the mass flux of oxygen across the thermocline.

The element thickness of the diffusion limiting element was considered to be 6.1 m. This thickness corresponds to the element thickness of the USBR temperature simulation of the reservoir. The epilimnion was considered to have a dissolved oxygen concentration corresponding to the saturation value for the surface temperature of the reservoir at each time segment. Saturation values were adjusted to account for the effects of altitude using the formula (Hutchinson 1957):

$$[O_2]_h = [O_2]_o \frac{P_h}{760} \qquad \dots\dots\dots\dots\dots(7)$$

and

$$\log P_h = \log P_o - \frac{273h}{18,241 \, (t+273+0.0025h)}$$
$$\dots\dots\dots\dots\dots(8)$$

where

$[O_2]_h$ = saturation concentration at elevation h, mg/l

$[O_2]_o$ = saturation concentration at sea level, mg/l

h = elevation, in m

P_h = atmospheric pressure, in mm Hg

P_o = 760 mm Hg

t = surface temperature of the lake, °C

The hypolimnion was considered to be saturated at the beginning of the first time increment (May 10 - May 20). The cross sectional area of the thermocline was determined using the area-depth curve accompanying the USBR temperature simulation. The data inputs, processes, and outputs for the segment of the model that computes the mass flux of oxygen across the hypolimnion are summarized in Figure 6.

Benthic demand

In this model of hypolimnetic dissolved oxygen, the two mechanisms by which the oxygen concentration is decreased is benthic demand and advection via the outflow. Of these, the benthic demand was expected to be the predominant mechanism.

For each time interval, i, the total benthic oxygen demand was calculated as follows:

$$\frac{dM_b}{dt} = B_i \times A_b \qquad \dots\dots\dots\dots\dots(9)$$

where

A_b = area of sediment under hypolimnion

B_i = areal rate of oxygen utilization by benthos during interval i

A literature review was conducted to find data on sediment oxygen demand (S.O.D.) values for other lakes. It was expected that SOD values could be grouped according to trophic status, with S.O.D. values increasing along the spectrum from oligotrophy to eutrophy. If such a categorization could be established, a S.O.D. value for the Ridges Basin Reservoir could be chosen on the basis of a knowledge of its trophic status (mesotrophic). The benthic demand was considered to be a constant with respect to time, but was considered to be a function of temperature and the dissolved oxygen concentration of the overlying water:

$$B_i = f(S.O.D._{temp,D.O.}) \qquad \dots\dots\dots\dots(10)$$

where

$S.O.D._{temp, D.O.}$ = sediment oxygen demand at specified temperature and oxygen concentration

INPUTS   PROCESSES   OUTPUT
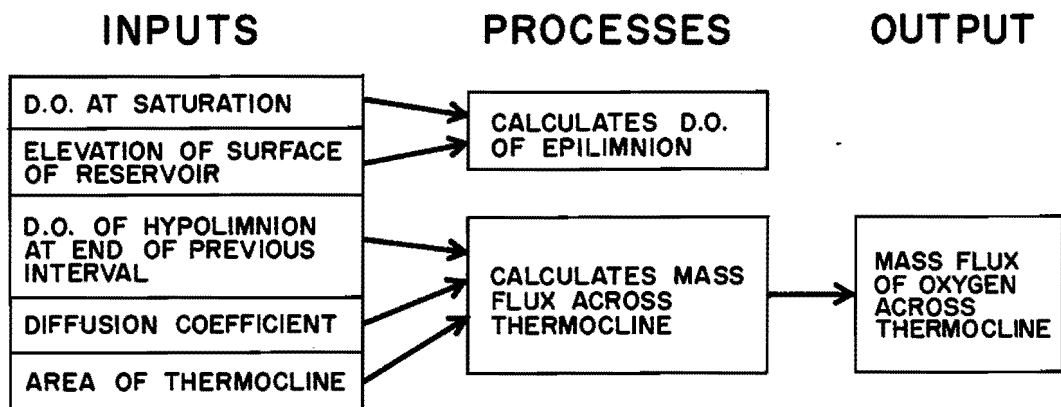
Figure 6. Diffusion submodel.

The literature on sediment oxygen demand was reviewed to establish the nature of the relationship between sediment oxygen demand and temperature and between sediment oxygen demand and dissolved oxygen concentration. Existing data were also reviewed with respect to establishing a relationship between S.O.D. and trophic status.

It should be noted that studies of sediment oxygen demand have been conducted under a variety of conditions. These differences dictate that comparisons in S.O.D. values found by various researchers be made with care. Usually these studies are conducted by enclosing a small area of sediment together with a volume of water in a cylinder composed of plexiglass or other material. Dissolved oxygen concentrations in the overlying water are measured with an oxygen electrode (Edberg and Hofsten 1973, Edwards and Rolley 1965, McDonnell and Hall 1969, Rolley and Owens 1967) or using the Winkler titration (Sonzogni et al. 1977, Hayes and MacAulay 1959, Hargrave 1969). Although some studies involve the use of mixed sediments (Porcella et al. 1975), only data from studies that involved the use of "undisturbed" cores are included in the following analysis. Most of the experiments involving the determination of S.O.D. values have been determined in the laboratory, although Sonzogni et al. (1977) conducted their experiments both in situ and in vitro. Edberg and Hofsten (1973) found S.O.D. values determined in vitro to be lower than S.O.D. values determined in situ and attributed this difference to disturbance of the sediments in the in vitro experiments. In vitro determinations were used where available in this paper, although it is realized that the application of in vitro S.O.D. values to the field may be somewhat erroneous, even after accounting for the effects of differences in temperature and D.O. in the overlying water.

The effect of temperature on S.O.D. values can be described using the van't Hoff-Arrhenius equation. In modified form, Metcalf and Eddy (1972) used a temperature coefficient, θ, to evaluate differences in reaction rates that can be attributed to differences in reaction temperature:

$$\frac{K_2}{K_1} = \theta^{(t_2 - t_1)} \qquad \ldots\ldots\ldots\ldots(11)$$

where

K_1, K_2 = reaction rates

t_1, t_2 = temperature

An equivalent expression can be derived to allow calculations of a temperature correction factor, t_c:

$$t_c = \frac{1}{t_2 - t_1} \ln \frac{K_2}{K_1} \qquad \ldots\ldots\ldots\ldots(12)$$

where

$t_c = \ln \theta$

Several investigators (Hargrave 1969, Pamatat and Banse 1969, Edwards and Rolley 1965, Edberg and Hofsten 1973, McDonnell and Hall 1969, Fair et al. 1941) have conducted studies of S.O.D. at various temperatures. Temperature coefficients obtained in these studies are presented in Table 9. In some cases, the temperature coefficient for a particular study was calculated from values of Q_{10} or other similar expressions. The data of Edberg and Hofsten (1973) were not included in the calculation of an average value for t_c because their experiments were conducted with pure cultures of cellulytic bacteria; it is not felt that this experiment was sufficiently representative of natural conditions.

Table 9. The effect of temperature on sediment oxygen demand.

Source	Temperature Range (°C)	t_c
Fair et al. (1941)	?	0.065-0.075
McDonnell and Hall (1969)	5-25	0.067
Edwards and Rolley (1965)	10-20	0.065-0.077
Pamatat and Banse (1969)	5-10	0.083
	5-15	0.041
Hargrave (1969)	2-12	0.203
	10-20	0.079

An average value of t_c was calculated from these data. Where several temperature ranges or sites were investigated, an average for the experiments was used. The average value for t_c was found to be 0.082 for these experiments. This value of t_c was used for adjusting S.O.D. values to 10°C in order to make comparisons in S.O.D. values among different lakes. It was also used to adjust the input S.O.D. value used in the model (S.O.D._temp, D.O.) to the temperature of each time interval for calculations of benthic demand.

The effect of D.O. concentration on S.O.D. can be described by the equation (Edwards and Rolley 1965):

$$y = aC^b \qquad \ldots\ldots\ldots\ldots(13)$$

An average value of t_c was calculated

where

C = D.O. concentration of the overlying water

y = S.O.D.

a,b = constants

22

Table 10. Determination of coefficients for correction of the effect of the oxygen concentration in the overlying water on sediment demand.[a]

C[b] (mg/ℓ)	$\ell n\ C$	y[b] R. IVEL	R. GAPE	R. HIZ	$\bar{y}$	$\ell n\ \bar{y}$
8	2.08	0.15	0.22	0.21	0.193	-1.65
6	1.79	0.13	0.20	0.19	0.173	-1.75
4	1.38	0.10	0.17	0.16	0.143	-1.94
2	0.693	0.07	0.13	0.12	0.107	-2.23

[a] Data taken from Figure 5, *Edwards and Rolley* 1965. Data from
R. Lark omitted because high concentration of invertebrates caused
poor fit.

[b] $y = aC^b$

C = concentration of oxygen in overlying water, mg/ℓ

y = S.O.D. $(gO_2/m^2\text{-hr})$

a,b = 0.08 and 0.42, respectively (established by plotting).

The effect of D.O. concentration on S.O.D. values depends largely on the abundance of invertebrates in the sediment. Sediments containing large numbers of invertebrates show a more pronounced change in S.O.D. with declining D.O. than do sediments containing fewer invertebrates; this is reflected in the coefficients of Equation 13. Values for a and b are listed for the work of McDonnell and Hall (1969), Knowles et al. (1962), and Edwards and Rolley (1965)[1] in Table 11. A more extensive compilation of these coefficients is presented in McDonnell and Hall (1969). Typical values for a are in the range 0.08-0.25 and for b, 0.30-0.42. Trial calculations indicate that this range of coefficients is too broad to permit reasonably accurate prediction of S.O.D. from a knowledge of D.O. concentration.

Thus, while S.O.D. decreases with decreasing D.O. concentration, the coefficients that have been found in the literature vary too much to permit an accurate generalization. However, most investigators have found a minimal effect of D.O. concentration on S.O.D. when the D.O. concentration was above 5-6 mg/1 (c.f. Figure 3 in Knowles et al. 1962, Figure 4 in McDonnell and Hall 1969, Figure 5 in Edwards and Rolley 1965). For the purpose of this model, S.O.D. values were assumed to follow 0th order kinetics (S.O.D. independent of D.O.) when the oxygen

concentration was above 5 mg/l. When the D.O. drops below this level, this model would overestimate the rate of decline, that is, the predicted D.O. concentration would be lower than the actual D.O. concentration. This error could be serious when very low D.O. concentrations are encountered.

Sediment oxygen demand values for a number of sediments are presented in Table 12. The separation into trophic categories was done somewhat subjectively since in most cases the authors of these studies did not present a great deal of field data on which to base a trophic categorization. The trophic status of most of these lakes was determined from the authors' description (Hargrave 1969, Brewer et al. 1977, Edberg and Hofsten 1973, Sonzogni et al 1977, McDonnell and Hall 1969). In other cases data on phosphorus concentration, hypolimnetic oxygen depletion, or visual descriptions were used as a basis of trophic class designation (Kreizenbeck 1974, Hayes and MacAulay 1959).

Since the experimental temperatures at which these S.O.D. values were determined were not uniform, the S.O.D. data were adjusted to 10°C using the value of t_c = 0.082 determined earlier. Oxygen concentrations for each experiment were noted, although no quantitative adjustment was made to account for differences in the D.O. concentration of the overlying water. In all experiments used for this evaluation the D.O. concentration in the overlying water was 6 mg/l or greater.

[1] The raw data of Edwards and Rolley (1965) was used to compute values for a and b in Equation 12 (Table 10).

Table 11. Effect of oxygen concentration of overlying water on sediment oxygen utilization.[a]

Source	Type of Sediment	Invertebrate Concentration	a	b
McDonnell and Hall (1969)	Eutrophic stream	"low"	0.08	0.39
		"high"	0.25	0.39
Knowles et al. (1962)		$39,000/m^2$	0.20	0.38
		$296,000/m^2$	0.31	0.38
Edwards and Rolley (1965)[b]	River muds		0.08	0.42

[a]Effect of oxygen concentration described by equation .

$$y = aC^b$$

where y = rate of oxygen utilization, gO_2/m^2-hr

C = concentration of dissolved oxygen in overlying water

a,b = 0.08 and 0.42, respectively (established by plotting).

[b]See Table 10 for calculation of a, b from raw data.

Data on S.O.D. values were compiled for six eutrophic lakes, eight mesotrophic lakes, and three oligotrophic lakes. In order to establish the range of S.O.D. values for each trophic class, frequency distributions were plotted (Figure 7). Inspection of this plot shows that eutrophic lakes have a wide range of S.O.D. values. For the six eutrophic lakes observed, the S.O.D. values ranged from 0.17-2.95 g O_2/m^2 day (95 percent confidence interval: 0.24-2.61 g O_2/m^2 day. It would be difficult to determine a reasonable value for sediment oxygen demand in eutrophic lakes using these data. For the three oligotrophic lakes, S.O.D. values ranged from 0.168-0.247 g O_2/m^2 day with a mean of 0.197 g O_2/m^2 day (95 percent C.I.: 0.089-0.305 g O_2/m^2 day). The six mesotrophic lakes ranged in S.O.D. values from 0.139-0.836 g O_2/m^2 day with a mean of 0.399 g O_2/m^2 day (95 percent C.I.: 0.203-0.595 g O_2/m^2 day). For a mesotrophic lake, the sediment oxygen demand at 10°C can be considered to be in the range of 0.2-0.6 g O_2/m^2 day. Values for the S.O.D. constant in the model used for the Ridges Basin Reservoir were considered to be within this range based on previous data and model runs were conducted for values of 0.2, 0.4, and 0.6 g O_2/m^2 day.

In order to calculate the benthic demand during each time interval (Equation 9), it was necessary to compute the bottom area under the thermocline throughout the stratification period. The area of the horizontal plane measured for each 6.1 m (20 ft) contour was determined using 1:400 scale topographic map and the USBR area-elevation curve. As a first step in measuring the bottom area along the sideslope, a map wheel was used to determine the linear distance around the reservoir halfway between the 6.1 m (20 ft)
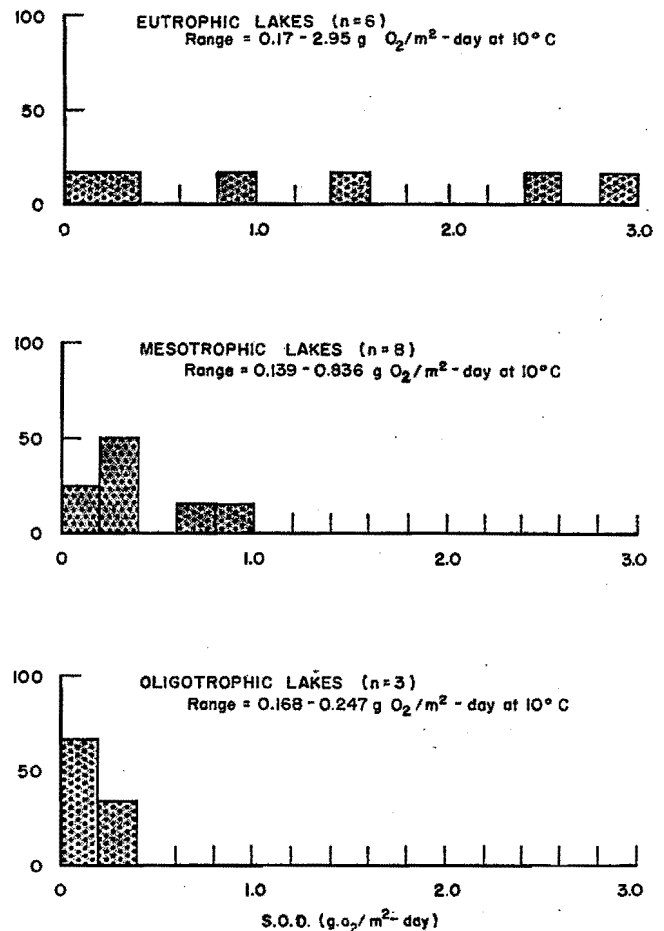
Figure 7. Frequency distribution for S.O.D. values for lakes.

24

Table 12. Oxygen consumed in water over enclosed sediments.[a]

Source	Lake and Trophic Status	Exp. Temperature (°C)	D.O. of Overlying Water (mg/1)	O_2 Demand (gO_2/m^2 day)	O_2 Demand Adjusted to 10°C (gO_2/m^2 day)
EUTROPHIC LAKES					
Sonzogni et al. (1977)	Shagawa L., Wisconsin	est. 10	8.0	0.12 – 0.22 $\bar{x} = 0.17$	0.12 – 0.22 $\bar{x} = 0.17$
Hayes and MacAulay (1959)	Montague, P.E.I. Canada	11.0 ± 0.5	"aerated"	1.63	1.52
Edberg and Hofsten (1973)	Norrviken 1	5	"<10"	1.8	2.53
	Norrviken 2	7	"<10"	2.4	2.95
Brewer et al. (1977)	L. Hartwell, S.C.	18		0.308–0.985 $\bar{x}=0.684$	0.178–0.570 $\bar{x}=0.374$
Kreizenbeck (1974)[b]	L. Milner, Idaho	21–23	6.3 – 8.4	0.89 – 5.33 $\bar{x} = 2.28$	0.392 – 1.86 $\bar{x} = 1.00$
MESOTROPHIC LAKES					
Edberg and Hofsten (1973)	Erken 1	4	"<10"	0.43	0.648
	Erken 2	14	"<10"	0.50	0.380
Hayes and MacAulay (1959)	Copper Lake	11.0 ± 0.5	"aerated"	0.309	0.289
	Lily Lake	11.0 ± 0.5	"aerated"	0.399	0.373
	Sutherland			0.198	0.185
	Crecy			0.149	0.139
	Gibson			0.376	0.343
	Southport			0.895	0.836
OLIGOTROPHIC LAKES					
Hayes and MacAulay (1959)	Bluff Lake	11.0 ± 0.5	"aerated"	0.188	0.176
	Grand Lake	11.0 ± 0.5	"aerated"	0.264	0.247
Hargrave (1970)	Marion Lake	10	> 6	0.168	0.168

[a] The S.O.D. values in column are adjusted to 10°C using a temperature correction factor (t_c) of 0.082 (see equation 12).

[b] Mean value of S.O.D. based on data from five stations.

contours (c in Figure 8). The average distance between contours was then calculated using this value and the difference between the surface areas between the two contours (k in Figure 8):

$$k = \frac{A_{c_i} - A_{c_{i-1}}}{\bar{C}} \quad \text{(see Figure 8)} \quad \ldots\text{(14)}$$

Since the vertical distance between contours was always 6.1 m, the average linear distance along the bottom between contours was calculated as:

$$j^2 = 37.2 + k^2 \quad \text{(see Figure 8)} \quad \ldots\text{(15)}$$

The area of the bottom between contours C_i and C_{i+1} was calculated directly:

$$A_i = j \cdot \bar{C} \quad \ldots\ldots\ldots\ldots\text{(16)}$$

25
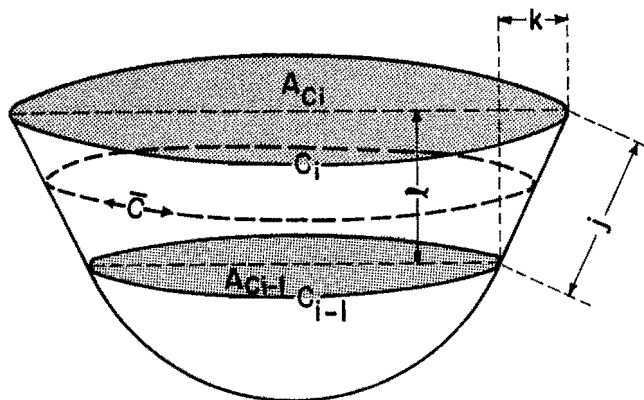
A_B = AREA OF BOTTOM

A_{Ci} = AREA WITHIN CONTOUR i

A_{Ci-l} = AREA WITHIN CONTOUR i-l

l = DISTANCE BETWEEN CONTOURS i and i-l

$\bar{C}$ = CIRCUMFERENCE OF CONTOUR BETWEEN i and i-l = $\dfrac{Ci + Ci-l}{2}$

ΔA_B = l x $\bar{C}$

A_{B_i} = CUMULATIVE AREA OF BOTTOM UNDER CONTOUR i

Figure 8. Schematic diagram showing method used to calculate surface area of reservoir bottom.

The total area under each contour, A_{B_i}, was then calculated by summing the areas between contours for all the lower contours. This technique seemed to work well for all contours above an elevation of 2054 m (6740 ft).

For contours below 2054 m (6740 ft) the surface area between consecutive contours was considered to be equal to the bottom area between the contours (due to measuring difficulties of the irregular topography). While this approach is not strictly correct, the error in calculating the total bottom area incurred by this simplification was very small: the surface area of 85 x 10^3 m^2 under the 2054 m (6740 ft) contour is about one percent of the total bottom area (8,327 x 10^3 m^2) of the reservoir. Data from this analysis are presented in Table 13.

A summary of all inputs, computation processes and outputs for the benthic demand segment of the model is presented in Figure 9.

Advective losses

A small amount of water leaves the Ridges Basin Reservoir via a hypolimnetic outlet and is returned to the Animas River for municipal and industrial supply downstream. The concentration of dissolved oxygen in this outflow was considered to be the same as that of the hypolimnion. The mass of oxygen lost by advection was calculated as:

$$\frac{dM_o}{dt} = Q_i \times C_h \qquad \ldots \ldots \ldots \ldots \ldots (17)$$

where

Q_i = outflow rate (m^3/sec)

C_h = concentration of dissolved oxygen in the hypolimnion (mg/l)

A summary of all the inputs, processes, and outputs from this model is presented in Figure 10. Input data used in the simulation are presented in Table 14. The computer program used in this simulation ("OXYHYP") is presented in Appendix G, Tables 54 and 55.

Results

"OXYHYP" was run using the range of S.O.D. values determined for mesotrophic lakes (0.2-0.6 g O_2/m^2 day). The diffusion coefficient, D_c, was varied over the range of values given by the U.S. Corps of Engineers (1975) (Table 14). Model runs were made using all possible combinations of values for S.O.D. and D_c (nine runs). The output from each model run is presented in Appendix G.

The output from model runs using S.O.D. values of 0.2, 0.4, and 0.6 g O_2/m^2 day and the middle set of diffusion coefficients are presented in Table 15 and Figure 11. In Figure 11, the three oxygen depletion curves are extrapolated from August 30 (Day 240) through November 30 (Day 330) by assuming that the rate of change in dissolved oxygen concentration in the hypolimnion is constant throughout the stratification period. The rate of change in dissolved oxygen concentration beyond Day 240 was determined as:

$$\frac{dC}{dt} = \frac{C_{130} - C_{240}}{110 \text{ days}}. \qquad \ldots \ldots \ldots \ldots \ldots (18)$$

where

$\dfrac{dC}{dt}$ = rate of change in D.O. concentration

C_{130} = D.O. concentration (mg/l at Day 130

C_{240} = D.O. concentration (mg/l) at Day 240

110 days = length of model run

26

Table 13. Calculation of the bottom surface area for Ridges Basin Reservoir.[a]

Contour (m) (Measured from Bottom)	ℓ (m)	A_{Ci} ($10^3 m^2$)	A_{Ci-1} ($10^3 m^2$)	$\frac{C_i+C_{i-1}}{2}$ (m)	k (m)	j (m)	ΔA_B (m x 10^3)	ΣA_B (m x 10^3)
0.0		0	-		-			
6.1	6.1	8.09	0	-	-		8.09	8.09
12.2	6.1	28.3	8.09	-	-		20.21	28.3
18.3	6.1	85.0	28.3	-			56.7	85.0
24.4	6.1	671	85.0	7,271	80.6	80.8	587	672
30.5	6.1	1,631	671	8,636	111.2	111.4	962	1,634
36.6	6.1	2,452	1,631	10,143	80.9	81.1	823	2,457
42.7	6.1	3,153	2,452	12,655	55.4	55.7	705	3,162
48.8	6.1	3,820	3,153	15,849	42.1	42.5	674	3,836
54.9	6.1	4,597	3,820	18,433	42.2	42.6	785	4,621
61.0	6.1	5,350	4,597	20,521	36.7	37.2	763	5,384
67.1	6.1	6,078	5,350	21,847	33.3	33.8	738	6,122
73.2	6.1	6,807	6,078	25,236	28.9	29.5	745	6,867
79.2	6.1	7,499	6,807	28,430	24.3	25.1	713	7,580
85.3	6.1	8,219	7,499	32,822	21.9	22.7	747	8,327

[a] All terms defined in Figure 8.
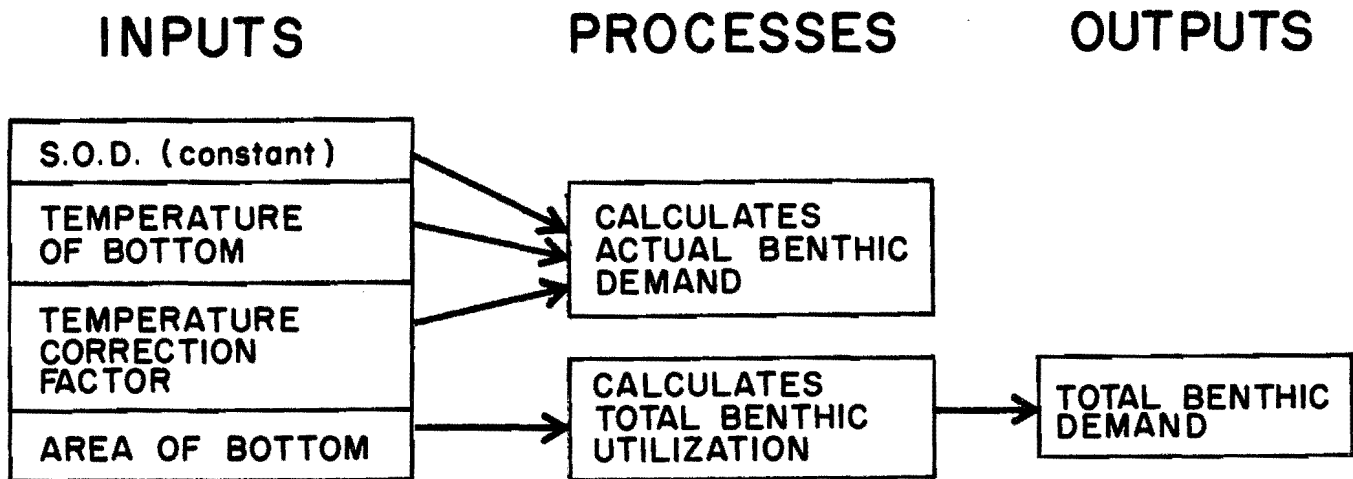
Figure 9. Benthic demand submodel.

Table 14. Input data used in the simulation of hypolimnetic dissolved oxygen in the Ridges Basin Reservoir.

Day	Distance to Thermocline(m) [b]	Hypolimnion Sediment Surface Area (x10^6 m^2) [2]	Hypolimnion Area of Thermocline (x10^6 m^2) [a]	Volume (x10^8 m^3) [a]	Temperature, °C Bottom	Temperature, °C Surface	Elevation of Surface, m. [a]	D.O., mg/l sat. at Surface Temp. under 760 mm Hg Pressure	Hypolimnetic Outflow [c] m^3/sec	Depth to Thermocline(m)	Stability(m^-1) [d]	Diffusion Coefficient [e] High	Low	High
121	1	7.580	7.499	2.355	4.44	4.44	2115.2	12.98	0.00	–	0	10.0	2.5	0.16
130	73.2	6.867	6.807	1.899	4.45	7.41	2121.1	12.05	0.00	73.2	5.72×10^{-5}	0.35	0.17	0.035
140	73.2	6.867	6.807	1.899	4.5	7.81	2120.4	11.93	1.53	73.2	4.32×10^{-5}	0.46	0.19	0.037
150	67.1	6.122	6.078	1.506	4.45	8.32	2119.6	11.78	0.00	67.1	6.64×10^{-5}	0.31	0.16	0.031
160	67.1	6.122	6.078	1.506	4.49	9.96	2119.4	11.32	0.00	67.1	9.84×10^{-5}	0.19	0.12	0.021
170	67.1	6.122	6.078	1.506	4.60	11.16	2118.9	11.04	0.00	67.1	1.17×10^{-4}	0.17	0.10	0.020
180	48.8	3.836	3.820	0.599	4.83	11.56	2117.5	10.94	0.00	48.8	6.08×10^{-5}	0.31	0.15	0.032
190	67.1	6.122	6.078	1.506	5.42	12.79	2115.7	10.65	1.64	67.1	1.27×10^{-4}	0.16	0.090	0.018
200	67.1	6.122	6.078	1.506	6.42	12.60	2113.8	10.46	0.65	67.1	1.12×10^{-4}	0.17	0.10	0.020
210	61.00	5.384	6.078	1.506	7.20	13.40	2113.3	10.51	0.00	61.0	1.19×10^{-4}	0.17	0.10	0.019
220	61.0	5.384	6.078	1.506	8.20	14.15	2112.7	10.34	0.00	61.0	1.33×10^{-4}	0.16	0.09	0.018
230	61.0	5.383	6.078	1.506	9.29	14.47	2112.4	10.27	0.00	61.0	1.08×10^{-4}	0.17	0.10	0.020
240	61.0	5.384	6.078	1.506	10.30	15.24	2112.8	10.10	0.00	61.0	1.14×10^{-4}	0.17	0.10	0.020

[a] Data from USBR temperature simulation of Ridges Basin Reservoir

[b] Computed by integration of contours (see text)

[c] From *Metcalf and Eddy* (1972)

[d] Stability, $E = \frac{1}{\rho} \frac{d\rho}{dz}$

[e] Diffusion coefficients from *USCE*, 1975, Figure II-2

INPUTS

VOLUME OF HYPOLIMNION
LENGTH AND NUMBER INTERVALS
TEMPERATURE OF SURFACE
TEMPERATURE OF BOTTOM
SEDIMENT OXYGEN DEMAND AT 10°C
FLOW THROUGH HYPOLIMNETIC OUTFLOW
OXYGEN SATURATION AT SURFACE TEMPERATURE (1.0 atm)
ELEVATION OF SURFACE
AREA OF THERMOCLINE
AREA OF HYPOLIMNETIC SEDIMENT
DIFFUSION COEFFICIENT

PROCESSES

UTILIZATION BY BENTHOS
EQUILIBRATION OF OXYGEN SATURATION AT SURFACE
LOSS BY ADVECTION
GAIN (LOSS) BY DIFFUSION

OUTPUTS

O_2 CONCENTRATION IN EPILIMNION
MASS OF O_2 USED BY BENTHOS
CHANGE IN MASS OF O_2 FROM DIFFUSION
MASS OF O_2 LOST BY ADVECTION
O_2 CONCENTRATION OF HYPOLIMNION

Figure 10. Summary of D.O. model.

The rates of change in D.O. concentration were determined to be 0.00754, 0.0132, and 0.0189 mg O_2/l day for S.O.D. values of 0.2, 0.4, and 0.6 g O_2/m^2 day, respectively.

Discussion

The output from this model indicates that most of the change in mass of hypolimnetic dissolved oxygen occurred as the result of benthic demand. Thus, for the middle values for S.O.D. and diffusion, benthic demand accounted for 86 percent, loss via the outflow accounted for 14 percent, and the diffusion accounted for less than one percent of the total change in mass of hypolimnetic oxygen. Variation of the diffusion coefficient over the range of values presented in the U.S. Corps of Engineers (1975) caused no changes in the predicted values for hypolimnetic dissolved oxygen concentration (Table 55), in spite of the fact that upper range of diffusion constants are approximately one order of magnitude larger than the lower range. Error associated with estimating the thickness of the element limiting diffusion should be very small considering the relatively small effect of diffusion on the overall oxygen budget of the reservoir.

This model indicates that the dissolved oxygen concentration in the hypolimnion will drop to between 7.3 and 8.6 mg/l by the end of August. This level of dissolved oxygen is adequate for the maintenance of a cold water fauna. Water quality problems associated with low concentrations of dissolved oxygen do not occur in this range of concentrations. However, this simulation stops on August 28 because the USBR thermal simulation was not continued to fall turnover. In this location fall turnover usually occurs in October or November, so this model does not include the last two or three months of the stratification period. The results of this simulation were linearly extrapolated to the end of November in order to estimate the D.O. concentration in the hypolimnion at the end of the stratification period. Extrapolation of this simulation to November 30 indicates that the hypolimnetic D.O. concentration would drop to between 5.5 and 7.9 mg/l (Figure 11). The lower estimate of 5.5 mg/l is below the Colorado Water Quality Standard established for the protection of cold water biota. However, an extrapolation of the model results beyond the period of simulation is not strictly valid since the rate of change in the D.O. concentration of the hypolimnion is not linear (Figure 11). To obtain a more accurate estimate of the D.O. concentration at the end of the stratification, the thermal simulation should be extended to the turnover period and the data obtained from this simulation should be used to extend the results of the oxygen simulation model. This procedure seems especially worthwhile in view of the possibility that the D.O. concentration in the hypolimnion may drop to a level that would be detrimental to a cold water biota.

These predictions of hypolimnetic dissolved oxygen were based on assumptions that: 1) the sediment oxygen demand in a lake is directly related to its trophic status, 2) benthic demand is the major oxygen depletion mechanism in the hypolimnion, 3) both the epilimnion and the hypolimnion can be treated as CSTR's, and 4) a lake undergoes

Table 15. Predicted dissolved oxygen concentration in Ridges Basin Reservoir.[a]

Date	Day	Epilimnion[b]	Hypolimnion[c]		
			S.O.D. = 0.200	S.O.D. = 0.400	S.O.D. = 0.600
5/10	130	9.39	9.39	9.39	9.39
5/20	140	9.24	9.39	9.39	9.39
5/30	150	9.17	9.34	9.29	9.24
6/9	160	8.79	9.20	9.09	8.97
6/19	170	8.57	9.14	8.97	8.81
6/29	180	8.49	9.09	8.86	8.64
7/9	190	8.35	8.95	8.58	8.22
7/19	200	8.20	8.91	8.51	8.11
7/29	210	8.20	8.77	8.32	7.87
8/8	220	8.05	8.68	8.17	7.66
8/18	230	8.06	8.62	8.06	7.49
8/20	240	7.90	8.56	7.94	7.31

[a] All D.O. values in mg/ℓ.

[b] Epilimnion considered saturated

[c] Values calculated using middle diffusion coefficient curve from *USCE*, 1975, Figure 11-2.
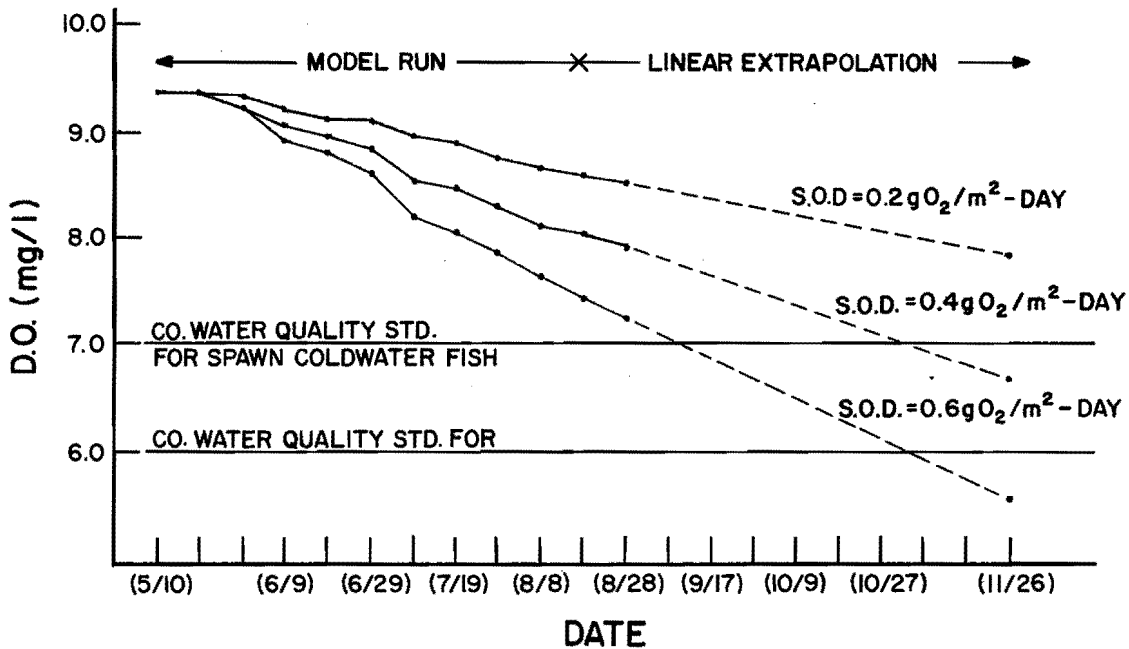
Figure 11. Dissolved oxygen simulation in the hypolimnion of the proposed Ridges Basin Reservoir.

complete mixing during turnover and becomes saturated with dissolved oxygen throughout its depth.

The clumping of S.O.D. values when plotted according to trophic status (Figure 7) suggests that there is a relationship between trophic status and sediment oxygen demand. The basis of this relationship is that the sediment oxygen demand is related to the amount of organic matter that falls to the bottom of lakes. Since there is more organic matter produced in lakes of higher trophic status, it follows that S.O.D. is related to trophic status. The relationship between S.O.D. and trophic status was alluded to by Hutchinson (1938), who proposed that the areal depletion of oxygen in the hypolimnion of lakes is related to trophic status. Hutchinson (1957) proposed ranges of the areal oxygen deficit of 0.04-0.33, 0.33-0.50, and greater than 0.50 g O_2/m^2 day for oligotrophic, mesotrophic, and eutrophic lakes, respectively. Newbold and Liggett (1974) found that the oxygen depletion in the hypolimnion of mesotrophic Lake Cayuga could be estimated by assuming that the organic material falling into the hypolimnion was completely decomposed. In the same study, Newbold and Liggett found that benthic uptake was the major mechanism of oxygen uptake in the hypolimnion. Their study adds support to the contention that benthic demand is a function of trophic status.

In the Ridges Basin Reservoir the sediment oxygen demand may be less than the range of values for S.O.D. proposed in this study for mesotrophic lakes as the result of heavy metal toxicity. Heavy metal toxicity would reduce the sediment oxygen demand by 1) preventing the growth of algae and thereby reducing the amount of organic material falling into the hypolimnion, and 2) decreasing the respiratory activity of bacteria in the sediments.

A second major assumption used in this model was that benthic demand is the major mechanism of oxygen depletion in the hypolimnion. The similarity between Hutchinson's (1957) proposed ranges for the areal oxygen deficits and the ranges for S.O.D. in oligotrophic and mesotrophic lakes in this study (0.09-0.25 and 0.20-0.60 g O_2/m^2 day, respectively) support the contention that sediment oxygen demand is a major mechanism of oxygen depletion in lakes. Although the oxygen demand of the open water may result in significant depletion of oxygen in some lakes, especially those containing humic matter (Hayes and MacAulay 1959), many researchers have found that the oxygen demand that occurs in the open water is relatively minor compared to the demand exerted by benthic processes. In studies of sediment oxygen demand, neither Pamatat and Banse (1969) in a study of Puget Sound, nor Hargrave (1969) studying oligotrohpic Lake Marion, could detect changes in oxygen concentration in enclosed samples of water containing no sediments. In Newbold and Liggett's (1974) study of Lake Cayuga, oxygen-utilizing processes in the hypolimnetic water were computed to result in a depletion of only 0.8 mg/l during the 120 day stratification period.

The assumption that both the epilimnion and the hypolimnion behave like CSTR's was made so that both the epilimnion and the hypolimnion could be considered to be vertically homogeneous with respect to the distribution of dissolved oxygen. Furthermore, the epilimnion was considered to be exactly saturated. The assumption that the epilimnion has a vertically homogeneous distribution of dissolved oxygen is probably valid for most lakes, although the concentration of dissolved oxygen in the epilimnion may be significantly different from the saturation due to photosynthesis or respiration. A eutrophic lake is often supersaturated with dissolved oxygen during the daytime, due to oxygen generated by photosynthesis, and undersaturated at night, due to respiration. However, since the rate of transfer of oxygen from the epilimnion to the hypolimnion is probably very low, the small error that may have resulted in assuming the epilimnion to be saturated would have had little effect on the oxygen dynamics of the hypolimnion. The assumption that the hypolimnion is vertically homogeneous with respect to dissolved oxygen may not be strictly correct since oxygen profiles of the hypolimnion often exhibit a marked decline in oxygen concentration near the sediment surface. This localized depression of oxygen concentration near the sediment surface is the result of limited diffusion to the sediment. Thus, a prediction of the average dissolved oxygen concentration in the hypolimnion does not indicate the lowest D.O. values that may be found near the sediment surface.

Finally, it was assumed that the Ridges Basin Reservoir will be completely mixed at turnover and will be saturated throughout its depth at this time. In reality, the dissolved oxygen concentration at the bottom of lakes may not be completely saturated due to incomplete mixing, biological respiration, and photosynthesis. Hutchinson (1957) cites examples to show that the oxygen concentration of lakes during turnover may be as low as 91 percent or as high as 116 percent of the saturation value. If the actual D.O. concentration in the Ridges Basin Reservoir at turnover is less than the saturation value, the actual D.O. concentrations in the hypolimnion will be proportionately lower throughout the summer.

The quality of the input data is also a constraint on the accuracy of predictions generated by this model. Of particular importance in this respect is the possible errors associated with the USBR temperature simulation. Since the oxygen model utilized output from the temperature simulation, the results of the oxygen model can only be as accurate as the results of the temperature

simulation. The accuracy of the results generated by the USBR thermal simulation is questionable and the use of these data may have produced errors in the oxygen simulation.

The predictions generated by this model are not applicable to the Ridges Basin Reservoir during its early life, since reservoirs often undergo a period of stabilization following their initial filling. During this period, the oxygen demand exerted by the decay of inundated soils and vegetation may result in hypolimnetic dissolved concentrations that are considerably lower than occur following the stabilization period. The extent of the oxygen depletion during the early life of a reservoir is related to the type and quantity of vegetation being merged (Ball et al. 1975) and probably to the organic content of the inundated soils.

There are numerous examples of reservoirs that have undergone a period of severe oxygen depletion following the initial filling. Purcell (1939) observed a gradual increase in the dissolved concentration in Wanague Reservoir, New Jersey, during the first 10 years following impoundment (from 0 percent to 20 percent of saturation). Associated with the increase in D.O. concentration was a decrease in concentrations of soluble iron and manganese and hydrogen sulfide. Similarly, Duffer and Harlin (1971) found a complete depletion in dissolved oxygen in Arbunkle Reservoir, Oklahoma, during the first two years after filling, although it is not known whether this problem has improved. Churchill (1957) states that the presence of hydrogen sulfide (associated with anoxic conditions) may be a problem in TVA reservoirs during the first year of operation. In some reservoirs a change in hypolimnetic D.O., at least in the first few years, does not seem to occur. Williams (1978) found no significant change in the hypolimnetic D.O. concentrations during the first three summers following filling of Raystown Dam, Pennsylvania. Barton and Johnson (1978) found no change in the D.O. concentration in the bottom of Cocchiti Reservoir, New Mexico, between the first and second years of filling.

Thus, although many reservoirs exhibit a pattern of severe oxygen depletion in the hypolimnion after their initial filling followed by subsequent improvement, this pattern is not ubiquitous. It would be difficult to predict whether or not the Ridges Basin Reservoir will undergo a period of oxygen depletion in its early life as the result of the decomposition of inundated plants and soils or how long this stabilization period will last. A microcosm study involving the use of soils from the reservoir site and water from the Animas River to simulate the period following initial filling may be useful in determining the potential for early oxygen depletion in the hypolimnion of the newly formed reservoir.

Introduction

The presence of heavy metals in a body of water is significant for several reasons: 1) certain metals, such as iron, magnesium, manganese, cobalt, zinc, and copper, are essential micronutrients in biological systems, 2) all of the heavy metals (including those that are essential micronutrients) are toxic to organisms in high concentrations, and 3) many of the metals react with other dissolved constituents. In evaluating the limnology of a new reservoir, it would be desirable to predict the concentrations and speciation of the heavy metals in the stored water, the sediments, and the various components of the biota. Unfortunately, available water quality models provide only a rough prediction of trace metal concentrations in aquatic systems (Leckie and James 1976). Furthermore, the water quality parameters measured for the Animas River during this study do not provide sufficient data for detailed chemical modeling. Nevertheless an attempt was made to predict the retention of several heavy metals using a simple mass balance model similar to that used by Dillon and Rigler (1974b) and Chapra (1975) to predict the retention of phosphorus in lakes. Literature values of metal retention were used in conjunction with the mass balance model to calculate average settling velocities for iron, zinc, copper, lead, manganese, and cadmium. These calculated settling velocities were used to predict the retention of four of these metals in the proposed Ridges Basin Reservoir.

Metal Retention Model

The movement of any metal m in a lake can be described by a simple mass balance equation:

$$V \frac{dm}{dt} = W_m - Qm - K_m Vm \quad \dots\dots\dots\dots (19)$$

where

V = lake volume

W_m = mass loading of metal m

Q = outflow

m = concentration of metal in lake water

K_m = a first-order rate constant for loss to the sediments for metal m

This model makes several limiting assumptions (Dillon and Rigler 1974b):

1. The lake is a continuously stirred tank reactor (CSTR).

2. The rate of sedimentation is proportional to the amount of substance that is in the lake (i.e., K is truly first-order).

3. The concentration of the outflow is equal to the concentration in the lake.

4. There are no seasonal fluctuations in loading rate.

Although these assumptions are violated in lake systems to various degrees, this approach has been widely used in the modeling of phosphorus (Vollenweider 1969, 1973, 1976, Dillon and Rigler 1974b, Chapra 1975, Kirchner and Dillon 1975).

If it is assumed that the concentration of any metal reaches equilibrium in a lake, the term dm/dt approaches 0. Under this condition,

$$W_m = Qm + K_m Vm \quad \dots\dots\dots\dots (20)$$

A retention coefficient, R_m, can be expressed as:

$$R_m = \frac{K_m Vm}{W_m} = \frac{W_m - Qm}{W_m} \quad \dots\dots\dots\dots (21)$$

Setting $\rho = Q/V$ and solving for m in Equation 20:

$$m = \frac{W_m}{Q + K_m V} \quad \dots\dots\dots\dots (22)$$

$$R_m = \frac{K_m V}{Q + K_m V} = \frac{K_m}{\rho + K_m} \quad \dots\dots\dots\dots (23)$$

33

Kirchner and Dillon (1975) showed that by multiplying both the numerator and the denominator on the right side of the equation by $\bar{z}$, the mean depth, the following equation is produced:

$$R_m = \frac{K_m \bar{z}}{\bar{z}\rho + \bar{z}K} = \frac{v_m}{v_m + q_s} \quad \cdots\cdots\cdots (24)$$

where

q_s = areal water load

v_m = apparent settling velocity for metal m

If v is a constant for the removal of metals, then the retention coefficient, R, can be predicted from q_s. If R is known, then the amount of a metal accumulated by a lake in a given year can be calculated:

$$R_m W_m = L_{s,m} \quad \cdots\cdots\cdots\cdots (25)$$

where

$L_{s,m}$ = loading to sediment for metal m

From this, the loss of metals in the lake discharge can be calculated:

$$L_{o,m} = L_{i,m} - L_{s,m} \quad \cdots\cdots\cdots (26)$$

where

$L_{i,m}$ = loading of metal m to outflow

$L_{o,m}$ = inflow loading of metal m

The use of an average settling velocity to calculate the retention of various metals ignores potentially important differences in transport mechanisms such as resolubilization at the sediment surface, chemical precipitation, and bioaccumulation. Although there are certainly differences in transport mechanisms of individual metals among lakes, several authors (Baccini 1976, Hem 1972, Delfino et al. 1969) have concluded that simple sedimentation of incoming suspended matter is a major mechanism by which metals are removed from the water column, adding support to the concept of using an average settling velocity to predict metals retention. The relationship between the loading of suspended metals and the overall retention of metals for several lakes is discussed later in this section.

Evaluation of Metal Retention Model

To determine values for v_m in Equation 24 for various metals data on metal retention coefficients and areal water loading was needed for a number of lakes. Data on metals retention coefficients in six lakes were extracted from the literature. In some cases data on retention coefficients for one or more metals were presented in the published literature, but for most lakes the retention coefficients for various metals were calculated using published data on metals concentrations and flow. The six lakes for which suitable data existed and the references used are:

1. Pueblo Reservoir, Colorado (Herrmann and Mahan 1977, W. C. Kregger USBR, unpublished data)

2. Derwent Reservoir, England (Harding and Whitton 1978)

3. Alpnachersee, Switzerland (Baccini 1976)

4. Lake Washington, Washington (Barnes and Schell 1972)

5. Coeur d'Alene Lake, Idaho (Funk et al. 1975, USEPA 1975b)

6. Yellowtail Reservoir, Montana (Wright and Soltero 1975)

Details concerning the calculation of loading, morphological data, and a brief description of each lake are discussed in Appendix H. It was recognized that for some of these lakes (Derwent Reservoir, L. Washington, and Yellowtail Reservoir) the metals loading data may be inaccurate, but they were all that were available. For lakes in which data were available for more than one year, the data were broken into time segments of approximately one year. For Pueblo Reservoir adequate data existed from June 1975 – September 1976. These data were divided into two segments, one extending from June through September 1975, and the other extending from October 1975 through September 1976. For Yellowtail Reservoir the data were also divided into two segments, one extending from February to December 1968, and the other extending from January through August 1969. These data are presented in Table 16.

The data collected on metals retention was used to calculate the settling velocity of each metal in each lake by rearranging Equation 24:

$$v_m = \frac{R_m q_s}{1-R_m} \quad \cdots\cdots\cdots\cdots (27)$$

Based on these settling velocities an average settling velocity for each metal was calculated, together with 95 percent confidence intervals. Data on the settling velocity of each metal in each lake, the average settling velocity for each metal and the 95 percent confidence intervals for each mean are presented in Table 17. Average settling velocities were calculated for iron, zinc, manganese, copper, cadmium and lead. The average settling velocities for manganese and cadmium were based on only two data points each. Since the 95 percent confidence

Table 16. Metal retention data for six lakes.[a]

Lake and Location	Ave. Volume (x 10^6 m^3)	Ave. Area (x 10^6 m^2)	Θ_h (yr.)	q_s (m/yr)	% Retention					
					Fe	Zn	Mn	Pb	Cu	Cd
Pueblo Reservoir, Colorado June-Sept., 1975	29.03	4.42	0.052	59.7	–	78.3	–	100.0	–	–
Oct., 1975-Sept., 1976	36.53	5.09	0.098	135.3	19.6	25.5	–	73.4	–	–
Coeur D'Alene Lake, Idaho	294.	129.5	0.035	64.9		17.5				
Yellowtail Reservoir, Montana Feb.-Dec., 1968	970	30.2	0.313	102.6	92.7	31.0	80.0	–	21.4	–
Jan.-Aug., 1969	1048	37.9	0.407	67.9	96.2	52.5	87.8	–	57.1	–
Alpnachersee, Switzerland	100.1	4.76	0.284	73.97	92	50	–	62	42	18
Derwent Reservoir, England	5.06	4.05	0.133	13.08		70.3		89.2	–	98.3
Lake Washington, Washington	2904	88	2.48	13.3	99.2	44.9		96.8	58.8	

[a]See Appendix H for sources of data.

intervals of the average settling velocities for cadmium and manganese were too broad for the estimate to be considered reliable, these metals were not considered further. The average settling velocity for lead does not include a value for Pueblo Reservoir for the period June - September 1975 because complete retention of the lead entering the reservoir made v_{Pb} undefined. The fact that all of the lead entering Pueblo Reservoir during this period was retained may indicate that 1) lead has a very high settling velocity in this reservoir, 2) the loading of lead was not constant, or 3) the reservoir is not behaving as a CSTR. The calculated average apparent settling velocity for lead is thus enclosed in parenthesis to indicate an element of uncertainty since the early 1975 data for Pueblo Reservoir was not included.

To test the statistical validity of metals retentions predicted from these average settling velocities, the average settling velocity for each metal and the areal water load (q_s) for each lake was used to calculate predicted values for metals retentions in each lake (R_p) using Equation 24 (Table 18). These values of predicted retention were compared to the observed values of retention (R_{ob}) for each metal using a coefficient of determination (r^2). Values of r^2 between R_p and R_{ob} were 0.53, 0.23, 0.47, and 0.39, respectively, for iron, zinc, copper, and lead.

Finally, the relationship between the areal water load (q_s) and predicted retention (R_p for iron, zinc, lead, and copper was depicted graphically in Figures 12-15 using the mean and the upper and lower boundary values of the 95 percent confidence interval of the average settling velocity for each metal.

In terms of statistical confidence, the best relationship between metal retention and areal water load was found for iron. Despite the wide confidence interval (248-1974 m/yr) surrounding the estimate of the mean settling velocity for iron, this range of values is so high with respect to the areal water load that a large fraction of the iron is retained throughout the range of areal water loads plotted. Even the lower 95 percent confidence interval estimate of v_{Fe}, 248 m/yr, results in over 60 percent of the iron being retained with an areal water load of 140 m/yr. The r^2 of 0.53 between the predicted values of retention (using the calculated average settling velocity) and the observed values indicates that there is a strong correlation between calculated and observed values. However, despite the apparent strength of the relationship between R and q_s for iron, it should be noted that the observed retention coefficient for iron in Pueblo Reservoir (0.20) was much less than the predicted value (0.89). This large discrepancy probably results from the fact that the mechanisms by which iron is trans-

35

Table 17. Apparent settling velocities for metals in six lakes.[a]

Lake	Apparent Settling Velocity,[b] v_m (m/yr)					
	Fe	Zn	Mn	Pb[c]	Cu	Cd
Pueblo Reservoir						
June-Sept., 1975		215		–		
Oct., 1975-Sept. 1976	33	46		371		
Coeur D'Alene Lake		14				
Yellowtail Reservoir						
Feb.-Dec., 1968	1,303	46	410		28	
Jan.-Aug., 1969	1,719	75	489		90	
Alpnachersee	851	74		121	55	16
Derwent Reservoir		31		108		756
Lake Washington	1,649	11		402	19	
Average	1,111	64	449	(251)	48	386
95% Confidence Intervals						
Upper	1,974	119	1018	(375)	99	3855
Lower	248	9	-120	(127)	-3	-3083

[a]See text for sources of data.

[b]Apparent settling velocity, $v_m = \dfrac{R_m q_s}{1 - R_m}$

where

R_m = fraction of metal m retained
q_s = areal water load, m/yr (m^3/yr/m^2)

[c]Calculation of ave. settling velocity does not include the early 1975 data for Pueblo Reservoir; 100 percent of the load was retained during this period, making v = undefined.

ported in Pueblo Reservoir is somehow different from the iron transport mechanisms in the other four lakes for which iron retention data were available and illustrates a basic weakness in using average settling velocities to predict metal retentions in lakes.

The plot of retention coefficient versus areal water load for lead (Figure 13) shows that the majority of lead entering the four study lakes was retained. For these four lakes the observed retention coefficient was never below 0.60 (X = 0.84). This plot also indicates that the retention of lead can be predicted with reasonable reliability. The r^2 between the predicted and observed values of the retention coefficient of lead was 0.39. The 95 percent confidence interval for the mean settling velocity for lead was 127-375 m/yr.

For zinc the average settling velocity was 64 m/yr (95 percent confidence interval: 9-119 m/yr). Because the settling velocity for zinc is so low, the distance between the 9 m/yr curve and the 119 m/yr curve is relatively large (Figure 14). Comparison of these curves with those for iron show that

while the relative width of the 95 percent confidence interval is similar ($\pm$ 85 percent of the mean for zinc; $\pm$ 77.7 percent of the mean for iron), the accuracy of predictions of iron retention are better than those for zinc. For example, for a lake with an areal water load of 100 m/yr, the 95 percent confidence interval estimate of retention for zinc is 0.08-0.58 (range of 0.50) while that for iron is 0.70-0.95 (range of 0.25). The narrower range of estimates for the retention of iron is a result of the fact that the average apparent settling velocity for iron (1,111 m/yr) is much greater than that for zinc (45 m/yr). As discussed earlier, retention coefficients can be predicted more accurately for metals whose apparent settling rate is high relative to normal water loading rates. The accuracy of predictions of zinc retention, based on data obtained in this study, would be very low and thus of limited usefulness. The value of r^2 for the relationship between predicted and observed values of zinc retention was only 0.23.

The 95 percent confidence interval for the estimate of the apparent settling velocity of copper is between -3 and 99 m/yr

36

Table 18. Comparison of measured vs. predicted metals retention in six study lakes.[a]

Lake	Fe		Zn		Cu		Pb	
	R_{ob}	R_p	R_{ob}	R_p	R_{ob}	R_p	R_{ob}	R_p
Pueblo Reservoir								
June-Sept., 1975			0.78	0.52			1.0	0.81
Oct. 1975-Sept., 1976	0.20	0.89	0.26	0.32			0.73	0.65
Coeur D'Alene L.			0.18	0.50				
Yellowtail Reservoir								
Feb.-Dec., 1968	0.93	0.92	0.31	0.38	0.21	0.32		
Jan.-Aug., 1969	0.96	0.94	0.53	0.49	0.57	0.41		
Alpnachersee	0.92	0.93	0.50	0.46	0.42	0.39	0.62	0.77
Derwent Reservoir	.		0.70	0.83			0.89	0.95
Lake Washington	0.99	0.99	0.45	0.83	0.59	0.78	0.97	0.95
r^2	0.53		0.23		0.47		0.39	

[a] R_{ob} = measured retention (see Table 16)

R_p = predicted retention, using average apparent settling velocity for each metal (Table 17)

$$R_p = \frac{v_m}{v_m + q_s}$$

where

v_m = average apparent settling velocity for metal, m/yr

q_s = areal water load, m/yr (m^3/yr/m^2)

(v_{Cu} = 48 m/yr). An apparent settling velocity of -3 m/yr indicates that copper is moving upward. Since this cannot occur, the 95 percent confidence interval for the v_{Cu} was taken as 0 - 99 m/yr. From inspection of Figure 15 it can be seen that the retention coefficient for copper was less than 0.60 for all four of the lakes observed. The plots of R vs q_s and v_{Cu} = 0 m/yr and v_{Cu} = 99 m/yr indicate that predictions of the retention of copper on the basis of its apparent settling velocity cover a broad range of values. Based on this range of settling velocities, a lake with an areal water load of 100 m/yr would have a predicted retention of 0 - 50 percent. Nevertheless, the value of r^2 for the relationship between the predicted and observed retention of copper in the four lakes for which data were available is 0.47.

The mean and confidence intervals of the apparent settling velocities of iron, lead, zinc, and copper are presented diagramatically in Figure 16. The calculated apparent settling velocities for these metals follows the sequence:

Fe $\geq$ Pb > Zn = Cu

This sequence suggests that iron and lead are retained much more effectively by lakes than are zinc and copper. Two possible explanations for this sequence are: 1) that the mechanisms by which iron and lead are removed are different from the mechanisms by which copper and zinc are removed, or 2) that the major removal mechanisms for all four metals is simple sedimentation. Iron and lead may have higher apparent settling velocities simply because they are relatively more abundant in the suspended fraction than are zinc and copper, and it is the suspended fraction that is most rapidly removed by sedimentation.

The second explanation is strongly supported by the data of Baccini (1976). In his study at Alpnachersee, Switzerland, Baccini (1976) found a very strong relationship between the proportion of iron, zinc, copper, and cadmium entering Alpnachersee in the particulate form and portions of each metal retained in the lake (r^2 = 0.95). From these data Baccini concluded that simple sedimentation of the suspended fraction entering the lake was the major mechniams by which these metals were retained. The data collected by Herrmann and Mahan (1976) for Pueblo Reservoir tend to support this hypoth-
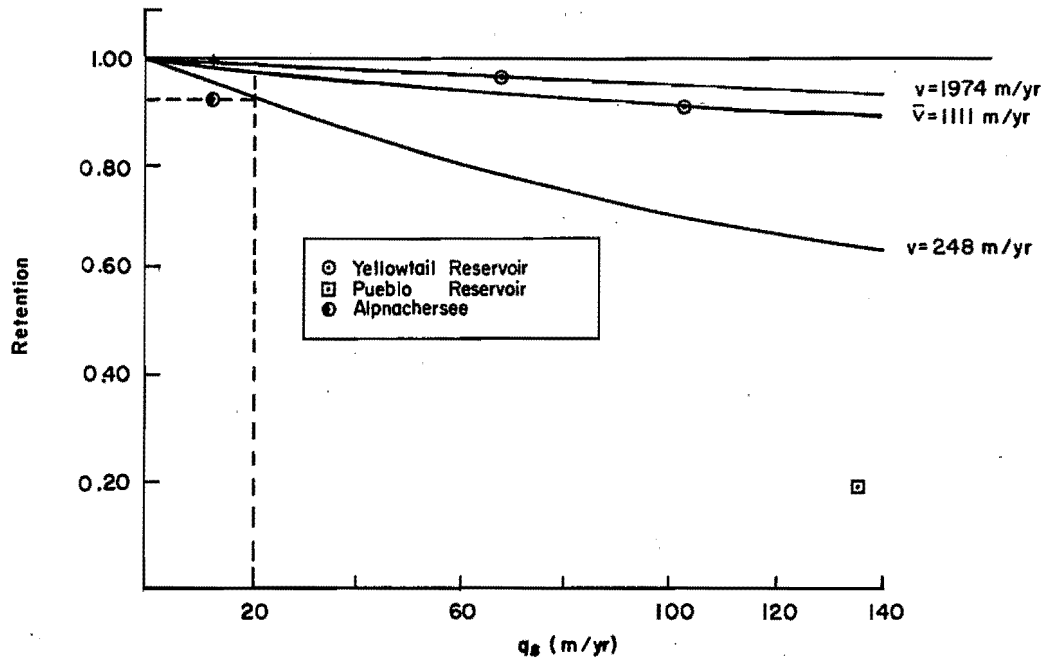
Figure 12. Retention of iron vs. areal water load.
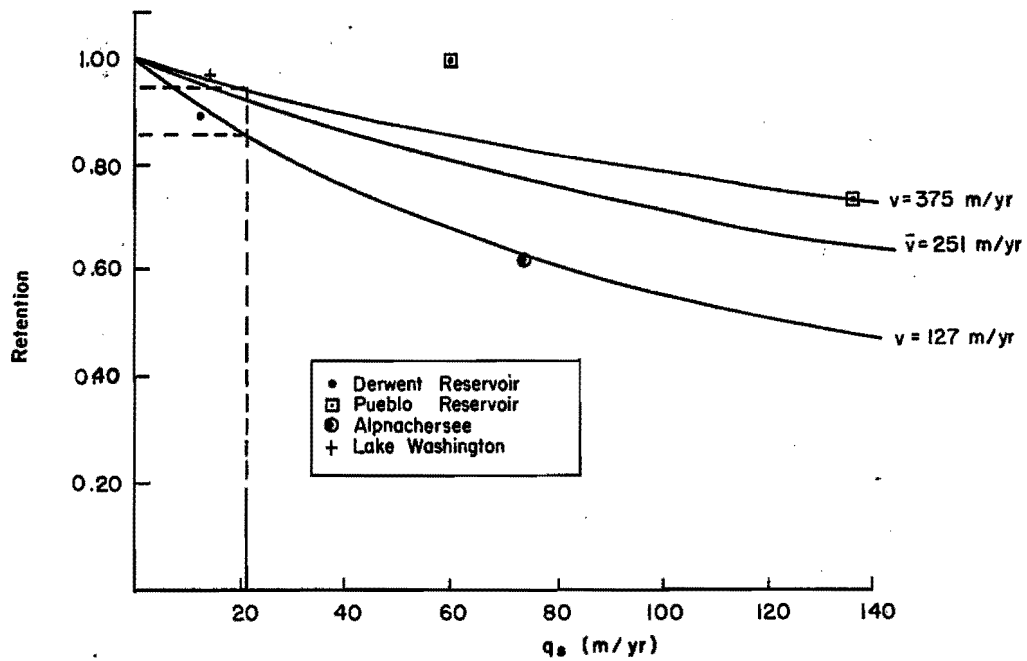
Figure 13. Retention of lead vs. areal water load.
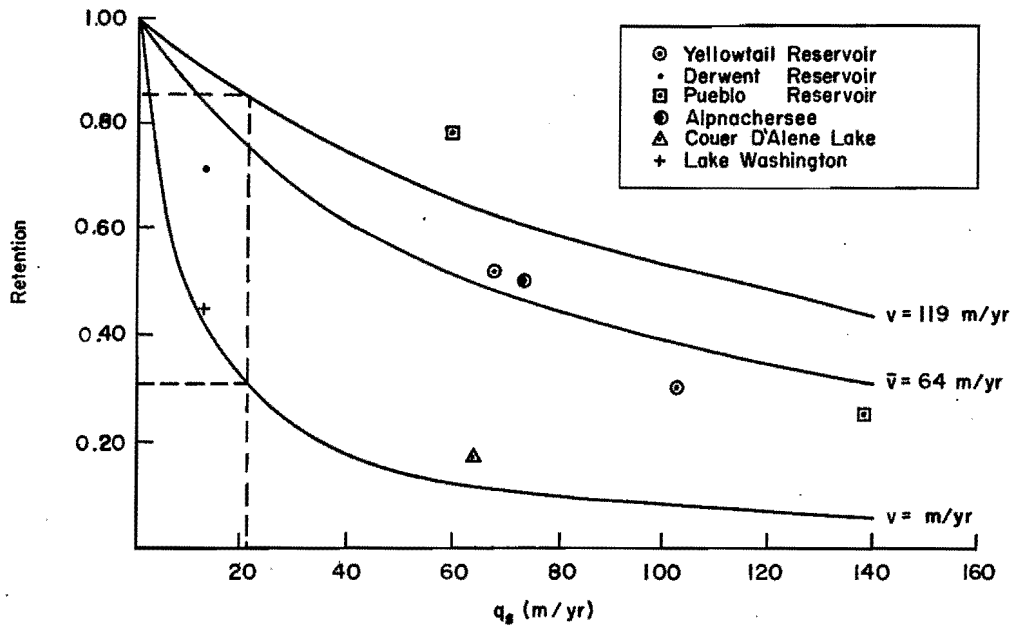
Figure 14. Retention of zinc vs. areal water load.
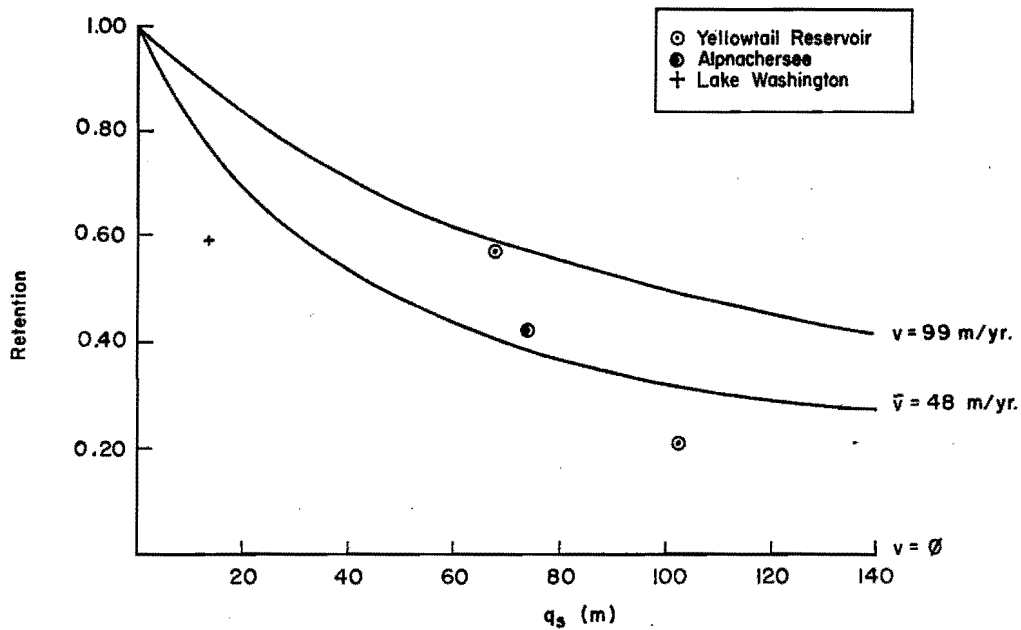
Figure 15. Retention of copper vs. areal water load.

esis. For Pueblo Reservoir, the relationship between the proportion of metals in the suspended fraction in the inflow (S:T, where S is the suspended load and T is the total load) and fraction retained is generally high, although discrepancies exist (Table 19). For the period June-September 1974, the relationship between retention and the ratio S:T is strong for both zinc and lead: for zinc, 86 percent of the inflow load occurred as suspended material while 78 percent was retained and for lead 100 percent was retained. For the 1975 water year, the relationship between S:T and R is strong for lead (S:T = 0.70; R = 0.73) but much weaker for zinc (S:T = 0.87; R = 0.26) and iron (S:T = 0.99; R = 0.20). The fact that less iron and zinc were retained than entered the reservoir as suspended material during the 1975 water year may be a reflection of the very high areal water load (135 m/yr) that occurred during this period that may have prevented the retention of much of the suspended water. During the period of June – September 1975, during which the reservoir was filling, the areal water load was about half as great (60 m/yr) and more complete retention of the suspended material in the inflow would be expected. Although more extensive data are required to support this hypothesis, it appears likely that the higher settling velocities of lead and iron compared with those of zinc and copper is a reflection of the fact that lead and iron are more highly associated with the suspended fraction of the inflow load to lakes than are zinc and copper.

Although much of the retention of these metals probably occurs as the result of their relative abundance in the suspended fraction, other mechanisms may account for a portion of their removal from the water column, including biological particularization of dissolved metals and chemical precipitation. Baccini (1976) found that 5 to 20 percent of the total zinc and 5 to 15 percent of the total copper in Alpnachersee was of biogenic origin. Baccini concluded that a portion of the total retention of these metals in Alpnachersee resulted from in-lake particularization of the dissolved copper and zinc by the biota followed by sedimentation. The fraction of both copper and zinc retained in Alpnachersee included both the suspended load of each metal plus a portion of the dissolved load, particularized by the biota. Although additional data on the amount of metals retained by lakes as the result of biological particularization could not be found, there is no doubt that dissolved metals are accumulated by the biota of lakes. Examples of the extent of accumulation of metals in various components of aquatic biotas can be found in the work of Thomann et al. (1974), Mathis and Kevern (1973), and Medine et al. (1977).

In addition to the sedimentation of metals entering lakes in the suspended form and the sedimentation of dissolved metals following particularization by the biota, chemical precipitation and resolubilization of metals may play an important part in determining the rate of accumulation of
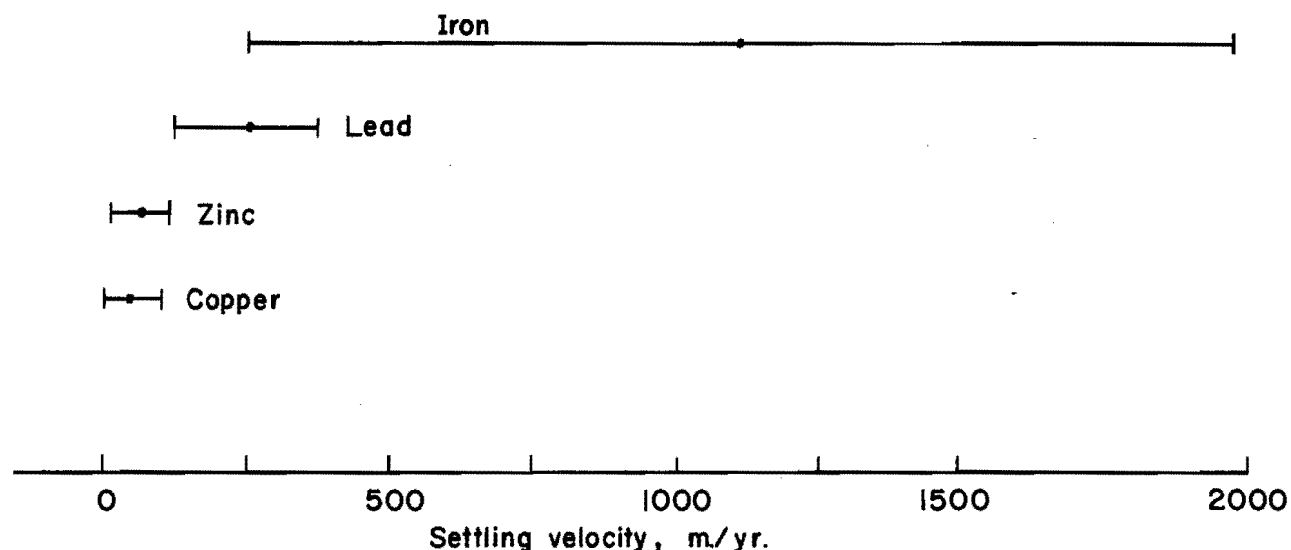
Figure 16.   Mean and confidence intervals for apparent settling velocities of iron, lead, zinc, and copper.

Table 19. Comparison of the composition of metals loading with metals retention.[a]

Lake	Zn		Fe		Pb		Cd		Cu	
	S/T	R	S/T	R	S/T	R	S/T	R	S/T	R
Alpnachersee	0.37	0.50	0.98	0.92	–	–	0.17	0.17	0.45	0.42
Pueblo Reservoir June–Sept., 1974	0.86	0.78	–	–	1.00	1.00	–	–	–	–
Pueblo Reservoir 1975 Wt. Yr.	0.87	0.26	0.99	0.20	0.70	0.73	–	–	–	–
Proposed Ridges Basin Reservoir[b]	0.80	0.75	0.98	0.98	0.95	0.92	1.00	–	0.89	0.69

[a] R = retention = $\dfrac{\text{mass in-mass out}}{\text{mass out}}$

S/T = suspended load/total load.

[b] Retention data for the Ridges Basin Reservoir are predicted values.

metals in the sediments of lakes. Although there appears to be a paucity of data as to the effects of precipitation and resolubilization of metals on the overall mass balance of metals in lakes, it seems very likely that, at least under certain conditions, purely chemical phenomena may have a significant effect on the overall mass balance of metals.

Application to Ridges Basin Reservoir

The analysis in the previous section indicates that, at least for the lakes included in the analysis, the retention of some metals can be predicted on the basis of average settling velocities. On the assumption that the lakes included in this analysis represent the conditions at Ridges Basin, the calculated average settling velocities determined for metals in these lakes were used to predict the retention of several metals in the proposed Ridges Basin Reservoir.

Other information required for these predictions included 1) data from the USBR hydrologic simulation (Appendix A) and 2) data on metals concentrations in the Animas River during the period September 1977 to August 1978 (Appendix B). The data on metals concentrations in the Animas River were used together with the hydrologic simulation of the reservoir for an average year to compute loadings for iron, zinc, manganese, copper, and lead into the reservoir (Table 20). The retention coefficient for each metal was determined from Equation 24 using the upper and lower 95 percent confidence limits for the average settling velocity and the areal water load, q_s, for the Ridges Basin Reservoir (21.3 m/yr). Values for the retention coefficients were used to calculate the annual loading of each metal to the sediment (L_s) and to the outflow:

$$L_{s,m} = \frac{R_m \, L_{i,m}}{100} \qquad \dots\dots\dots\dots (28)$$

$$L_{o,m} = L_{i,m} - L_{s,m} \qquad \dots\dots\dots\dots (29)$$

where

$L_{s,m}$ = loading of metal m to sediment, kg/yr

$L_{i,m}$ = loading of metal m into reservoir, kg/yr

$L_{o,m}$ = loading of metal m to outflow, kg/yr

R_m = retention coefficient, as percent

In addition, the average flow-weighted inflow and outflow concentration of each metal was calculated. The data used in this analysis and the results obtained are presented in Table 21.

Discussion

This analysis indicates that most of the iron and lead entering the Ridges Basin Reservoir will be retained as will lesser amounts of the zinc and copper. The predicted retention percentages correlate well with the ratio of suspended to total metal load (Table 19). Thus iron (S:T of inflow = 0.98) has a predicted retention of 92 to 99 percent, zinc (S:T of inflow = 1.00) has a predicted retention of 86 to 95 percent and lead (S:T of inflow = 0.92) has a predicted retention of 0.92. The correlation fails only for copper, whose predicted retention (0 to 92 percent) is much less than the ratio of

Table 20. Loading of heavy metals into the proposed Ridges Basin Reservoir.[a]

Date	Load (kg)				
	Fe	Zn	Mn	Cu[b]	Pb[b]
9/77	3,631	3,050	945	630	–
10/77	2,347	2,973	1,538	65	–
11/77	2,349	14,226	1,624	157	4
12/77	1,583	803	1,124	0	3
1/78	2,196	921	757	58	2
2/78	2,480	617	832	20	2
3/78	7,120	1,080	1,696	–	4
4/78	10,730	9,230	1,220	363	49
5/78	230,294	18,493	15,432	2,961	2,584
6/78	195,078	11,675	7,113	1,771	960
7/78	38,864	6,964	5,539	935	514
8/78	13,637	1,546	3,718	266	0
Annual	510,309	71,581	41,538	7,254[c]	4,130[c]

[a]Inflow data from USBR simulation of hydrologic regime for average year. All data for total metals, based on analysis by UWRL.

[b]During months when concentrations were below detection limits, the concentration was considered to be halfway between zero and the detection limit.

[c]Loading not for entire annual period due to missing data.

Table 21. Retention of total iron, zinc, lead, and copper in the proposed Ridges Basin Reservoir.

	Metal			
	Iron	Zinc	Pb	Cu
Settling Velocity[a] (m/yr)	248–1974	9–119	127–375	0–99
$R(\%)$[b]	92–99	30–85	86–95	0–82
Loading Into Reservoir, L_i (10^4 kg/yr)[c]	51.03	7.08	0.41	0.73
Loading to Sediments, L_s (10^4 kg/yr)[d]	46.95–50.52	2.12–6.02	0.35–0.39	0–0.58
Loading to Outflow, L_o (10^4 kg/yr)[e]	4.08–0.51	4.96–1.06	0.06–0.02	0.71–0.13
Flow Weighted Average Concentration in Inflow (μg/ℓ)[f]	3117	432	32	47
Flow Weighted Average Concentration in Outflow	33–266	69–324	2–5	9–51[g]

[a]See Table 17.

[b]See Figures 12–15.

[c]See Table 20.

[d]See Equation 27.

[e]See Equation 28.

[f]$[M] = \dfrac{\text{loading}}{\text{total flow}}$. Data for lead and copper adjusted to account for missing inflow concentration data.

[g]Outflow concentration higher than inflow due to evaporation (6% of inflow).

42

S:T = 100 for the inflow. This correlation suggests that the metals contained in the suspended fraction of the inflow to the Ridges will be retained.

The predicted values of retention for each metal were used to calculate the amount of iron, lead, zinc, and copper that will be retained in the sediments and that will be released to the outflow. The calculation of the amount of each metal that will be retained by the sediment is, of itself, of little value. However, if data on the amount of sediment that will be retained were available, these data could be used in conjunction with the data on the metals loadings to the sediment to make an estimate of the concentrations of each metal in the sediment:

$$C_m = \frac{L_{s,m}}{A_s \times d_s} \qquad \ldots\ldots\ldots\ldots\ldots (30)$$

where

C_m = concentration of metal in sediment (kg/m^3)

$L_{s,m}$ = rate of accumulation of metal m in sediment (kg/yr)

A_s = area of bottom, m^2

d_s = rate of accumulation of sediments (m/yr)

Equation 30 was developed on the assumption that retained metals and sediment are deposited evenly over the entire bottom and that the metals, once deposited, do not migrate vertically through the sediment or into the water column. Although neither of these assumptions is strictly valid, these calculations would provide a gross approximation of the metals concentrations in the sediments of the proposed reservoir. This knowledge would allow a crude evaluation of the accumulation of each metal in a benthic feeding food chain based on concentration factors for metals determined by various investigators. Considering the relatively high levels of various metals in the inflow to this reservoir, a more detailed analysis of the effects of the metals that will enter the Ridges Basin Reservoir on the biota may be justified.

The predicted loading of iron, zinc, copper, and lead in the outflow was used to calculate the flow-weighted average concentration of each of these metals in the outflow (Table 21). Inspection of these data indicates that the concentrations of iron, zinc, and lead will be substantially reduced between the inflow and the outflow. These reductions in metal concentrations will improve the quality of the outflow water, particularly with respect to the protection of an aquatic biota (Appendix D: Proposed Colorado Water Quality Standards: Aquatic Biota).

The predicted values for metal retentions obtained in this study should be used with caution, since they are based on the concept of universal "apparent settling velocities" for each metal. This concept of a universal apparent settling velocity ignores potential differences in removal mechanisms in individual lakes and may therefore lead to erroneous predictions of metal retentions, particularly when applied to lakes with unique water quality characteristics. The model also assumes that lakes behave like CSTR's, an assumption that is never strictly correct. In spite of these weaknesses, the success with which this approach has been used for predicting phosphorus retention supports the validity of this approach. In the future the availability of additional data on metal loadings in lakes may allow more accurate calculations of the apparent settling velocities of metals in lakes and thus enable more accurate calculations of metal retentions.

CONCLUSIONS

1. The water from the Animas River frequently exceeds the proposed Colorado Water Quality Standards. Concentrations of dissolved aluminum, total copper, dissolved manganese, total mercury, total zinc, and total cyanide exceeded the proposed standards for one or more water uses during over half of the sampling periods between May 1977 and August 1978. The metals problem is supported by symptoms of metal toxicity found in algal bioassays of filtered water from the Animas River. The high concentrations of metals is probably the result of upstream mining activity.

2. Water quality in the La Plata River deteriorates between Hesperus, Colorado, and Farmington, New Mexico. The concentrations of dissolved aluminum, total mercury, and total cyanide exceeded the proposed standards in over half of the sampling periods. Several other metals exceeded the standards, but less frequently. The sulfate concentration in the La Plata River at the Colorado-New Mexico border and at Farmington exceeded the proposed standard for raw water supply throughout most of the study period.

3. The actual mean summer epilimnetic concentration of chlorophyll a in lakes and reservoirs in the Intermountain West usually falls within the 99 percent confidence intervals of prediction associated with Vollenweider's phosphorus loading model. For lakes in which a) the ratio of TSIN:OP is less than 11.3:1 throughout the season, b) turbidity limits algal growth, or c) the growth of macrophytes is extensive, Vollenweider's model may not yield accurate predictions of the chlorophyll a standing crop.

4. The mean summer epilimnetic concentrations of chlorophyll a in the proposed Ridges Basin Reservoir is expected to be between 5 and 13 µg/l. On the basis of algal standing crop, the proposed reservoir can be classified as mesotrophic. The average summer Secchi disc transparency is expected to be about 1.8 m (6 ft). The actual algal standing crop may be lower than this predicted value if metal toxicity limits algal growth in the reservoir. A change in the phosphorus loading regime would also change the algal standing crop.

5. The average concentration of dissolved oxygen in the hypolimnion is not expected to drop below 7.0 mg/l by the end of August. However, a linear extrapolation of the results of the dissolved oxygen model (decrease in D.O.) to the end of the stratification period (probably late October or November) indicated that the dissolved oxygen concentration in the hypolimnion could drop to between 5.0 and 6.0 mg/l before the fall turnover. Oxygen depletion in the hypolimnion may be less than predicted if metal toxicity inhibits algae production or benthic respiration, or greater than predicted if consumption in the water column or other mechanisms of depletion not considered are significant. The accuracy of the oxygen simulation is also constrained by the accuracy of the input data from the USBR temperature simulation.

6. Ninety-two to 99 percent of the iron, 30 to 85 percent of the zinc, 86 to 95 percent of the lead, and 0 to 82 percent of the copper that enters the Ridges Basin Reservoir will be retained in the sediments at the bottom of the reservoir. The concentration of these metals in the outflow to the Dryside Canal will be reduced proportionately to these retention values.

7. A comparison of the observed retention of metals in lakes with the ratio of the suspended to the total metals loads suggests that the sedimentation of the suspended load carried in the inflow is the major mechanism by which metals are retained in lakes.

8. Since the proposed Ridges Basin Reservoir is off-stream, the pumping of river water into the reservoir may be varied over time to avoid periods of high pollutant concentrations and thereby reduce the loading of nutrients and metals into the reservoir. A carefully planned pumping strategy may thus be utilized to some extent to control ecological characteristics of the reservoir.

9. The above predictions of dissolved oxygen concentration and algal standing crop apply to the reservoir following the period of initial filling and stabilization. Because of the variability in the stabilization process among reservoirs, quantitative predictions were not made of the limnological parameters for the newly formed reservoir.

RECOMMENDATIONS

Reservoir Operation

Since the Ridges Basin Reservoir is off stream, the loading of nutrients and other constituents into the reservoir is determined by the inflow pumping regime. If this reservoir is built, a plan should be developed and evaluated to control the loading of nutrients and heavy metals by manipulation of the inflow pumping schedule. For example, Vollenweider's phosphorus loading model could be utilized to predict the effects of alternative pumping schedules on the algae standing crop in the reservoir (Equation 2). A mass balance model could be used to predict the effects of alternative pumping schedules on the retention of iron, lead, zinc, and copper in the reservoir.

Since the concentrations of phosphorus and most of the heavy metals were highest during the period of spring runoff (April through June), an attempt should be made to minimize inflow pumping during this period. As illustrated by the example presented on page 18, a minor alteration in the hydrologic regime of the reservoir may have a considerable effect on its algal productivity during the summer.

Areas of Future Study

1. The temperature simulation performed by the USBR should be repeated, and the apparent error in the computation of diffusion coefficients should be corrected. In rerunning the temperature model, the simulation period should be extended to the end of the stratification period. The model used in this study to predict concentrations of hypolimnetic dissolved oxygen should be rerun using the data from the new temperature simulation in order to more accurately predict the extent of oxygen depletion in the hypolimnion of the Ridges Basin Reservoir.

2. The potential problems that may arise from the accumulation of metals in the reservoir should be studied further. Specifically, a study should be conducted to determine whether metals will accumulate in fish and other components of the biota. Such a study would be particularly important if the lake formed would be used as a sport fishery.

3. The predictions made in this study apply to a stabilized reservoir. The decay of inundated organic matter and the leaching of salts from the soils and vegetation may have a profound effect on the water quality of new reservoirs. Further study should be directed toward developing an understanding of the extent to which these processes will affect the water quality of the Ridges Basin Reservoir during its early life. A microcosm study involving the use of enclosed soils and water from the Animas River may be a useful tool in elucidating water quality problems that may occur during the period following the initial filling.

4. Considering the high level of metals found in the Animas and the La Plata Rivers, it is suggested that a study be conducted to determine methods of controlling the pollution of these rivers. Particular attention should be directed toward controlling erosion and runoff from existing tailing piles.

APHA. 1975. Standard methods for the examination of water and wastewater. 14th Ed. American Public Health Association, Washington, DC. 1193 p.

Baccini, Peter. 1976. Investigation of the heavy metal content of lakes (in German). Hydrologie 38:128-151.

Ball, John, Clark Weldon, and Ben Crocker. 1975. Effects of original vegetation on reservoir water quality. Texas A and M University Water Resources Institute Technical Report No. 64. 120 p.

Barnes, R. S., and W. R. Schell. 1972. Physical transport of trace metals in the Lake Washington watershed. In: USEPA National Environmental Research Center: Conf. on Cycling and Control of Metals, Oct. 31-Nov. 2, 1972. p. 45-53.

Barton, Larry L., and Gordon V. Johnson. 1978. Characterization of nutrients and algal blooms at Abiquiu and Cochiti Reservoirs. New Mexico Water Resources Research Institute Completion Report 3109-069 A-058 NMEX. 105 p.

Bolke, E. L., and K. M. Waddell. 1975. Chemical water quality and temperature of water in Flaming Gorge Reservoir, Wyoming and Utah, and the effect of the reservoir on the Green River. USGS Water-Supply Paper 2039-A. 26 p.

Brewer, W. S., A. R. Abernathy, and M. J. B. Paynter. 1977. Oxygen consumption by freshwater sediments. Water Res. 11:471-473.

Burdick, J. C., and F. L. Parker. 1971. Estimation of water quality in a new reservoir. Report #8, Dept. of Environmental and Water Resources Engineering, Vanderbilt U.

Carlson, Robert E. 1977. A trophic state index for lakes. Limnol. Oceanog. 22:361-369.

Chapra, Steven C. 1975. Comment on 'An empirical method of estimating the retention of phosphorus in lakes' by W. B. Kirchner and P. J. Dillon. Water Resources Research 11:1033-1036.

Churchill, M. A. 1957. Effects of storage impoundments on water quality. J. Sanit. Eng. Div., ASCE. 83:1171-1-1171-48.

Delfino, J. J., G. C. Bortleson, and G. F. Lee. 1969. Surface sediments on Lake Mendota, Wisconsin. Env. Sci. and Technol. 3:1189-1192.

Dillon, P. J., and F. H. Rigler. 1974a. The phosphorus-chlorophyll relationship in lakes. Limnol. Oceanog. 19:767-773.

Dillon, P. J., and F. H. Rigler. 1974b. A test of a simple nutrient budget model predicting the phosphorus content in lake water. J. Fish. Res. Board Can. 31:1771-1778.

Duffer, William R., and Curtis C. Harlin. 1971. Changes in water quality resulting from impoundment. USEPA Water Pollution Control Series 16080 GGH 08/71. 110 p.

Edberg, Nils, and Bengt V. Hofsten. 1973. Oxygen uptake of bottom sediments studied in situ and in the laboratory. Water Res. 7:1285-1294.

Edwards, R. W., and H. L. J. Rolley. 1965. Oxygen consumption of river muds. J. Ecol. 53:1-19.

Fair, G. M., J. C. Geyer, and D. A. Okun. 1958. Water and wastewater engineering. Volume I. Water supply and wastewater removal. 505 pp.

Fair, G. M., E. W. Moore, and H. A. Thomas, Jr. 1941. The natural purification of river muds and pollutional sediments, Part I. Sew. Works J. 13:271.

Funk, William H., F. W. Rabe, R. Filby, G. Bailey, P. Bennet, K. Shah, J. C. Sheppard, N. Savage, S. B. Bauer, A. Bourg, G. Bannon, C. Edwards, D. Anderson, P. Syms, J. Rothert, and A Seamster. 1975. An integrated study of the impact of metallic trace element pollution in the Coeur D'Alene-Spokane Rivers-Lake drainage system. Wash. State U./U of Idaho Joint Project Completion Report, OWRT Title II Project C-4145. 332 p.

Gould, H. R. 1954. Sedimentology. In: Lake Mead Comprehensive Study, 1948-49. Vol. 3. Cooperative project by the USGS, the USBR, and the U. S. Dept. of the Navy. p. 186-210.

Greene, J. C., R. A. Soltero, W. E. Miller, A. F. Gasperino, and T. Shiroyama. 1975. The relationship of laboratory algal assays to measurements of indigenous phytoplankton in Long Lake, Washington. In: Middlebrooks, E. J., D. H. Falkenborg, and T. E. Maloney (eds.). Biostimulation and Nutrient Assessment Workshop Proceedings, Sept. 10-12, 1975:93-126.

Hannan, H. H., and W. J. Young. 1974. The influence of a deep-storage reservoir on the physiolochemical limnology of a central Texas river. Hydrobiologia 44(2):177-207.

Harding, J. P. C., and B. A. Whitton. 1978. Zinc, cadmium, and lead in water, sediments, and submerged plants in the Derwent Reservoir, Northern England. Water Res. 12:307-316.

Hargrave, Barry T. 1969. Similarity of oxygen uptake by benthic communities. Limnol. Oceanog. 14:801-809.

Hayes, F. R., and M. A. MacAulay. 1959. Lake water and sediment V: Oxygen consumed in water over sediment cores. Limnol. Oceanog. 4:291-298.

Hem, John D. 1972. Chemistry and occurrence of cadmium and zinc in surface water and groundwater. Water Resources Research 8:661-679.

Herrmann, S. J., and K. I. Mahan. 1977. Effects of Impoundment on water and sediment in the Arkansas River at Pueblo Reservoir. Prepared for the U.S. Bureau of Reclamation as REC-ERC-76-19. 159 p.

Howard, C. S. 1954. Chemical limnology. In: Lake Mead Comprehensive Survey, 1948-49, Vol. 2. Cooperative project by the USGS, the USBR, and the U. S. Dept. of the Navy. p. 173-186.

Hutchinson, G. Evelyn. 1938. On the relation between the oxygen deficit and the productivity and typology of lakes. Int. Revue ges. Hydrobiol. Hydrogr. 36:336-355.

Hutchinson, G. E. 1957. Treatise on limnology, Vol. 1: Geography, physics and chemistry. New York: John Wiley & Sons. 1013 pp.

Hutchinson, T. C., and P. M. Stokes. 1975. Heavy metal toxicity and algal bioassays. Water Quality Parameters, ASTM. STP573: 320-343.

Kirchner, W. B., and P. J. Dillon. 1975. An empiricial method of estimating the retention of phosphorus in lakes. Water Resources Research 11(1):182-184.

Knowles, G., R. W. Edwards, and R. Briggs. 1962. Polarographic mesurement of the rate of respiration of natural sediments. Limnol. Oceanog. 7:481-484.

Kreizenbeck, Ronald. 1974. Milner Reservoir benthic oxygen demand study. Unpublished data, USEPA Region X. 9 p.

Lake Tahoe Area Council. 1971. Eutrophication of surface waters - Lake Tahoe: Indian Creek Reservoir. USEPA Water Pollution Control Research Series 16010 DNY 07/71. 115 p.

Leckie, J. O., and R. O. James. 1976. Control mechanisms for trace metals in natural waters. In: Rubin, A. J. (ed.) Aqueous-Environmental Chemistry of Metals. Ann Arbor: Ann Arbor Science Publishers, Inc. p. 1-77.

Mathis, B. J., and N. R. Kevern. 1973. Distribution of mercury, cadmium, lead and thallium in a eutrophic lake. Michigan State University Institute of Water Research Completion Report A-062-MICH(1). 14-31-0001-3522. 25 p.

McDonnell, Archie J., and S. Douglas Hall. 1969. Effect of environmental factors on benthal oxygen uptake. JWPCF 41: R353-363.

Medine, A. J., D. B. Porcella, and P. A. Cowan. 1977. Microcosm dynamics and response to a heavy metal loading in Lake Powell sediment-water-gas ecosystem. Report prepared for Southern California Edison Company, Contract No. U0966901 with the USU Foundation. 131 p.

Metcalf and Eddy, Inc. 1972. Wastewater engineering: Collection treatment, disposal. San Francisco: McGraw-Hill Book Co. 782 pp.

Neel, Joe Kendall. 1963. Impact of Reservoirs. In: Frey, David G. (ed.) Limnology of North America. Madison: U. of Wisconsin Press. p. 575-593.

Newbold, J. Denis, and James A. Ligget. 1974. Oxygen depletion model for Lake Cayuga. J. Env. Div., ASCE. 41-59.

Pamatat, Mario M., and Karl Banse. 1969. Oxygen consumption by the seabed. II. in situ measurements to a depth of 180 m. Limnol. Oceanog. 14:250-259.

Porcella, D. B., V. D. Adams, P. A. Cowan, S. Austriheim-Smith, W. F. Holmes, J. Hill IV, W. J. Grenney, and E. J. Middlebrooks. 1975. Nutrient dynamics and gas production in aquatic ecosystems: The effects and utilization of mercury and nitrogen in sediment-water microcosms. Utah Water Research Laboratory PRWG 121-1, Utah State U. 142 p.

Porcella, D. B., and A. Bruce Bishop. 1975. Comprehensive management of phosphorus water pollution. Ann Arbor: Ann Arbor Science Publishers Inc. 303 p.

Purcell, Lee T. 1939. The aging of reservoir waters. J. Am. Water Works Assoc. 31:1775-1806.

Rolley, H. L. J., and M. Owens. 1967. Oxygen consumption rates and some chemical properties of river muds. Water Res. 1:759-766.

Sakamoto, M. 1966. Primary production by phytoplankton community in some Japanese lakes and its dependence on depth. Arch. Hydrobiol. 62:1-28.

Sartoris, James J. 1978. Users manual: Corps/RE Reservoir Temperature simulation model. U. S. Bureau of Reclamation Engineering and Research Center, Denver. 80 p.

Soltero, R. A., J. C. Wright, and A. A. Horpestad. 1973. Effects of impoundment on the water quality of the Bighorn River. Water Res. 7:343-354.

Sonzogni, W. C., D. P. Larsen, K. W. Malueg, and M. D. Schuldt. 1977. Use of large submerged chambers to measure sediment-water interactions. Water Res. 11:461-464.

Thomann, R. V., D. S. Szumski, D. M. DiToro, and D. J. O'Connor. 1974. A food chain model of cadmium in Western Lake Erie. Water Res. 8:841-849.

U. S. Bureau of Reclamation. 1978. The Animas - La Plata Project. Unpublished planning report prepared by the USBR, Jan. 1978. 14 p.

U. S. Corps of Engineers, Hydrologic Engineering Center. 1975. Water quality for river-reservoir systems computer programs 401-F2-L2100 and 401-F2-L2100A. U. S. Army Corps of Engineers Hydrologic Research Center 401-100/401-100A.

USEPA. 1975a. National eutrophication survey methods, 1973-1976. National Eutrophication Survey Working Paper #175, National Environmental Research Center, Corvallis, Ore. 91 p.

USEPA. 1975b. River basin water quality status - Spokane River basin profile. Surveillance & Analysis Division, Region X. 225 p.

USEPA. 1976a. Methods for chemical analysis of water and wastes. EPA-625/6-74-003a. 297 pp.

USEPA. 1976b. Quality criteria for water. U. S. Government Printing Office: 1978. 258-389/6057. 256 pp.

USEPA. 1977. National eutrophication working paper series:

Working Paper # 817. Report on Almogordo Reservoir, DeBaca and Guadalupe Counties, New Mexico. 44 p.

Working Paper # 765. Report on Barker Reservoir, Boulder County, Colorado. 37 p.

Working Paper # 881. Report on Big Sandy Reservoir, Sublette and Sweetwater Counties, Wyoming. 53 p.

Working Paper # 767. Report on Blue Mesa Reservoir, Gunnison County, Colorado. 52 p.

Working Paper # 818. Report on Bluewater Lake, McKinley and Valencia Counties, New Mexico. 41 p.

Working Paper # 882. Report on Boulder Lake, Sublette County, Wyoming. 37 p.

Working Paper # 883. Report on Boysen Reservoir, Fremont County, Wyoming. 53 p.

Working Paper # 768. Report on Cherry Creek Lake, Arapohoe County, Colorado. 40 p.

Working Paper # 778. Report on Coeur d'Alene Lake, Benewah and Kootenai Counties, Idaho. 25 p.

Working Paper # 819. Report on Conchas Reservoir, San Miguel County, New Mexico. 47 p.

Working Paper # 837. Report on Deer Creek Reservoir, Wasatch County, Utah. 49 p.

Working Paper # 769. Report on Dillon Reservoir, Summit County, Colorado. 60 p.

Working Paper # 820. Report on Eagle Nest Lake, Colfax County, New Mexico. 41 p.

Working Paper # 838. Report on Echo Reservoir, Summit County, Utah. 38 p.

Working Paper # 821. Report on Elephant Butte Reservoir, Sierra and Socorro Counties, New Mexico. 52 p.

Working Paper # 822. Report on El Vado Reservoir, Rio Arriba County, New Mexico. 44 p.

Working Paper # 839. Report on Fish Lake, Sevier County, Utah. 40 p.

Working Paper # 886. Report on Fremont Lake, Sublette County, Wyoming. 37 p.

Working Paper # 841. Report on Joes Valley Reservoir, Emery County, Utah. 39 p.

Working Paper # 888. Report on Keyhole Reservoir, Crook County, Wyoming. 46 p.

Working Paper # 884. Report on Lake DeSmet, Johnson County, Wyoming. 35 p.

Working Paper # 823. Report on Lake McMillan, Eddy County, New Mexico. 48 p.

Working Paper # 846. Report on Minersville Reservoir, Beaver County, Utah. 44 p.

Working Paper # 847. Report on Moon Lake, Duschesne County, Utah. 37 p.

Working Paper # 775. Report on Navajo Reservoir, Arculeta County, Colorado, and San Juan and Rio Arriba Counties, New Mexico. 58 p.

Working Paper # 889. Report on Ocean Lake, Fremont County, Wyoming. 43 p.

Working Paper # 850. Report on Otter Creek Reservoir, Piute County, Utah. 36 p.

Working Paper # 851. Report on Panguitch Lake, Garfield County, Utah. 37 p.

Working Paper # 852. Report on Pelican Lake, Uintah County, Utah. 34 p.

Working Paper # 853. Report on Pineview Reservoir, Weber County, Utah. 45 p.

Working Paper # 854. Report on Piute Reservoir, Piute County, Utah. 38 p.

Working Paper # 890. Report on Seminoe Reservoir, Carbon County, Wyoming. 55 p.

Working Paper # 857. Report on Sevier Bridge Reservoir, Juab and Sanpete Counties, Utah. 43 p.

Working Paper # 858. Report on Starvation Reservoir, Duchesne County, Utah. 34 p.

Working Paper # 859. Report on Steinaker Reservoir, Uintah County, Utah. 37 p.

Working Paper # 860. Report on Tropic Reservoir, Garfield County, Utah. 38 p.

Working Paper # 861. Report on Utah Lake, Utah County, Utah. 89 p.

Working Paper # 824. Report on Ute Reservoir, Quay County, New Mexico. 45 p.

Working Paper # 892. Report on Viva Naughton Reservoir, Lincoln County, Wyoming. 37 p.

Working Paper # 862. Report on Willard Reservoir, Box Elder County, Utah. 46 p.

Working Paper # 893. Report on Woodruff Narrows Reservoir, Uinta County, Wyoming. 39 p.

Vollenweider, R. A. 1968. Scientific fundamental of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD Technical Report DAS/CSI/68.27.159 p. Revised 1971.

Vollenweider, R. A. 1969. Moglich-Keiten und grenzen elementarer modelle der stoffbilanz von seen. Arch. Hydrobiol. 66:1-36.

Vollenweider, R. A. 1975. Input-output models with special reference to the phosphorus loading concept in limnology. Schweiz. Z. Hydrologie 37:53-84.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. 1st Ital. Idrobiol. 33:53-83.

Ward, J. C., and S. Karaki. 1969. Evaluation of the effect of impoundment on water quality in Cheney Reservoir. Colorado State University Sanitary Engineering Paper No. 4. 69 p.

Wetzel, Robert G. 1975. Limnology. Philadelphia: W. B. Saunders Co. 743 p.

Whipple, G. C. 1933. The microscopy of drinking water (4th Ed.). London: John Wiley and Sons. 586 p.

Williams, D. R. 1978. Postimpoundment study of water quality characteristics of Raystown Lake, Huntington and Bedford Counties, Pa. USGS Water Resources Investigations 78-42. 53 p.

Woodling, John D. 1977. Investigations of point sources of acid metals mine drainage locations and water quality effects in the Upper Animas River Basin. Report prepared for the Water Quality Control Division, Colorado Department of Health. 16 p.

Wright, John C., and Raymond A. Soltero. 1973. Limnology of Yellowtail Reservoir and the Bighorn River. USEPA R3-73-002. 105 p.

HYDROLOGIC SIMULATION OF RIDGES BASIN RESERVOIR

Table 22. Ridges Basin end of month content (1,000 ac-ft).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1929	280.0	280.0	280.0	280.0	280.0	272.7	262.4	261.3	270.1	280.0	280.0	280.0
1930	280.0	280.0	280.0	280.0	280.0	272.7	261.4	255.7	245.6	252.4	256.7	259.2
1931	261.0	260.6	260.4	257.2	264.3	257.0	232.1	210.5	198.2	204.4	208.6	212.2
1932	215.3	218.6	230.9	249.6	260.9	253.6	343.3	238.7	233.5	239.9	245.5	246.6
1933	246.1	245.9	250.6	252.2	253.6	246.3	231.0	208.7	203.6	211.5	215.0	217.7
1934	219.0	220.5	223.9	231.2	239.1	213.0	176.5	163.7	158.5	155.5	157.1	157.5
1935	158.2	159.1	165.1	179.8	188.7	181.6	171.2	168.5	166.1	175.5	181.2	184.1
1936	186.9	188.9	199.7	213.4	218.2	198.5	192.3	183.4	195.5	203.7	207.6	
1937	210.4	213.8	222.9	242.4	264.5	257.8	242.8	218.2	206.6	213.0	218.0	220.2
1938	222.3	224.8	234.4	249.8	261.7	254.5	244.2	229.7	232.6	247.9	258.5	264.2
1939	268.5	271.1	280.0	280.0	280.0	272.7	239.9	210.9	207.6	212.4	217.5	219.9
1940	221.5	222.8	229.3	239.7	249.0	240.6	204.9	180.1	176.4	185.2	193.2	196.8
1941	200.0	205.9	216.4	233.2	256.1	258.1	251.4	251.1	255.6	273.8	280.0	280.0
1942	280.0	280.0	280.0	280.0	280.0	276.6	266.2	253.2	243.8	248.2	253.0	255.8
1943	258.4	261.5	269.0	280.0	280.0	272.7	260.8	258.8	255.2	262.9	271.7	277.7
1944	280.0	280.0	280.0	280.0	280.0	272.9	262.6	249.6	236.0	245.0	251.9	255.8
1945	258.8	262.6	268.5	276.0	280.0	272.7	261.5	252.5	239.4	249.1	256.7	260.3
1946	264.6	267.5	271.7	280.0	280.0	272.2	259.0	244.6	230.0	234.8	242.9	248.9
1947	253.0	256.6	262.4	270.3	279.5	272.2	261.2	256.8	259.0	270.0	280.0	280.0
1948	280.0	280.0	280.0	280.0	280.0	272.7	262.4	251.6	238.5	245.7	251.4	264.3
1949	257.0	259.5	265.9	277.1	280.0	276.6	266.5	255.4	242.6	250.5	258.3	253.2
1950	268.3	273.0	280.0	280.0	280.0	272.7	257.1	227.1	213.6	216.0	219.4	222.3
1951	223.9	224.3	225.7	223.0	228.9	221.7	197.7	178.0	168.2	166.7	169.5	171.4
1952	174.9	179.3	183.3	201.4	216.2	210.9	200.7	195.8	189.9	195.9	200.3	203.3
1953	206.9	210.3	217.2	225.3	231.3	224.0	205.8	186.6	174.8	177.4	184.2	186.3
1954	186.7	187.4	188.6	201.6	210.8	203.6	190.3	176.1	172.3	181.1	188.3	193.9
1955	198.1	200.9	206.5	211.8	221.0	213.8	193.7	182.3	170.1	166.7	170.1	173.4
1956	177.1	180.4	188.2	200.3	209.5	202.3	174.5	162.1	152.6	150.3	153.8	155.1
1957	158.0	162.1	167.3	177.0	186.9	183.1	173.4	172.3	172.3	183.7	197.2	210.0
1958	220.0	227.4	236.9	252.5	274.8	271.9	256.3	233.3	226.5	234.6	242.3	248.5
1959	253.2	257.3	262.6	264.0	268.7	261.5	229.1	211.0	191.2	197.8	207.5	212.0
1960	215.3	219.1	227.5	246.3	255.8	248.5	235.4	208.8	194.9	202.6	209.6	215.1
1961	219.3	221.5	227.1	240.6	249.8	242.6	217.5	204.3	203.6	219.3	232.3	239.5
1962	244.4	253.6	262.2	278.4	280.0	272.7	262.2	238.4	223.4	232.8	242.3	248.1
1963	252.1	257.1	264.7	280.0	280.0	272.0	240.3	223.1	218.2	218.8	223.8	226.7
1964	228.7	229.9	230.6	231.0	232.4	225.1	195.3	182.8	173.0	169.6	173.3	176.6
1965	180.3	183.3	188.7	197.8	208.4	201.2	190.0	189.2	197.5	214.0	227.2	238.7
1966	248.5	256.5	268.4	280.0	280.0	272.7	255.0	232.4	218.4	221.6	226.0	230.7
1967	233.0	236.0	243.4	244.3	247.0	239.8	218.1	205.2	192.5	190.6	193.4	195.8
1968	198.5	201.7	210.5	221.9	231.3	224.1	212.7	207.0	189.7	191.0	195.6	199.3
1969	202.8	205.7	211.2	230.2	240.9	233.6	223.3	213.4	215.2	231.8	245.2	256.0
1970	261.9	266.8	270.6	272.1	279.1	271.8	259.4	246.3	253.4	269.2	280.0	280.0
1971	280.0	280.0	280.0	280.0	280.0	272.7	260.6	244.9	231.6	239.9	251.8	260.6
1972	267.3	272.9	280.0	280.0	280.0	272.7	238.0	208.2	196.3	206.0	219.4	233.1
1973	245.0	254.8	268.6	280.0	280.0	280.0	269.6	265.9	264.2	271.7	276.1	279.9
1974	280.0	280.0	280.0	280.0	280.0	272.7	251.5	223.7	202.1	203.4	209.0	212.0
1975	214.6	216.2	222.9	236.0	256.5	257.6	247.2	240.9	234.9	240.0	243.4	246.1
1976	248.8	252.7	259.6	271.3	280.0	272.7	258.0	240.2	227.9	232.2	236.1	238.6
1977	239.5	239.6	239.2	232.8	221.3	204.9	177.3	173.3	168.3	167.1	170.3	172.9
AVG.	233.2	236.1	241.7	249.6	255.8	248.8	231.6	218.0	210.7	217.2	223.8	227.9

[a] USBR (1978).

55

Table 23.   Water pumped through Durango pumping plant to Ridges Basin
Reservoir (1,000 ac-ft).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1929	2.8	.4	.5	4.6	12.7	25.1	25.9	25.9	24.0	12.6	.5	.5
1930	.4	.4	.5	3.2	12.7	25.1	25.0	21.3	5.0	9.4	4.8	2.9
1931	2.2	.1	.3	3.0	23.8	25.1	11.3	6.0	6.6	12.9	4.6	4.1
1932	3.5	3.7	12.8	24.9	25.9	25.1	25.9	22.4	9.9	9.0	6.1	1.5
1933	0.0	.2	5.2	7.8	18.0	25.1	20.9	4.8	10.7	10.7	4.0	3.2
1934	1.7	1.8	3.9	14.3	24.7	6.5	.0	.1	1.2	3.2	2.1	.9
1935	1.1	1.3	6.5	20.8	25.6	25.1	25.8	24.4	12.6	12.1	6.2	3.4
1936	3.2	2.4	11.3	19.6	25.9	25.1	16.5	20.8	11.2	9.7	8.7	4.4
1937	3.3	3.8	9.6	20.6	25.9	25.1	21.3	2.9	3.4	9.1	5.5	2.7
1938	2.6	2.9	10.1	20.3	25.9	25.1	25.9	12.7	17.9	18.0	11.1	6.1
1939	4.7	3.0	9.4	6.3	16.2	25.1	4.8	.3	14.3	8.5	5.5	2.9
1940	2.0	1.7	7.0	16.6	25.9	24.0	1.9	1.0	8.5	15.3	8.4	4.1
1941	3.6	6.2	11.1	17.8	25.9	25.1	25.9	22.9	18.0	19.8	6.7	.5
1942	.4	.4	.5	.9	6.1	24.6	25.9	14.1	5.7	7.1	5.2	3.3
1943	3.0	3.5	8.0	17.0	12.6	25.1	24.3	25.2	11.4	10.4	9.3	6.5
1944	2.7	.4	.5	6.2	13.5	25.1	25.9	14.2	1.4	11.7	7.4	4.3
1945	3.5	4.2	6.4	13.4	15.5	25.1	25.0	18.1	2.0	12.4	8.0	4.1
1946	4.7	3.4	4.6	14.6	16.7	24.6	23.0	12.7	4.3	11.5	8.6	6.5
1947	4.5	4.0	6.2	14.2	25.9	25.1	25.2	22.5	21.2	17.1	10.5	.5
1948	.4	.4	.5	6.1	15.2	25.1	25.9	16.4	2.0	9.8	6.2	3.4
1949	3.1	2.9	6.8	17.4	18.9	25.1	25.9	16.1	2.3	10.5	8.3	5.4
1950	5.6	5.1	7.5	5.2	13.0	25.1	20.6	.0	1.6	6.2	3.9	3.3
1951	2.1	.8	1.9	4.2	22.4	25.1	12.2	5.0	1.1	4.8	3.3	2.4
1952	3.9	4.7	4.6	22.9	25.9	25.1	25.9	22.2	9.2	8.6	4.9	3.5
1953	4.0	3.8	7.3	14.4	22.1	25.1	18.0	7.8	.3	4.9	7.3	2.5
1954	.9	1.1	1.7	19.2	25.8	25.1	22.9	8.2	7.1	15.2	7.7	6.1
1955	4.6	3.3	6.0	11.5	25.9	25.1	16.1	14.1	.5	2.8	3.9	3.8
1956	4.1	3.7	8.3	18.2	25.9	25.1	3.9	.3	0.0	.8	4.0	1.7
1957	3.3	4.5	5.7	15.8	25.7	25.1	25.9	25.9	15.0	14.1	13.9	13.3
1958	10.5	7.8	10.0	17.0	25.9	25.1	20.7	4.1	8.3	10.7	8.2	6.7
1959	5.1	4.5	5.7	7.7	21.5	25.1	4.5	9.0	.2	13.3	10.1	4.9
1960	3.7	4.3	8.8	25.1	25.9	25.1	23.1	2.3	1.4	10.4	7.4	6.0
1961	4.7	2.6	6.1	19.7	25.9	25.1	11.2	13.8	17.1	18.6	13.6	7.7
1962	5.2	9.7	9.0	22.5	18.3	25.1	25.8	4.0	3.6	12.9	10.1	6.3
1963	4.4	5.5	8.0	21.6	16.7	24.4	5.4	10.1	14.0	7.3	5.5	3.4
1964	2.4	1.7	1.2	6.6	18.1	25.1	6.5	13.9	2.9	2.9	4.2	3.8
1965	4.1	3.5	5.9	15.1	25.9	25.1	25.9	25.3	23.4	19.2	13.6	12.0
1966	10.2	8.4	12.4	16.1	12.7	25.1	18.5	5.0	1.1	5.9	4.8	5.2
1967	2.8	3.4	7.9	7.2	19.8	25.1	14.6	14.2	6.2	4.7	3.3	3.0
1968	3.1	3.5	9.3	17.6	25.8	25.1	24.8	21.4	2.0	6.5	5.0	4.2
1969	3.9	3.4	5.9	24.8	25.9	25.1	25.9	17.2	16.9	19.2	13.9	11.2
1970	6.3	5.4	4.3	7.8	23.7	25.1	23.9	14.0	22.1	18.5	11.3	.5
1971	.4	.4	.5	6.2	16.7	25.1	24.2	11.4	5.6	14.9	12.5	9.2
1972	7.1	6.1	7.6	6.3	16.7	25.1	3.1	.2	7.1	15.8	13.9	14.2
1973	12.3	10.2	14.3	12.7	3.8	23.0	25.9	23.5	13.4	10.1	5.0	4.2
1974	.5	.4	.5	6.2	16.7	25.1	15.1	1.5	0.0	5.6	6.1	3.5
1975	3.1	2.0	7.2	14.8	25.9	25.1	25.9	20.8	9.1	7.7	3.9	3.1
1976	3.2	4.3	7.4	18.0	25.4	25.1	21.6	9.3	6.7	10.9	4.4	3.0
1977	1.3	.5	.1	1.4	5.8	15.9	4.4	10.3	4.8	5.0	3.7	3.0
AVG.	3.6	3.3	6.1	13.4	20.4	24.4	19.0	12.7	8.0	10.6	7.1	4.5

[a] *USBR* (1978).

Table 24. Ridges Basin releases for New Mexico M&I (1,000 ac-ft).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1929	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1930	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1931	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.50	0.00	0.00	0.00	0.00
1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1933	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1934	0.00	0.00	0.00	.80	0.00	.10	3.90	2.50	0.00	0.00	0.00	0.00
1935	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1936	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1937	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.30	0.00	0.00	0.00	0.00
1938	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1939	0.00	0.00	0.00	0.00	0.00	0.00	1.10	2.30	0.00	0.00	0.00	0.00
1940	0.00	0.00	0.00	0.00	0.00	0.00	.80	.70	0.00	0.00	0.00	0.00
1941	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1942	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1943	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1944	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1945	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1946	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1947	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1948	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1949	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	0.00	0.00	0.00	0.00
1951	0.00	0.00	0.00	.80	0.00	0.00	0.00	.50	.60	0.00	0.00	0.00
1952	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70	0.00	0.00	0.00
1954	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.80	0.00	0.00	0.00
1956	0.00	0.00	0.00	0.00	0.00	0.00	.80	2.80	3.10	.30	0.00	0.00
1957	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1959	0.00	0.00	0.00	.10	0.00	0.00	.40	0.00	1.50	0.00	0.00	0.00
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70	.40	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00	0.00	0.00	.70	.30	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00	.10	0.00	.10	0.00	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.40	0.00	0.00	0.00	0.00
1967	0.00	0.00	0.00	0.00	.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.80	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00	0.00	0.00	1.20	2.90	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	2.70	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.00	1.60	.80	0.00	1.90	0.00	.10	0.00	0.00	0.00
AVG.	0.00	0.00	0.00	.07	.03	.00	.22	.41	.24	.01	0.00	0.00

[a] *USBR* (1978).

Table 25. Water pumped from Ridges Basin Reservoir to Dryside Canal (1,000 ac-ft).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1929	0.0	0.0	0.0	3.7	11.4	30.7	34.7	25.7	14.1	1.9	0.0	0.0
1930	0.0	0.0	0.0	2.3	11.4	30.7	34.7	25.7	14.1	1.9	0.0	0.0
1931	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1932	0.0	0.0	0.0	5.4	13.2	30.7	34.7	25.7	14.1	1.9	0.0	0.0
1933	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	14.9	2.0	0.0	0.0
1934	0.0	0.0	0.0	5.4	15.4	30.7	30.9	8.8	5.5	5.4	.0	0.0
1935	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1936	0.0	0.0	0.0	5.1	12.5	30.7	34.7	25.7	14.1	1.9	0.0	0.0
1937	0.0	0.0	0.0	.2	2.5	30.1	34.7	25.9	14.1	1.9	0.0	0.0
1938	0.0	0.0	0.0	4.0	12.7	30.6	34.7	25.9	14.1	1.9	0.0	0.0
1939	0.0	0.0	0.0	5.4	14.8	30.7	34.7	25.9	16.6	2.9	0.0	0.0
1940	0.0	0.0	0.0	5.4	15.4	30.7	34.7	24.2	11.3	5.7	.0	0.0
1941	0.0	0.0	0.0	.2	1.7	21.4	31.0	21.9	12.5	.8	0.0	0.0
1942	0.0	0.0	0.0	0.0	4.7	26.4	34.7	25.9	14.1	1.9	0.0	0.0
1943	0.0	0.0	0.0	5.1	11.3	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1944	0.0	0.0	0.0	5.4	12.1	30.5	34.7	25.9	14.1	1.9	0.0	0.0
1945	0.0	0.0	0.0	5.1	10.1	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1946	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1947	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.6	18.0	5.2	.0	0.0
1948	0.0	0.0	0.0	5.2	13.8	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1949	0.0	0.0	0.0	5.4	14.6	26.8	34.5	25.8	14.1	1.9	0.0	0.0
1950	0.0	0.0	0.0	4.3	11.6	30.7	34.7	25.9	14.1	3.0	0.0	0.0
1951	0.0	0.0	0.0	5.4	15.1	30.7	34.7	23.0	9.8	5.4	.0	0.0
1952	0.0	0.0	0.0	4.0	9.8	28.7	34.7	25.9	14.1	1.9	0.0	0.0
1953	0.0	0.0	0.0	5.4	14.8	30.7	34.7	25.8	9.8	1.6	0.0	0.0
1954	0.0	0.0	0.0	5.4	15.4	30.7	34.7	21.2	10.0	5.6	.0	0.0
1955	0.0	0.0	0.0	5.4	15.4	30.7	34.7	24.3	11.4	5.4	.0	0.0
1956	0.0	0.0	0.0	5.4	15.4	30.7	28.9	8.6	5.5	2.0	0.0	0.0
1957	0.0	0.0	0.0	5.4	14.5	27.3	34.2	25.8	14.1	1.9	0.0	0.0
1958	0.0	0.0	0.0	.6	2.3	26.3	34.7	25.9	14.1	1.9	0.0	0.0
1959	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1960	0.0	0.0	0.0	5.4	15.1	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1961	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	16.8	2.1	0.0	0.0
1962	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	17.6	2.8	0.0	0.0
1963	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1964	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.2	11.8	5.5	.0	0.0
1965	0.0	0.0	0.0	5.1	14.0	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1966	0.0	0.0	0.0	3.6	11.4	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1967	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1968	0.0	0.0	0.0	5.4	15.1	30.7	34.7	25.9	18.0	4.4	0.0	0.0
1969	0.0	0.0	0.0	5.0	13.9	30.7	34.7	25.9	14.1	1.9	0.0	0.0
1970	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	14.0	1.9	0.0	0.0
1971	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1972	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.4	.0	0.0
1973	0.0	0.0	0.0	.4	2.4	21.3	34.7	25.9	14.1	1.9	0.0	0.0
1974	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	3.5	0.0	0.0
1975	0.0	0.0	0.0	.9	4.1	22.4	34.7	25.9	14.1	1.9	0.0	0.0
1976	0.0	0.0	0.0	5.4	15.4	30.7	34.7	25.9	18.0	5.9	.0	0.0
1977	0.0	0.0	0.0	5.4	15.4	30.7	28.2	13.2	8.8	5.4	.0	0.0
AVG.	0.0	0.0	0.0	4.5	12.8	29.8	34.3	24.6	14.3	3.2	.0	0.0

[a] USBR (1978).

APPENDIX B

RAW WATER QUALITY DATA

Table 26. Water quality parameter codes and explanation.

A. METALLIC CONSTITUENTS

101. Aluminum, Dissolved, µg/ℓ
102. Aluminum, Total, µg/ℓ
103. Barium, Dissolved, µg/ℓ
104. Barium, Total, µg/ℓ
105. Cadmium, Dissolved, µg/ℓ
106. Cadmium, Total, µg/ℓ
107. Calcium, mg/ℓ
108. Chromium, Hexavalent, µg/ℓ
109. Chromium, Total, µg/ℓ
110. Copper, Dissolved, µg/ℓ
111. Copper, Total, µg/ℓ
112. Hardness, Total, mg/ℓ
113. Iron, Dissolved, µg/ℓ
114. Iron, Total, µg/ℓ
115. Lead, Dissolved, µg/ℓ
116. Lead, Total µg/ℓ
117. Magnesium, mg/ℓ
118. Manganese, Dissolved, µg/ℓ
119. Manganese, Total, µg/ℓ
120. Mercury, Dissolved, µg/ℓ
121. Mercury, Total, µg/ℓ
122. Molybdenum, Dissolved, µg/ℓ
123. Molybdenum, Total, µg/ℓ
124. Nickel, Dissolved, µg/ℓ
125. Nickel, Total, µg/ℓ
126. Potassium, mg/ℓ
127. Selenium, Dissolved, µg/ℓ
128. Selenium, Total, µg/ℓ
129. Silver, Dissolved, µg/ℓ
130. Silver, Total, µg/ℓ
131. Sodium, mg/ℓ
132. Zinc, Dissolved, µg/ℓ
133. Zinc, Total, µg/ℓ

B. NON-METALLIC CONSTITUENTS

201. Alkalinity, Total, mg/ℓ
202. Arsenic, Dissolved, µg/ℓ
203. Arsenic, Total, µg/ℓ
204. Bicarbonate Hardness, mg/ℓ
205. Boron, mg/ℓ
206. Carbonate Hardness, mg/ℓ
207. Chloride, mg/ℓ
208. Cyanide, mg/ℓ
209. Fluoride, mg/ℓ
210. Nitrogen, Nitrate, mg/ℓ
211. Nitrogen, Nitrite, mg/ℓ
212. Nitrogen, Total Organic, mg/ℓ
213. Phosphorus, Ortho, mg/ℓ
214. Phosphorus, Total, mg/ℓ
215. Sulfate, mg/ℓ
216. Total Dissolved Solids, mg/ℓ

Table 27. Raw water quality data, Animas River at Durango, May 1977 — August 1978.

CODE	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
101		260.		410.	440.	280.	79.	156.	74.	96.	308.	-50.	129.	129.	844.	182.	341.
102	1044.	720.		570.	1100.	403.	81.	368.	242.	1271.	389.	621.	513.	5290.	4160.	1033.	341.
103								-100.	-100.	-100.	-100.	-100.	-100.	-100.	-100.	-100.	-100.
104								119.	-100.	124.	-100.	170.	320.	970.	-100.	-100.	-100.
105		-3.		-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-5.	-3.	-3.	-3.	-3.	5.
106	129.	19.		5.	18.	-3.	14.	7.	-3.	-3.	-3.	-3.	10.	3.	-3.	-3.	3.
107		14.		97.	66.	68.	95.	100.	104.	91.	95.	93.	58.	32.	23.	38.	90.
108		-1.		-1.	-1.	-1.	-1.	2.	-1.	-1.	-1.	-1.	-1.	5.	-1.	-1.	2.
109										-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
110		-10.		-10.	16.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.
111	10.	22.		-10.	40.	64.	-10.	16.	-10.	13.	-10.		22.	118.	59.	40.	17.
112		134.		320.	194.	256.	276.	286.	298.	291.	281.	269.	138.	75.	62.	108.	236.
113		61.		90.	58.	41.	-21.	82.	82.	27.	-21.	-21.	36.	26.	54.	68.	63.
114	629.	836.		376.	1021.	364.	180.	269.	296.	496.	611.	949.	651.	9178.	6500.	1663.	873.
115								-1.	-1.	-1.	-1.	-1.	-1.	-1.	3.	3.	-1.
116								-1.	-1.	-1.	-1.	-1.	3.	105.	32.	22.	-1.
117		4.		19.	8.	21.	10.	9.	9.	15.	10.	10.	-1.	-1.	1.	3.	3.
118		100.		90.	65.	76.	118.	174.	203.	160.	197.	158.	59.	72.	142.	140.	201.
119	152.	107.		124.	118.	96.	118.	166.	203.	171.	205.	226.	74.	615.	588.	237.	238.
120		-0.2		0.5	0.2	0.2	0.3	-0.2	-0.2	0.3	-0.2	-0.2	0.1	-0.2	0.4	0.6	2.7
121	1.0	-0.2		2.8	0.9	0.2	0.3	0.6	-0.2	0.3	-0.2	-0.2	0.7	-0.2	0.8	0.7	2.7
122		-5.		13.	6.	5.	-5.	-5.	5.	5.	-5.	-5.	-5.	-5.	-5.	-5.	6.
123	-5.	18.		26.	10.	6.	-5.	-5.	5.	5.	15.	-5.	7.	-5.	-5.	-5.	93.
124		-6.		-6.	-6.	-6.	-6.	21.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.
125	21.			16.	52.	77.	18.	21.	-6.	-6.	-6.	-6.	46.	32.	-6.	-6.	18.
126		2.0		8.0	3.0	3.0	4.2	2.4	0.6	2.2	2.7	2.8	1.3	1.8	3.0	3.0	5.0
127		-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	2.
128	-1.	-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	2.	5.
129		-9.		-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.		-9.	-9.	-9.
130	-9.	-9.		-9.	-9.	-9.	-9.	-9.	-9.	10.	-9.	-9.	-9.	-9.	-9.	-9.	-9.
131		12.		40.	14.	36.	27.	18.	23.	16.	17.	5.	9.	3.	2.	6.	25.
132		95.		-5.	72.	82.	84.	114.	120.	137.	150.	118.	65.	46.	81.	127.	75.
133	325.	298.		190.	625.	310.	228.	1629.	145.	208.	152.	144.	560.	737.	389.	298.	99.
201				213.	87.	97.	137.	141.	232.	112.	132.	113.	81.	56.	34.	50.	165.
202		-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	-1.
203	-1.	-1.		-1.	1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		9.	2.	-1.
204				208.	87.	97.	137.	141.	232.	112.	132.	113.	81.	56.	34.	50.	165.
205		0.44		0.81	0.11	0.23	0.32	-0.05	-0.05	0.28	-0.05	0.17	0.13	0.65	-0.05	0.07	-0.05
206				6.	0	0	0	0	0	0	0	0	0	0	0	0	0
207		11.		46.		12.	23.	30.	45.	23.	27.	19.	12.	-1.	3.	10.	33.
208		0.01		-0.01	0.01	-0.01	0.08	0.17	-0.01	0.01	-0.01	0.01	-0.01	-0.01	0.01	0.03	0.02
209		0.17		0.29	0.22	0.27	0.32	0.30	0.48		0.27	0.35	0.02	0.01	-0.01	0.02	0.05
210		0.17		0.15	0.16	0.16	0.20	0.27	0.15	0.27	0.19	0.20	0.17	0.23	0.20		
211		0.001		0.004	0.005	0.012	0.002	0.005	0.006	0.004	0.002	0.004	0.003	0.002	0.003	0.003	0.005
212		0.3		-0.1	0.1	0.9	0.1	-0.1	-0.1	0.3	0.6	-0.1	-0.1	-0.1	0.5	-0.1	2.4
213		0.003		0.003	0.003	-0.001	0.004	0.003	0.001	0.004	-0.001	0.001	0.006	0.004	0.002	0.022	0.001
214		0.003		0.019	0.029	0.010	0.014	0.008	0.004	0.017	0.011	0.008	0.039	0.338	0.037	0.025	0.024
215		52.		162.	111.	87.	157.	151.	153.		181.	152.	50.	35.	40.	56.	140.
216		228.		532.	222.	243.	418.	435.	409.	322.	385.	382.	125.	101.	91.	168.	928.

Table 28. Raw water quality data, La Plata River at Hesperus, May 1977 – August 1978.

CODE	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
101	203.	260.		220.	54.	140.	-50.	-50.	-50.	-50.	-50.	-50.	-50.	142.	1280.	109.	175.
102	413.	260.		280.	480.	451.	-50.	-50.	51.	351.	-50.	-50.	-50.	3000.	864.	118.	175.
103								-100.	-100.	-100.	134.	-100.	-100.	-100.	-100.	-100.	-100.
104								-100.	119.	184.	134.	-100.	200.	1209.	-100.	-100.	-100.
105	-3.	-3.		-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.	-3.
106	6.	57.		8.	9.	6.	11.	-3.	-3.	-3.	-3.	-3.	5.	6.	-3.	-3.	-3.
107	30.	27.		6.	34.	42.	35.	36.	35.	32.	35.	32.	28.	20.	16.	24.	26.
108		-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	2.	4.	-1.	-1.
109									-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.	-20.
110	-10.	20.		-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.	-10.
111	-10.	29.		-10.	20.	32.	-10.	-10.	-10.	24.	-10.	-10.	-10.	104.	-10.	14.	-10.
112	87.	79.		97.	86.	165.	108.	94.	178.	111.	112.	92.	82.	54.	48.	69.	76.
113	-21.	-21.		-21.	-21.	-21.	-21.	-21.	26.	-21.	-21.	-21.	-21.	64.	18.	41.	25.
114	226.	89.		54.	161.	151.	35.	-21.	107.	286.	-21.	-21.	190.	4312.	475.	80.	70.
115								-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
116								-1.	-1.	-1.	-1.	-1.	1.	7.	-1.	15.	-1.
117	3.	3.		20.	-1.	11.	5.	1.	21.	8.	6.	3.	3.	1.	2.	2.	2.
118	8.	5.		-5.	6.	8.	8.	10.	6.	-5.	-5.	20.	13.	22.	-5.	14.	14.
119	24.	5.		-5.	6.	25.	8.	10.	26.	7.	-5.	26.	13.	745.	24.	8.	14.
120	0.2	-0.2		0.5	0.3	0.2	-0.2	-0.2	-0.2	-0.2	0.2	-0.2	0.3	-0.2	0.6	0.2	1.1
121	0.2	-0.2		4.1	2.4	0.2	1.2	-0.2	0.2	-0.2	0.2	0.2	0.5	-0.2	2.3	0.2	1.1
122	-5.	-5.		7.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	-5.
123	-5.	-5.		12.	19.	6.	-5.	-5.	-5.	-5.	6.	-5.	-5.	-5.	-5.	7.	-5.
124	-6.	-6.		-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.
125	11.	20.		18.	14.	58.	28.	-6.	-6.	-6.	-6.	-6.	11.	18.	-6.	-6.	-6.
126	1.0	0.5		1.0	1.0	1.0	1.3	0.9	3.7	0.7	0.8	1.5	1.1	1.6	2.0	2.0	2.0
127	-1.	-1.		-1.	-1.	7.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	1.
128	-1.	-1.		-1.	2.	7.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	2.	13.
129	-9.	-9.		-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.
130	-9.	-9.		-9.	-9.	11.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	9.	-9.	-9.	-9.
131	2.	1.		2.	4.	11.	17.	3.	5.	3.	3.	5.	2.	2.	1.	4.	3.
132	-5.	-5.		-5.	-5.	7.	-5.	-5.	-5.	-5.	-5.	-5.	-5.	8.	28.	-5.	-5.
133	439.	183.		118.		183.	320.	92.	-5.	-5.	-5.	-5.	410.	179.	-5.	73.	-5.
201	56.	54.		59.	53.	61.	64.	64.	61.	57.	66.	58.	54.	40.		52.	61.
202	-1.	-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	-1.
203	-1.	-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	4.
204	56.	54.		59.	58.	61.	64.	64.	61.	57.	66.	58.	54.	40.		52.	61.
205	2.16	0.05		0.86	0.10	-0.05	-0.05	0.25	-0.05	0.19	-0.05	0.11	-0.05	1.03	0.25	-0.05	-0.05
206	0	0		0	0	0	0	0	0	0	0	0	0	0		0	0
207	3.	-1.		-1.	-1.	-1.	-1.	2.	1.	1.	-1.	1.	11.	-1.	2.	-1.	-1.
208	-0.01	0.01		-0.01	-0.01	-0.01	0.08	0.11	-0.01	0.02	-0.01	0.01	-0.01	-0.01	0.01	0.02	0.05
209	0.18	0.11		0.12	0.47	0.14	0.11	0.13	0.22		0.18	0.01	0.01	0.01	-0.01	0.02	0.03
210	0.14	0.15		0.02	0.13	0.09	0.07	0.07	0.15	0.12	0.12	0.13	0.22	0.23	0.15	0.09	0.07
211	0.003	0.001		0.004	0.021	0.009	0.001	0.002	0.004	0.002	0.003	0.003	0.002	0.001	0.002	0.002	0.003
212	0.5	0.6		1.4	0.2	0.6	0.1	0.9	-0.1	-0.1	-0.1	-0.1	-0.1	0.7	0.4	-0.1	0.2
213	0.001	0.004		0.003	0.004	-0.001	0.002	0.004	0.001	0.001	0.001	-0.001	0.003	0.006	0.003	0.002	-0.001
214	0.004	0.004		0.003	0.005	0.003	0.011	0.008	0.001	0.022	0.005	0.001	0.015	0.156	0.024	0.062	0.008
215	54.	35.		27.	27.	31.	35.	28.	30.	28.	22.	27.	26.	14.	33.	17.	19.
216	28.	118.		108.	50.	76.	119.	117.	94.	110.	5751.	157.	71.	92.	65.	88.	99.

61

Table 29. Raw water quality data, La Plata River at Colorado/New Mexico border, May 1977 – August 1978.

CODE	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/15/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
101	717.	490.		770.	550.	300.	156.	163.	119.	202.	341.	229.	219.	74.	1460.	254.	245.
102	1127.	800.		7010.	3300.	575.	313.	368.	413.	316.	394.	841.	12111.	23180.	3600.	775.	245.
103								-100.	-100.	-100.	125.	-100.	103.	134.	-100.	100.	-100.
104								172.	-100.	415.	362.	134.	359.	635.	196.	106.	-100.
105	-5.	-3.		-3.	6.	-3.	5.	-3.	-3.	-3.	-3.	-3.	3.	-3.	-3.	-3.	-3.
106	100.	91.		13.	85.	-3.	15.	4.	-3.	21.	-3.	-3.	11.	-3.	7.	-3.	4.
107	140.	124.		139.	200.	117.	180.	169.	161.	85.	200.	203.	72.	40.	50.	68.	121.
108		-1.		-1.	-1.	-1.	-1.	-1.	2.	-1.	-1.	-1.	-1.	2.	4.	-1.	-1.
109										-20.	-20.	-20.	-29.	-20.	-20.	-20.	-20.
110	-10.	-10.		20.	-10.	-10.	-10.	-10.	-10.	-10.	26.	-10.	-10.	-10.	-10.	-10.	-10.
111	-10.	84.		20.	50.	32.	-10.	-10.	20.	19.	26.	-10.	12.	100.	16.	-10.	11.
112		626.		704.	724.	645.	631.	576.	724.	336.	814.	832.	239.	126.	181.	466.	515.
113	210.	23.		62.	33.	-21.	33.	-21.	28.	-21.	-21.	-21.	36.	69.	62.	40.	18.
114	543.	536.		4396.	2207.	306.	346.	334.	148.	254.	271.	404.	4656.	31591.	3000.	396.	174.
115								9.	2.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
116								9.	2.	-1.	-1.	-1.	-1.	22.	-1.	28.	-1.
117		74.		86.	54.	85.	44.	34.	78.	30.	76.	78.	14.	1.	14.	71.	51.
118	24.	11.		-5.	48.	10.	14.	15.	13.	18.	22.	47.	25.	-5.	-5.	-5.	-5.
119	24.	16.		88.	96.	13.	14.	15.	16.	25.	30.	72.	176.	519.	118.	31.	-5.
120	1.0	-0.2		1.8	0.3	0.3	1.7	0.3	-0.2	0.4	0.3	0.9	0.6	-0.2	-0.2	-0.2	0.9
121	1.2	-0.2		4.1	0.7	0.3	1.7	0.7	-0.2	0.4	0.3	0.9	3.6	-0.2	0.2	0.6	2.4
122	-5.	12.		10.	-5.	11.	7.	-5.	9.	8.	-5.	-5.	-5.	-5.	-5.	-5.	-5.
123	-5.	12.		39.	15.	14.	11.	-5.	9.	11.	27.	-5.	11.	-5.	-5.	52.	-5.
124	-6.	-6.		-6.	-6.	-6.	7.	80.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.
125	21.	49.		30.	51.	56.	100.	80.	-6.	-6.	-6.	-6.	184.	57.	35.	-6.	-6.
126	3.0	2.0		3.0	5.0	3.0	2.7	1.5	5.1	1.3	1.6	2.4	1.5	4.3	3.0	3.0	3.0
127	-1.	-1.		-1.	-1.	-1.	-1.	4.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	-1.
128	-1.	-1.		-1.	2.	-1.	-1.	-1.	7.	-1.	-1.	-1.	-1.		-1.	1.	2.
129	-9.	-9.		-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.
130	-9.	-9.		-9.	-9.	11.	-9.	-9.	-9.	-9.	-9.	17.	9.	-9.	-9.	-9.	-9.
131	66.	47.		58.	50.	61.	68.	62.	63.	58.	62.	72.	19.	3.	8.	32.	45.
132	-5.	-5.		5.	9.	8.	10.	18.	-5.	-5.	-5.	5.	17.	11.	-5.	-5.	8.
133	411.	217.		510.	501.	250.	346.	18.	-5.	16.	158.	5.	446.	194.	30.	74.	23.
201	176.	174.		207.	199.	184.	205.	221.	218.	217.	234.	181.	118.	130.	86.	172.	156.
202	-1.	-1.		-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.		-1.	-1.	-1.
203	-1.	-1.		2.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	4.			-1.	21.
204	176.	174.		190.	199.	178.	205.	217.	218.	217.	234.	181.	118.	130.	86.	172.	153.
205		-0.05			0.89	0.15	0.27	0.17	-0.05	-0.05	-0.05	0.17	-0.05	0.17	0.28	0.29	-0.05
206	0	0		17.	0	8.	0	4.	0	0	0	0	0	0	0	0	0
207	31.	3.		29.	24.	40.	24.	31.	36.	29.	34.	32.	17.	3.	4.	12.	19.
208		0.02		-0.01	0.01	-0.01	0.09	0.03	-0.01	0.06	0.01	0.01	-0.01	0.01	0.01	0.02	0.06
209	0.17	0.15.		0.15	0.19	0.17	0.19	0.18	0.29		0.21	0.04	0.01	0.01	0.02	0.04
210	0.10	0.03		0.32	0.21	0.07	0.04	0.38	0.27	0.61	0.36	0.35	0.34	0.49	0.06	0.05	0.05
211	0.002	0.001		0.007	0.004	0.004	0.003	0.004	0.007	0.005	0.007	0.008	0.005	0.004	0.003	0.003	0.002
212	0.7	1.2		2.1	1.7	0.4	0.5	0.2	-0.1	0.2	0.3	-0.1	0.6	3.6	0.6	-0.1	0.6
213	0.001	0.004		0.014	0.004	0.004	0.002	0.001	0.002	0.001	0.004		0.006	0.010	0.002	0.003	0.001
214	0.001	0.004		0.014	0.165	0.029	0.024	0.010	0.009	0.013	0.018	0.021	0.270	1.420	0.084	0.017	0.022
215	511.	409.		560.	455.	478.	502.	536.	607.	493.	620.	664.	133.	57.	110.	314.	403.
216		932.		1038.	982.	1006.	1032.	1011.	1124.	925.	1169.	1269.	307.	186.	241.	659.	780.

62

Table 30. Raw water quality data, La Plata River at Farmington.

CODE	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
101				840.	350.	520.	246.	278.	215.	1961.	504.	456.	224.	155.	1760.	317.	609.
102				12120.	1500.	1450.	357.	977.	302.	310000.	34430.	5529.	1302.	77200.	9510.	1491.	609.
103								157.	-100.	-100.	153.	195.	172.	127.	-100.	125.	-100.
104								157.	134.	2206.	570.	809.	772.	1799.	621.	125.	367.
105				-3.	5.	4.	6.	7.	-3.	-3.	-3.	4.	3.	-3.	-3.	-3.	10.
106				20.	19.	14.	14.	7.	4.	-3.	-3.	4.	18.	7.	-3.	-3.	11.
107	206.			100.	169.	167.	170.	211.		80.	260.	430.	93.	70.	150.	95.	241.
108				4.	-1.	-1.	-1.	3.		5.	-1.	-1.	3.	6.	-1.	-1.	-1.
109										138.	24.	-20.	37.	43.	-20.	-20.	32.
110				20.	10.	-10.	-10.	-10.	-10.	-10.	-10.	36.	-10.	-10.	-10.	-10.	12.
111				31.	20.	30.	17.	-10.	-10.	401.	62.	46.	54.	203.	74.	-10.	44.
112	733.			317.	531.	562.	543.	605.		232.	930.	1395.	338.	222.	81.	352.	821.
113				50.	28.	41.	45.	21.	52.	1274.	-21.	192.	36.	73.	32.	72.	65.
114				7203.	980.	1315.	358.	931.	396.	323000.	13430.	9678.	29177.	93372.	8400.	1109.	834.
115								5.	-1.	-1.	-1.	-1.	-1.	1.	-1.	-1.	-1.
116								5.	-1.	24.	-1.	-1.	-1.	31.	-1.	-1.	
117	53.			16.	26.	35.	41.	19.	8.	.67	77.	25.	12.	26.	28.		53.
118				36.	425.	572.	637.	858.	903.	16.	42.	112.	24.	34.	-5.	560.	852.
119				138.	465.	685.	642.	859.	908.	1900.	363.	272.	704.	1606.	238.	602.	852.
120				1.3	0.4	0.2	0.5	0.2	0.8	0.9	0.8	0.3		-0.2	-0.2	-0.2	1.0
121				4.3	0.4	2.0	1.0	0.4	0.8	0.9	0.8	0.3	1.5	-0.2	0.2	0.3	2.1
122				41.	22.	7.	15.	25.	20.	27.	32.	23.	-5.	-5.	-5.	6.	21.
123				41.	25.	11.	17.	25.	20.	36.	30.	24.	59.	9.	-5.	34.	25.
124				-6.	-6.	9.	-6.	21.	25.	-6.	-6.	-6.	-6.	-6.	-6.	-6.	-6.
125				70.	14.	119.	-6.	100.	40.	311.	34.	61.	58.	-6.		-6.	25.
126				8.0	7.0	5.0	3.5	2.1	6.0	4.1	2.9	4.6	1.7	11.8	5.0	3.0	5.0
127				-1.	-1.	-1.	-1.	3.	-1.	2.	-1.	-1.	-1.		-1.	1.	-1.
128				-1.	2.	-1.	-1.	4.	-1.	2.	-1.	-1.	-1.		-1.	9.	2.
129				-9.	-9.	-9.	-9.	-9.	-9.	-9.	-9.	17.	-9.	-9.	-9.	-9.	-9.
130				-9.	-9.	-9.	-9.	-9.	-9.	22.	10.	17.	-9.	-9.	-9.	-9.	13.
131				272.	182.	97.	275.	268.	426.	247.	250.	515.	40.	11.	60.	92.	334.
132				-5.	13.	16.	10.	18.	-5.	-5.	55.	68.	7.	6.	-5.	12.	53.
133				268.	334.	202.	338.	18.	136.	1394.	219.	287.	577.	573.	255.	105.	296.
201	174.			117.	195.	247.	272.	266.		152.	270.	227.	156.	158.	164.	236.	266.
202				-1.	-1.	-1.	-1.	-1.	-1.	2.	-1.	-1.	-1.		-1.	-1.	-1.
203				-1.	-1.	-1.	-1.	-1.	-1.	6.	-1.	15.	6.		-1.	-1.	-1.
204	174.			117.	195.	247.	272.	266.		152.	270.	227.	156.	158.	164.	236.	266.
205	0			-0.05	1.11	0.02	-0.05	0.78	-0.05	-0.05	-0.05	0.11	0.67	0.62	0.38	-0.05	-0.05
206	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0
207	100.			38.	81.	109.	88.	142.		34.	65.	192.	33.	7.	20.	35.	296.
208	-0.01			-0.01	-0.01	-0.01	0.08	0.07		0.03	-0.01	0.01	-0.01	0.01	0.01	0.02	0.05
209	0.38			0.48	0.43	0.59	0.78	0.49		0.33	0.02	0.01	0.02	0.02	0.04	0.08	
210	0.03																
211	0.009			0.031	0.017	0.004	0.001	0.002		0.022	0.006	0.006	0.006	0.007	0.003	0.002	0.002
212	0.6			1.3	1.1	0.6	1.2	-0.1		4.7	-0.1	-0.1	1.0	3.1	-0.1	-0.1	2.0
213	0.011			0.018	0.009	0.002	0.004	0.004	0.001	0.013	0.008	0.005	0.013	0.025	0.004	0.013	0.002
214	0.011			0.089	0.057	0.034	0.017	0.016	0.002	0.177	0.360	0.096	0.400	1.000	0.029	0.027	0.030
215	819.			574.	422.	541.	526.	664.		507.	1224.	2536.	137.	150.	740.	322.	1009.
216	1796.			1160.	1084.	1263.	1471.	1468.		946.	1799.	3704.	482.	352.	835.	688.	2139.

APPENDIX C

ION BALANCE CALCULATIONS

Table 31. Ion balances for water quality stations in Animas – La Plata project.

ANIMAS-LA PLATA PROJECT

STATION 8:   LA PLATA AT FARMINGTON

	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
CA	206.0	0.0	0.0	100.0	169.0	167.0	170.0	211.0	0.0	80.0	260.0	430.0	93.0	70.0	150.0	95.0	241.0
MG	53.0	0.0	0.0	16.0	26.0	35.0	41.0	19.0	0.0	8.0	67.0	77.0	25.0	12.0	26.0	28.0	53.0
NA	0.0	0.0	0.0	272.0	182.0	97.0	275.0	268.0	426.0	247.0	250.0	515.0	40.0	11.0	69.0	92.0	334.0
K	0.0	0.0	0.0	8.0	7.0	5.0	3.5	2.1	6.0	4.1	2.9	4.6	1.7	11.8	5.0	3.0	5.0
HCO3	174.0	0.0	0.0	117.0	195.0	247.0	272.0	266.0	0.0	152.0	270.0	227.0	156.0	158.0	164.0	236.0	266.0
CO3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	109.0	0.0	0.0	38.0	81.0	109.0	88.0	142.0	0.0	34.0	65.0	192.0	33.0	7.0	20.0	35.0	296.0
SO4	819.0	0.0	0.0	574.0	422.0	541.0	526.0	664.0	0.0	507.0	1224.0	2536.0	137.0	150.0	740.0	322.0	1009.0
STDS	1361.0	0.0	0.0	1125.0	1052.0	1201.0	1375.5	1572.1	432.0	1032.1	2138.9	3981.6	485.7	419.8	1174.0	811.0	2204.0
MTDS	1796.0	0.0	0.0	1160.0	1094.0	1263.0	1471.0	1468.0	0.0	946.0	1799.0	3704.0	482.0	352.0	835.0	688.0	2139.0
SC	14.639	0.000	0.000	18.343	18.668	15.560	23.908	23.804	18.684	15.499	29.435	50.311	8.481	5.260	12.753	11.122	31.043
SA	23.606	0.000	0.000	15.363	14.971	19.279	18.874	23.150	0.000	14.555	32.717	62.756	6.903	6.480	19.251	12.411	34.678
ADIFF	8.967	0.000	0.000	2.980	3.697	3.719	5.034	0.653	18.684	0.945	3.283	12.445	1.577	1.220	6.498	1.289	3.635
ERR(%)	23.447	0.000	0.000	8.841	10.990	10.674	11.766	1.391	100.000	3.143	5.282	11.006	10.254	10.392	20.303	5.477	5.531

ANIMAS-LA PLATA PROJECT

STATION 14:   LA PLATA AT HESPERAS.

	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
CA	30.0	27.0	0.0	6.0	34.0	42.0	35.0	36.0	35.0	32.0	35.0	32.0	28.0	20.0	16.0	24.0	26.0
MG	3.0	3.0	0.0	20.0	-1.0	11.0	5.0	1.0	21.0	8.0	6.0	3.0	3.0	1.0	2.0	2.0	2.0
NA	2.0	1.0	0.0	2.0	4.0	11.0	17.0	3.0	5.0	3.0	3.0	5.0	2.0	2.0	1.0	4.0	3.0
K	1.0	0.5	0.0	1.0	1.0	1.0	1.3	0.9	3.7	0.7	0.8	1.5	1.1	1.6	2.0	2.0	2.0
HCO3	56.0	54.0	0.0	59.0	58.0	61.0	64.0	64.0	61.0	57.0	66.0	58.0	54.0	40.0	0.0	52.0	61.0
CO3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	3.0	-1.0	0.0	-1.0	-1.0	-1.0	-1.0	2.0	1.0	1.0	-1.0	1.0	11.0	-1.0	2.0	-1.0	-1.0
SO4	54.0	35.0	0.0	27.0	27.0	31.0	35.0	28.0	30.0	28.0	22.0	27.0	26.0	14.0	33.0	17.0	19.0
STDS	149.0	120.5	0.0	115.0	124.0	157.0	157.3	134.9	156.7	129.7	132.8	127.5	125.1	78.6	56.0	101.0	113.0
MTDS	28.0	118.0	0.0	108.0	50.0	76.0	119.0	117.0	94.0	110.0	5751.0	157.0	71.0	92.0	65.0	88.0	99.0
SC	1.856	1.650	0.000	2.057	1.896	3.505	2.931	2.032	3.786	2.403	2.391	2.099	1.759	1.208	1.058	1.587	1.644
SA	2.329	1.809	0.000	1.742	1.722	1.865	2.009	1.919	1.873	1.751	1.778	1.750	1.932	1.091	0.743	1.394	1.616
ADIFF	0.473	0.158	0.000	0.315	0.174	1.639	0.922	0.113	1.913	0.652	0.613	0.349	0.173	0.117	0.314	0.193	0.028
ERR(%)	11.291	4.577	0.000	8.292	4.810	30.526	18.664	2.854	33.810	15.697	14.703	9.068	4.674	5.074	17.439	6.485	0.859

Table 31. Continued.

ANIMAS-LA PLATA PROJECT

STATION 22:   ANIMAS AT DURANGO

	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
CA	0.0	48.0	0.0	97.0	66.0	68.0	95.0	100.0	104.0	91.0	95.0	91.0	58.0	32.0	23.0	38.0	90.0
MG	0.0	4.0	0.0	19.0	8.0	21.0	10.0	9.0	9.0	15.0	10.0	10.0	-1.0	-1.0	1.0	3.0	3.0
NA	0.0	12.0	0.0	44.0	14.0	36.0	27.0	18.0	23.0	16.0	17.0	5.0	9.0	3.0	2.0	8.0	25.0
K	0.0	2.0	0.0	8.0	3.0	3.0	4.2	2.4	6.6	2.2	2.7	2.8	1.3	1.8	3.0	3.0	5.0
HCO3	0.0	0.0	0.0	208.0	87.0	97.0	137.0	141.0	232.0	112.0	132.0	113.0	81.0	56.0	34.0	50.0	165.0
CO3	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	0.0	11.0	0.0	46.0	0.0	12.0	23.0	30.0	45.0	23.0	27.0	19.0	12.0	-1.0	3.0	10.0	33.0
SO4	0.0	52.0	0.0	162.0	111.0	87.0	157.0	151.0	153.0	0.0	181.0	152.0	50.0	30.0	49.0	56.0	140.0
STDS	0.0	129.0	0.0	590.0	289.0	324.0	453.2	451.4	572.6	259.2	464.7	392.8	211.3	122.8	115.0	168.0	461.0
MTDS	0.0	228.0	0.0	532.0	222.0	244.0	418.0	435.0	409.0	322.0	385.0	382.0	125.0	101.0	91.0	168.0	428.0
SC	0.000	3.297	0.000	8.522	4.637	6.763	6.845	6.575	7.099	6.527	6.372	5.653	3.319	1.773	1.394	2.568	5.953
SA	0.000	1.393	0.000	8.951	4.051	4.090	6.658	6.810	9.095	2.889	7.170	5.961	3.000	1.745	1.785	2.448	7.146
ADIFF	0.000	1.904	0.000	0.429	0.586	2.674	0.187	0.235	1.996	3.638	0.798	0.308	0.319	0.029	0.391	0.120	1.193
ERR(%)	0.000	40.603	0.000	2.454	6.747	24.633	1.388	1.759	12.324	38.639	5.896	2.652	5.055	0.817	12.306	2.386	9.105

ANIMAS-LA PLATA PROJECT

STATION 4:   LA PLATA RIVER AT CO./N.M. BORDER

	5/25/77	6/16	6/30	7/19	8/24	9/21	10/19	11/15	12/13	1/18/78	2/15	3/21	4/18	5/18	6/16	7/19	8/24
CA	140.0	128.0	0.0	139.0	200.0	117.0	180.0	169.0	161.0	85.0	200.0	203.0	72.0	49.0	50.0	68.0	121.0
MG	0.0	74.0	0.0	86.0	54.0	85.0	44.0	38.0	78.0	30.0	76.0	78.0	14.0	1.0	14.0	71.0	51.0
NA	66.0	47.0	0.0	58.0	50.0	61.0	68.0	62.0	63.0	58.0	62.0	72.0	19.0	3.0	8.0	32.0	45.0
K	3.0	2.0	0.0	3.0	5.0	3.0	2.7	1.5	5.1	1.3	1.6	2.4	1.5	4.3	3.0	3.0	3.0
HCO3	176.0	174.0	0.0	190.0	199.0	178.0	205.0	217.0	218.0	217.0	234.0	181.0	118.0	130.0	86.0	172.0	153.0
CO3	0.0	0.0	0.0	17.0	0.0	8.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CL	31.0	3.0	0.0	29.0	29.0	40.0	24.0	31.0	36.0	29.0	34.0	32.0	17.0	3.0	4.0	12.0	19.0
SO4	511.0	409.0	0.0	560.0	455.0	478.0	502.0	536.0	607.0	493.0	620.0	664.0	133.0	57.0	110.0	314.0	403.0
STDS	927.0	837.0	0.0	1082.0	992.0	970.0	1025.7	1058.5	1168.1	913.3	1227.6	1232.4	374.5	247.3	275.0	672.0	795.0
MTDS	0.0	932.0	0.0	1038.0	982.0	1006.0	1032.0	1011.0	1124.0	925.0	1169.0	1269.0	307.0	188.0	241.0	659.0	780.0
SC	9.934	14.570	0.000	16.610	16.725	15.561	15.628	14.294	17.321	9.266	18.970	19.739	5.609	2.768	4.071	10.702	12.267
SA	15.034	12.080	0.000	16.617	14.271	14.800	15.229	16.454	18.013	15.422	18.548	18.347	5.609	3.871	4.123	10.316	11.986
ADIFF	5.100	2.490	0.000	0.007	2.454	0.760	0.400	2.160	0.692	6.157	0.422	1.392	0.001	1.104	0.052	0.386	0.281
ERR(%)	20.426	9.344	0.000	0.021	7.916	2.504	1.296	7.024	1.959	24.939	1.125	3.655	0.006	16.622	0.631	1.838	1.158

67

APPENDIX D

PROPOSED COLORADO WATER QUALITY STANDARDS

Table 32. Proposed Colorado water quality standards: Class II water supply.

Parameter	Standard
Physical	
D.O. (mg/ℓ)[1]	Aerobic[2]
pH	5.0-9.0
Suspended solids and turbidity	[3]
Temperature	X
TDS (mg/ℓ)	Y
Biological	
Algae[4]	Free of toxic and objectionable algae
Fecal coliforms (#/100 mℓ)	1,000
Inorganics	
Ammonia (mg/ℓ as N)	0.5
Total residual chlorine (mg/ℓ)	X
Cyanide (mg/ℓ)	0.2
Fluoride (mg/ℓ)	[5]
Nitrate (mg/ℓ as N)	10
Nitrite (mg/ℓ as N)	1.0
Sulfide as H_2S (mg/ℓ)	0.05
Boron (mg/ℓ)	X
Chloride (mg/ℓ)	250
Magnesium (mg/ℓ)	125
Sodium adsorbtion ratio	X
Sulfate (mg/ℓ)	250
Phosphorus (mg/ℓ as P)	Bioassay[6]
Toxic Metals (mg/ℓ)	
Aluminum	X
Arsenic	0.05
Barium	1.0
Beryllium	X
Cadmium	0.01
Chromium	0.05
Copper	1.0
Iron	0.3 (soluble)
Lead	0.05
Manganese	0.05 (soluble)
Mercury	0.002
Molybdenum	Y
Nickel	X

X = numerical limit generally not needed for protection of classified use.

Y = limit may be required but there is insufficient data for setting a general standard.

70

Table 32. Continued.

Parameter	Standards
Toxic Metals (mg/ℓ)	
Selenium	0.01
Silver	0.05
Thallium	X
Zinc	5.0
Organics[7] ($\frac{\mu g}{\ell}$)	
Chlorinated pesticides[8]	
Aldrin[9]	Y
Chlordane[9]	Y
Dieldrin[8]	Y
DDT[9]	Y
Endrin	0.2
Heptachlor[9]	Y
Lindane	4
Methoxychlor	Y
Mirex	100
Toxaphene	5
Organophosphate pesticides[8]	
Demeton	Y
Endosulfan	Y
Guthion	Y
Malathion	Y
Parathion	Y
Chlorophenoxy Herbicides	
2, 4-D	100
2, 4, 5-TP	10
PCB's[10]	Y
Phenol	1
Radiological[11] (pCi/ℓ)	
Alpha[11, 12]	15
Beta[11, 12]	50
Cesium 134	80
Plutonium	15
Radium 226 and 228[12, 13]	5
Strontium 90[12, 13]	8
Thorium 230 and 232	60
Tritium	20,000
Uranium (total, mg/ℓ)	5

[1]Where dissolved oxygen levels less than the standard occur naturally, a discharge shall not cause a further reduction in dissolved oxygen in receiving water.

[2]An effluent shall be regulated to maintain aerobic conditions, and a guideline of 2.0 mg/ℓ dissolved oxygen in an effluent should be maintained, unless demonstrated otherwise.

[3]Suspended solid levels will be controlled by Effluent Limitations and Basic Standards.

[4]Free from objectionable and toxic algae. It has been well established that heavy growth of some strains of blue-green algae, upon death and degradation, may release one or more substances which are toxic to humans and many other animals. Although no fixed numbers can be recommended at this time, it is clear that streams, lakes and reservoirs should not be permitted to bear heavy growth of algal blooms, nor allow these blooms to disintegrate. Every effort should be made to control algal growths to levels that are not hazardous.

[5]Fluoride limits vary from 2.4 mg/ℓ at 12.0 C and below, to 1.4 mg/ℓ between 26.3 C and 32.5 C, based upon the annual average of the maximum daily air temperature (see *National Interim Primary Drinking Water Regulations* for specific limitations).

[6]Phosphorus standards are to be determined by an algal bioassay using the method described in the latest edition of *Standard Methods for the Examination of Water and Wastewater*.

[7]All organics, not on this partial list, are covered under Basic Standards, Section 3.1., 1978 Colorado Water Quality Standards.

[8]Numerical limits in tables based on experimental evidence of toxicity. No point source discharges of organic pesticides shall be permitted to state waters.

[9]The persistence, bioaccumulation potential, and carcinogenicity of these organic compounds cautions human exposure to a minimum (EPA).

[10]Every reasonable effort should be made to minimize human exposure (EPA).

[11]Concentrations given are maximum permissible concentrations above naturally occurring or "background" concentrations except where otherwise noted.

[12]If Alpha or Beta are measured in excess of 15 or 50 pCi/ℓ respectively, it will be necessary to determine by specific analysis the particular radionuclide or radionuclides responsible for the elevated level. Particular radionuclides should not exceed the limit given in the table. If an elevated level of Alpha or Beta emissions is caused by radionuclides, the Division should be consulted.

[13]Maximum permissible concentrations including naturally occurring or background contributions.

Table 33. Proposed Colorado water quality standards (non-metallic): Protection of Aquatic Biota.

Parameter	Cold Water Biota	Warm Water Biota
Physical		
D.O. (mg/ℓ)[1]	6.0	5.0
	7.0 (spawning)[2]	
pH	6.5 - 9.0	6.5 - 9.0
Suspended solids and turbidity	[3]	[3]
Temperature (°C)	Maximum 20°C w/ 3° increase[4]	Maximum 30°C w/ 3° increase[4]
TDS (mg/ℓ)	Y	Y
Biological		
Algae[5]	Free from objectionable and toxic algae	Same as Cold Water
Fecal coliforms	X	X
Inorganics		
Ammonia (mg/ℓ as N)	0.02 unionized	0.10 unionized
Total residual chlorine (mg/ℓ)	0.002	0.01
Cyanide (mg/ℓ)	0.005	0.005
Fluoride (mg/ℓ)	X	X
Nitrate (mg/ℓ as N)	X	X
Nitrite (mg/ℓ as N)	0.05	0.5
Sulfide as H_2S (mg/ℓ)	0.002 undissociated	0.002 undissociated
Boron (mg/ℓ)	X	X
Chloride (mg/ℓ)	X	X
Magnesium (mg/ℓ)	X	X
Sodium adsorbtion ratio	X	X
Sulfate (mg/ℓ)	X	X
Phosphorus (mg/ℓ as P)	Bioassay[6]	Bioassay[6]
Organics[7] ($\frac{\mu g}{\ell}$)		
Chlorinated Pesticides[8]		
Aldrin[9]	.003	.003
Chlordane	0.01	0.01
Dieldrin[9]	0.003	0.003
DDT	0.001	0.001
Endrin	0.004	0.004
Heptachlor	0.001	0.001
Lindane	0.01	0.01
Methoxychlor	0.03	0.03
Mirex	0.001	0.001
Toxaphene	0.005	0.005

Table 33. Continued.

Parameter	Cold Water Biota	Warm Water Biota
Organophosphate Pesticides[8]		
Demeton	1	1
Endosulfan	0.003	0.003
Guthion	0.01	0.01
Malathion	1	1
Parathion	0.04	0.04
Chlorophenoxy Herbicides		
2, 4-D	Y	Y
2, 4, 5-TP	Y	Y
PCB's	0.001	0.001
Phenols	1	1
Radiological[10] in (pCi/ℓ)		
Alpha (excluding uranium and radium[11])	15	15
Beta (excluding Sr^{90} [11]	50	50
Cesium 134	80	80
Plutonium 238, 239, and 240	15	15
Radium 226 and 228	5	5
Strantium 90[12]	8	8
Thorium 230 and 232	60	60
Tritium	20,000	20,000
Uranium (total)[13]	--	--

X = numerical limit generally not needed for protection of classified use.

Y = limit may be required but there is insufficient data for setting a general standard.

[1]Where dissolved oxygen levels less than the standard occur naturally a discharge shall not cause a further reduction in dissolved oxygen in receiving water.

[2]A 7 mg/ℓ standard, during periods of spawning of coldwater fish, shall be set on a case by case basis as defined in the NPDES permit for those dischargers whose effluent would affect fish spawning.

[3]Suspended solid levels will be controlled by Effluent Limitations and Basic Standards.

[4]Temperature shall maintain a normal pattern of diurnal and seasonal
fluctuations with no abrupt changes and shall have no increase in
temperature of a magnitude, rate and duration deemed deleterious to
the resident aquatic life. Generally, a maximum 3°C increase over
a minimum of a 4-hour period, lasting for 12 hours maximum, is deemed
acceptable for discharges fluctuating in volume or temperature.
Where temperature increases cannot be maintained within this range
using BMP, BATEA, and BPWITT control measures, the Division will
determine whether the resulting temperature increases preclude an
Aquatic Life classification.

[5]Free from objectionable and toxic algae. It has been well established
that heavy growth of some strains of blue-green algae, upon death and
degradation, may release one or more substances which are toxic to
humans and many other animals. Although no fixed numbers can be
recommended at this time, it is clear that streams lakes and reservoirs
should not be permitted to bear heavy growth of algal blooms, nor
allow these blooms to disintegrate. Every effort should be made to
control algal growths to levels that are not hazardous.

[6]Phosphorus standards are to be determined by an algal bioassay using
the method described in the latest edition of *Standard Methods for
the Examination of Water and Wastewater*, American Public Health
Association.

[7]All organics, not on this partial list, are covered under Basic
Standards, Section 3.1., 1978 Colorado Water Quality Standards.

[8]Numerical limits in tables based on experimental evidence of toxicity.
No point source discharges of organic pesticides shall be permitted to
state waters.

[9]Aldrin and dieldrin in combination should not exceed 0.000003 mg/ℓ.

[10]Concentrations given are maximum permissible concentrations above
naturally occurring or "background" concentrations except where
otherwise noted.

[11]If Alpha or Beta are measured in excess of 15 of 50 pCi/ℓ respectively,
it will be necessary to determine by specific analysis the particular
radionuclide or radionuclides responsible for the elevated level.
Particular radionuclides should not exceed the limit given in the table.
If an elevated level of Alpha or Beta emissions is caused by radio-
nuclides, the Division should be consulted.

[12]Maximum permissible concentrations including naturally occurring
or background contribution.

[13]See Uranium in Table 41 for aquatic life limitations.

Table 34. Proposed Colorado water quality standards (metallic): Protection of Aquatic Biota.

Parameter	Water Hardness[1] – Cold and Warm Water Biota				
	0-100	100-200	200-300	300-400	over 400
Toxic Metals[2] (mg/ℓ)					
Aluminum (soluble)	0.1	0.1	0.1	0.1	0.1
Arsenic	0.05	0.05	0.05	0.05	0.05
Barium	X	X	X	X	X
Beryllium	0.01	0.3	0.6	0.9	1.1
Cadmium	0.004	0.001	0.005	0.01	0.015
Chromium	0.1	0.1	0.1	0.1	0.1
Copper	0.01	0.01	0.01	0.02	0.04
Iron	1.0	1.0	1.0	1.0	1.0
Lead[3]	0.004	0.025	0.050	0.100	0.150
Manganese	1.0	1.0	1.0	1.0	1.0
Mercury	0.00005	0.00005	0.00005	0.00005	0.00005
Molybdenum	X	X	X	X	X
Nickel	0.05	0.10	0.20	0.30	0.40
Selenium	0.05	0.05	0.05	0.05	0.05
Silver	0.00010	0.00010	0.00015	0.00020	0.00025
Thallium	0.15	0.15	0.15	0.15	0.15
Uranium	0.03	0.2	0.4	0.8	1.4
Zinc	0.05	0.05	0.10	0.30	0.60

X = numerical limit generally not needed for protection of classified use.

[1] Concentrations of total alkalinity or other chelating agents attributable to municipal, industrial or other discharges or agriculatural practices should not alter the total alkalinity or other chelating agents of the receiving water by more than 20 percent. Where the complexing capacity of the receiving water is altered by more than 20 percent or where chelating agents are released to the receiving water which are not naturally characteristic of that water, specific effluent limitations on pertinent parameters will be established. In no case shall instream modification or alteration of total alkalinity or other chelating agents be permitted without Commission authorization.

[2] Bioassay procedures may be used to establish criteria or standards for a particular situation. Requirements for bioassay procedures outlined in Section 3.1.10, Colorado Water Quality Standards, May 2. 1978.

[3] For bioassay lead concentration is based on soluble lead measurements (*i.e.* non-filterable lead using a 0.45 micron filter).

Table 35. Proposed Colorado water quality standards; Agricultural use.

Parameter	Standard
Physical	
D.O. (mg/ℓ)[1]	Aerobic[2]
pH	X
Suspended solids and turbidity	[3]
Temperature	X
TDS (mg/ℓ)	Y
Biological	
Algae[4]	Free of toxic and objectionable algae
Fecal coliforms (#/100 mℓ)	1,000
Inorganics	
Ammonia (mg/ℓ as N)	X
Total residual chlorine (mg/ℓ)	X
Cyanide (mg/ℓ)	0.2
Fluoride (mg/ℓ)	X
Nitrate (mg/ℓ as N)	100[5]
Nitrite (mg/ℓ as N)	10[5]
Sulfide as H S (mg/ℓ)	X
Boron (mg/ℓ)[2]	0.75
Chloride (mg/ℓ)	X
Magnesium (mg/ℓ)	X
Sodium adsorbtion ratio	X
Sulfate (mg/ℓ)	X
Phosphorus (mg/ℓ as P)	X
Toxic Metals (mg/ℓ)	
Aluminum	X
Arsenic	0.1
Barium	X
Beryllium	0.1
Cadmium	0.01
Chromium	0.0
Copper	0.2
Iron	X
Lead	0.1
Manganese	0.2
Mercury	X
Molybdenum	Y
Nickel	0.2

X = numerical limit generally not needed for protection of classified use.

Y = limit may be required but there is insufficient data for setting a general standard.

Table 35. Continued.

Parameter	Standard
Toxic Metals (mg/ℓ)	
Selenium	0.02
Silver	X
Thallium	X
Zinc	2.0
Organics[6], ($\frac{\mu g}{\ell}$)	
Chlorinated Pesticides[7]	
Aldrin[8]	Y
Chlordane[8]	Y
Dieldrin[8]	Y
DDT[8]	Y
Endrin	Y
Heptachlor[8]	Y
Lindane	Y
Methoxychlor	Y
Mirex	Y
Toxaphene	Y
Organophosphate Pesticides[7]	
Demeton	Y
Endosulfan	Y
Guthion	Y
Malathion	Y
Parathion	Y
Chlorophenoxy Herbicides	
2, 4-D	Y
2, 4, 5-TP	Y
PCB's[9]	Y
Phenol	Y
Radiological[10] (pCi/ℓ)	
Alpha[11, 12]	15
Beta[11, 12]	50
Cesium	80
Plutonium	15
Radium 226, and 228[12]	5
Strontium 90[12]	8
Thorium 230 and 232	60
Tritium	20,000
Uranium (total, mg/ℓ)	5

[1]Where dissolved oxygen levels, less than the standard, occur naturally, a discharge shall not cause a further reduction in dissolved oxygen in receiving water.

[2]An effluent shall be regulated to maintain aerobic conditions, and a guideline of 2.0 mg/ℓ dissolved oxygen in an effluent should be maintained, unless demonstrated otherwise.

[3]Suspended solid levels will be controlled by Effluent Limitations and Basic Standards.

[4]Free from objectionable and toxic algae. It has been well established that heavy growth of some strains of blut-green algae, upon death and degradation, may release one or more substances which are toxic to humans and many other animals. Although no fixed numbers can be recommended at this time, it is clear that streams, lakes and reservoirs should not be permitted to bear heavy growth of algal blooms, or allow these blooms to disintegrate. Every effort should be made to control algal growths to levels that are not hazardous.

[5]In order to provide a reasonable margin of safety to allow for unusual situations such as extremely high water ingestion or nitrite formation in slurries, the NO_3-N plus NO_2-N content in drinking waters for livestock and poultry should be limited to 100 ppm or less, and the NO_2-N content alone be limited to 10 ppm or less.

[6]All organics, not on this partial list, are covered under Basic Standards, Section 3.1., 1978 Colorado Water Quality Standards.

[7]Numerical limits in tables based on experimental evidence of toxicity. No point source discharges of organic pesticides shall be permitted to state waters.

[8]The persistence, bioaccumulation potential, and carcinogenicity of these organic compounds cautions human exposeure to a minimum (EPA).

[9]Every reasonable effort should be made to minimize human exposure (EPA).

[10]Concentrations given are maximum permissible concentrations above naturally occurring or "background" concentrations except where otherwise noted.

[11]If Alpha or Beta are measured in excess of 15 or 50 pCi/ℓ respectively, it will be necessary to determine by specific analysis the particular radionuclide or radionuclides responsible for the elevated level. Particular radionuclides should not exceed the limit given in the table. If an elevated level of Alpha or Beta emissions is caused by radionuclides, the Division should be consulted.

[12]Maximum permissible concentrations including naturally occurring or background contributions.

Table 36. Proposed Colorado water quality standards: Recreational use.

Parameter	Standard	
	Class I (Primary Contact)	Class II (Secondary Contact)
Physical		
D.O.[1] ($\frac{mg}{\ell}$ D.O.)	Aerobic[2]	Aerobic[2]
pH	6.5-9.0	X
Suspended solids and turbidity	X	X
Temperature	X	X
TDS (mg/ℓ)	X	X
Biological		
Algae[4]	Free of objectionable and toxic algae	Free of objectionable and toxic algae
Fecal coliforms (#/100 mℓ)	200	1,000
Inorganics		
Ammonia ($\frac{mg}{\ell}$ as N)	X	X
Chloride (mg/ℓ)	X	X
Cyanide (mg/ℓ)	X	X
Fluoride (mg/ℓ)	X	X
NO_3 (mg/ℓ as N)	X	X
NO_2 (mg/ℓ as N)	X	X
Sulfide as H_2S (mg/ℓ)	X	X
Boron (mg/ℓ)[2]	X	X
Chloride (mg/ℓ)	X	X
Magnesium (mg/ℓ)	X	X
SAR	X	X
Sulfate (mg/ℓ)	X	X
Phosphorus (mg/ℓ as P)	Bioassay[5]	Bioassay[5]
Toxic Metals (mg/ℓ)		
Aluminum	X	X
Arsenic	X	X
Barium	X	X
Beryllium	X	X
Cadmium	X	X
Chromium	X	X
Copper	X	X
Iron	X	X
Lead	X	X
Manganese	X	X
Mercury	X	X
Molybdenum	X	X
Nickel	X	X
Selenium	X	X

Table 36. Continued.

Parameter	Standard	
	Class I (Primary Contact)	Class II (Secondary Contact)
Toxic Metals (mg/ℓ)		
Silver	X	X
Thallium	X	X
Uranium	X	X
Zinc	X	X
Organics[6]		
Chlorinated Pesticides[7]		
Aldrin[8]	Y	Y
Chlordane[8]	Y	Y
Dieldrin[8]	Y	Y
DDT[8]	Y	Y
Endrin	Y	Y
Heptachlor[8]	Y	Y
Lindane	Y	Y
Methoxychlor	Y	Y
Mirex	Y	Y
Toxaphene	Y	Y
Organophosphate Pesticides[7]		
Demeton	Y	Y
Endosulfan	Y	Y
Guthion	Y	Y
Malathion	Y	Y
Parathion	Y	Y
Chlorophenoxy Herbicides		
2, 4-D	Y	Y
2, 4, 5-TP	Y	Y
PCB's[9]	Y	Y
Phenol	Y	Y
Radiological		
Alpha	X	X
Beta	X	X
Cesium 134	X	X
Plutonium 238, 239, and 240	X	X
Radium 226 and 228	X	X
Strantium	X	X
Thorium 230 and 232	X	X
Tritium	X	X
Uranium (total)	X	X

X = numerical limit generally not needed for protection of classified
use.

Y = limit may be required but there is insufficient data for setting
a general standard.

[1]Where dissolved oxygen levels, less than the standard, occur naturally,
a discharge shall not cause a further reduction in dissolved oxygen
in receiving water.

[2]An effluent shall be regulated to maintain aerobic conditions, and a
guideline of 2.0 mg/ℓ dissolved oxygen in an effluent should be
maintained, unless demonstrated otherwise.

[3]Suspsended solid levels will be controlled by Effluent Limitations
and Basic Standards.

[4]Free from objectionable and toxic algae. It has been well established
that heavy growth of some strains of blue-green algae, upon death and
degradation, may release one or more substances which are toxic to
humans and many other animals. Although no fixed numbers can be
recommended at this time, it is clear that streams, lakes and
reservoirs should not be permitted to bear heavy growth of algal blooms,
nor allow these blooms to disintegrate. Every effort should be made
to control algal growths to levels that are not hazardous.

[5]Phosphorus standards are to be determined by an algal bioassay using
the method described in the latest edition of *Standard Methods for
the Examination of Water and Wastewater*, American Public Health
Association.

[6]All organics, not on this partial list, are covered under Basic
Standards, Section 3.1., 1978 Colorado Water Quality Standards.

[7]Numerical limits in tables based on experimental evidence of toxicity.
No point source discharge of organic pesticides shall be permitted to
state waters.

[8]The persistence, bioaccumulation potential, and carcinogenicity of
these organic compounds cautions human exposure to a minimum (EPA).

[9]Every reasonable effort should be made to minimize human exposure
(EPA).

APPENDIX E

COMPARISON OF WATER QUALITY DATA WITH PROPOSED COLORADO WATER QUALITY STANDARDS

Table 37. Comparison of water quality data with proposed Colorado water quality standards, Animas River at Durango, May 1977 - August 1978.

CODE	CONSTITUENT	STANDARD	SOURCE	NUMBER EXCEEDING	NUMBER OF SAMPLES	PERCENT EXCEEDING
101	ALUMINIUM, DISSOLVED (UG/L)	100.000	AB	11	14	78.57
104	BARIUM, TOTAL (UG/L)	1000.000	WS	0	5	0.00
106	CADMIUM, TOTAL (UG/L)	10.000	AG	4	9	44.44
		10.000	AS	4	9	44.44
		0.400	ABL1	1	9	11.11
		1.000	AB12	3	9	33.33
		5.000	AB23	2	9	22.22
		10.000	AB34	0	9	0.00
		15.000	ABG4	0	9	0.00
109	CHROMIUM, TOTAL (UG/L)	100.000	AG	0	9	0.00
		50.000	WS	0	9	0.00
		100.000	AB	0	9	0.00
111	COPPER, TOTAL (UG/L)	200.000	AG	0	11	0.00
		1000.000	WS	0	11	0.00
		10.000	ABL1	2	11	18.18
		10.000	AB12	4	11	36.36
		10.000	AB23	4	11	36.36
		20.000	AB34	0	11	0.00
		40.000	ABG4	0	11	0.00
113	IRON, DISSOLVED (UG/L)	300.000	WS	0	12	0.00
114	IRON, TOTAL (UG/L)	1000.000	AB	4	16	25.00
116	LEAD, TOTAL (UG/L)	100.000	AG	1	4	25.00
		50.000	WS	1	4	25.00
		4.000	ABL1	2	4	50.00
		25.000	AB12	0	4	0.00
		50.000	AB23	0	4	0.00
		100.000	AB34	0	4	0.00
		150.000	ABG4	0	4	0.00
117	MAGNESIUM (MG/L)	125.000	WS	0	13	0.00
118	MANGANESE, DISSOLVED (UG/L)	50.000	WS	15	15	100.00
119	MANGANESE, TOTAL (UG/L)	200.000	AG	7	16	43.75
		1000.000	AB	0	16	0.00
121	MERCURY, TOTAL (UG/L)	2.000	WS	2	11	18.18
		0.050	AB	11	11	100.00
125	NICKEL, TOTAL (UG/L)	200.000	AG	0	9	0.00
		50.000	ABL1	0	9	0.00
		100.000	AB12	0	9	0.00
		200.000	AB23	0	9	0.00
		300.000	AB34	0	9	0.00
		400.000	ABG4	0	9	0.00
128	SELENIUM, TOTAL (UG/L)	20.000	AG	0	2	0.00
		10.000	WS	0	2	0.00
		50.000	AB	0	2	0.00
130	SILVER, TOTAL (UG/L)	50.000	WS	0	1	0.00
		0.100	ABL1	0	1	0.00
		0.100	AB12	0	1	0.00
		0.150	AB23	1	1	100.00
		0.200	AB34	0	1	0.00
		0.250	ABG4	0	1	0.00
133	ZINC, TOTAL (UG/L)	2000.000	AG	0	16	0.00
		5000.000	WS	0	16	0.00
		50.000	ABL1	2	16	12.50
		50.000	AB12	4	16	25.00
		100.000	AB23	7	16	43.75
		300.000	AB34	0	16	0.00
		600.000	ABG4	0	16	0.00
202	ARSENIC, DISSOLVED (UG/L)	100.000	AG	0	0	0.00
		50.000	WS	0	0	0.00
		50.000	AB	0	0	0.00
205	BORON (MG/L)	750.000	AG	0	10	0.00
207	CHLORIDE (MG/L)	250.000	WS	0	13	0.00
208	CYANIDE (MG/L)	0.200	AG	0	9	0.00
		0.200	WS	0	9	0.00
		0.005	AB	9	9	100.00
209	FLUORIDE (MG/L)	2.400	WS	0	13	0.00
210	NITROGEN, NITRATE (MG/L)	100.000	AG	0	15	0.00
		10.000	WS	0	15	0.00
211	NITROGEN, NITRITE (MG/L)	10.000	AG	0	15	0.00
		1.000	WS	0	15	0.00
		0.050	AFC	0	15	0.00
		0.500	AFW	0	15	0.00
215	SULFATE (MG/L)	250.000	WS	0	13	0.00

SOURCE CODES:
AB = AQUATIC BIOTA
ABC = AQUATIC BIOTA (COLD)
ABW = AQUATIC BIOTA (WARM)
ABL1 = AQUATIC BIOTA (TOTAL HARDNESS LESS THAN 100)
AB12 = AQUATIC BIOTA (TOTAL HARDNESS 100-200)
AB23 = AQUATIC BIOTA (TOTAL HARDNESS 200-300)
AB34 = AQUATIC BIOTA (TOTAL HARDNESS 300-400)
ABG4 = AQUATIC BIOTA (TOTAL HARDNESS GREATER THAN 400)
AG = AGRICULTURE
AS = CLASS 2 MAX WATER SUPPLY

83

Table 38. Comparison of water quality data with proposed Colorado water quality standards, La Plata River at Hesperus, May 1977 – August 1978.

CODE	CONSTITUENT	STANDARD	SOURCE	NUMBER EXCEEDING	NUMBER OF SAMPLES	PERCENT EXCEEDING
101	ALUMINIUM, DISSOLVED (UG/L)	100.000	AB	8	9	88.89
104	BARIUM, TOTAL (UG/L)	1000.000	WS	1	5	20.00
106	CADMIUM, TOTAL (UG/L)	10.000	AG	2	8	25.00
		10.000	WS	2	8	25.00
		0.400	ABL1	6	8	75.00
		1.000	ABL2	2	8	25.00
		5.000	AB23	0	8	0.00
		10.000	AB34	0	8	0.00
		15.000	ABG4	0	8	0.00
109	CHROMIUM, TOTAL (UG/L)	100.000	AG	0	9	0.00
		50.000	WS	0	9	0.00
		100.000	AB	0	9	0.00
111	COPPER, TOTAL (UG/L)	200.000	AG	0	6	0.00
		1000.000	WS	0	6	0.00
		10.000	ABL1	4	6	66.67
		10.000	ABL2	2	6	33.33
		10.000	AB23	0	6	0.00
		20.000	AB34	0	6	0.00
		40.000	ABG4	0	6	0.00
113	IRON, DISSOLVED (UG/L)	300.000	WS	0	5	0.00
114	IRON, TOTAL (UG/L)	1000.000	AB	1	13	7.69
116	LEAD, TOTAL (UG/L)	100.000	AG	0	3	0.00
		50.000	WS	0	3	0.00
		4.000	ABL1	2	3	66.67
		25.000	ABL2	0	3	0.00
		50.000	AB23	0	3	0.00
		100.000	AB34	0	3	0.00
		150.000	ABG4	0	3	0.00
117	MAGNESIUM (MG/L)	125.000	WS	0	15	0.00
118	MANGANESE, DISSOLVED (UG/L)	50.000	WS	0	12	0.00
119	MANGANESE, TOTAL (UG/L)	200.000	AG	1	14	7.14
		1000.000	AB	0	14	0.00
121	MERCURY, TOTAL (UG/L)	2.000	WS	3	11	27.27
		0.050	AB	11	11	100.00
125	NICKEL, TOTAL (UG/L)	200.000	AG	0	8	0.00
		50.000	ABL1	0	8	0.00
		100.000	ABL2	0	8	0.00
		200.000	AB23	0	8	0.00
		300.000	AB34	0	8	0.00
		400.000	ABG4	0	8	0.00
128	SELENIUM, TOTAL (UG/L)	20.000	AG	0	4	0.00
		10.000	WS	1	4	25.00
		50.000	AB	0	4	0.00
130	SILVER, TOTAL (UG/L)	50.000	WS	0	2	0.00
		0.100	ABL1	1	2	50.00
		0.100	ABL2	1	2	50.00
		0.150	AB23	0	2	0.00
		0.200	AB34	0	2	0.00
		0.250	ABG4	0	2	0.00
133	ZINC, TOTAL (UG/L)	2000.000	AG	0	9	0.00
		5000.000	WS	0	9	0.00
		50.000	ABL1	7	9	77.78
		50.000	ABL2	2	9	22.22
		100.000	AB23	0	9	0.00
		300.000	AB34	0	9	0.00
		600.000	ABG4	0	9	0.00
202	ARSENIC, DISSOLVED (UG/L)	100.000	AG	0	6	0.00
		50.000	WS	0	6	0.00
		50.000	AB	0	6	0.00
205	BORON (MG/L)	750.000	AG	0	9	0.00
207	CHLORIDE (MG/L)	250.000	WS	0	7	0.00
208	CYANIDE (MG/L)	0.200	AG	0	8	0.00
		0.200	WS	0	8	0.00
		0.005	AB	8	8	100.00
209	FLUORIDE (MG/L)	2.000	WS	0	14	0.00
210	NITROGEN, NITRATE (MG/L)	100.000	AG	0	16	0.00
		10.000	WS	0	16	0.00
211	NITROGEN, NITRITE (MG/L)	10.000	AG	0	16	0.00
		1.000	WS	0	16	0.00
		0.050	ABC	0	16	0.00
		0.500	AB4	0	16	0.00
215	SULFATE (MG/L)	250.000	WS	0	16	0.00

SOURCE CODES:
AB = AQUATIC BIOTA
ABC = AQUATIC BIOTA (COLD)
ABW = AQUATIC BIOTA (WARM)
ABL1 = AQUATIC BIOTA (TOTAL HARDNESS LESS THAN 100)
ABL2 = AQUATIC BIOTA (TOTAL HARDNESS 100-200)
AB23 = AQUATIC BIOTA (TOTAL HARDNESS 200-300)
AB34 = AQUATIC BIOTA (TOTAL HARDNESS 300-400)
ABG4 = AQUATIC BIOTA (TOTAL HARDNESS GREATER THAN 400)
AG = AGRICULTURE
WS = WATER SUPPLY

Table 39. Comparison of water quality data with proposed Colorado water quality
standards, La Plata River at Colorado/New Mexico border, May 1977 –
August 1978.

CODE	CONSTITUENT	STANDARD	SOURCE	NUMBER EXCEEDING	NUMBER OF SAMPLES	PERCENT EXCEEDING
101	ALUMINIUM, DISSOLVED (UG/L)	100.000	AB	15	16	93.75
104	BARIUM, TOTAL (UG/L)	1000.000	AS	0	8	0.00
106	CADMIUM, TOTAL (UG/L)	10.000	AG	6	10	60.00
		10.000	AS	6	10	60.00
		0.200	ABL1	0	10	0.00
		1.000	ABL2	1	10	10.00
		5.000	AB23	1	10	10.00
		10.000	AB34	1	10	10.00
		15.000	ABG4	3	10	30.00
109	CHROMIUM, TOTAL (UG/L)	100.000	AG	0	0	0.00
		50.000	AS	0	0	0.00
		100.000	AB	0	0	0.00
111	COPPER, TOTAL (UG/L)	200.000	AG	0	11	0.00
		1000.000	AS	0	11	0.00
		10.000	ABL1	0	11	0.00
		10.000	ABL2	2	11	18.18
		10.000	AB23	1	11	9.09
		20.000	AB34	0	11	0.00
		40.000	ABG4	2	11	18.18
113	IRON, DISSOLVED (UG/L)	300.000	AS	0	11	0.00
114	IRON, TOTAL (UG/L)	1000.000	AB	5	16	31.25
116	LEAD, TOTAL (UG/L)	100.000	AG	0	4	0.00
		50.000	AS	0	4	0.00
		8.000	ABL1	0	4	0.00
		25.000	ABL2	0	4	0.00
		50.000	AB23	0	4	0.00
		100.000	AB34	0	4	0.00
		150.000	ABG4	0	4	0.00
117	MAGNESIUM (MG/L)	125.000	AS	0	15	0.00
118	MANGANESE, DISSOLVED (UG/L)	50.000	AS	0	11	0.00
119	MANGANESE, TOTAL (UG/L)	200.000	AG	1	15	6.67
		1000.000	AS	0	15	0.00
121	MERCURY, TOTAL (UG/L)	2.000	AS	3	13	23.08
		0.050	AB	13	13	100.00
125	NICKEL, TOTAL (UG/L)	200.000	AG	0	10	0.00
		50.000	ABL1	0	10	0.00
		100.000	ABL2	0	10	0.00
		200.000	AA23	0	10	0.00
		300.000	AB34	0	10	0.00
		400.000	ABG4	0	10	0.00
128	SELENIUM, TOTAL (UG/L)	20.000	AG	0	4	0.00
		10.000	AS	0	4	0.00
		50.000	AB	0	4	0.00
130	SILVER, TOTAL (UG/L)	50.000	AS	0	3	0.00
		0.100	ABL1	0	3	0.00
		0.100	ABL2	0	3	0.00
		0.150	AB23	1	3	33.33
		0.200	AB34	0	3	0.00
		0.250	ABG4	2	3	66.67
133	ZINC, TOTAL (UG/L)	2000.000	AG	0	15	0.00
		5000.000	AS	0	15	0.00
		50.000	ABL1	0	15	0.00
		50.000	ABL2	1	15	6.67
		100.000	AB23	1	15	6.67
		300.000	AB34	0	15	0.00
		600.000	ABG4	0	15	0.00
202	ARSENIC, DISSOLVED (UG/L)	100.000	AG	0	0	0.00
		50.000	AS	0	0	0.00
		50.000	AB	0	0	0.00
205	BORON (MG/L)	750.000	AG	0	8	0.00
207	CHLORIDE (MG/L)	250.000	AS	0	16	0.00
208	CYANIDE (MG/L)	0.200	AG	0	11	0.00
		0.200	AS	0	11	0.00
		0.005	AB	11	11	100.00
209	FLUORIDE (MG/L)	2.000	AS	0	15	0.00
210	NITROGEN, NITRATE (MG/L)	100.000	AG	0	16	0.00
		10.000	AS	0	16	0.00
211	NITROGEN, NITRITE (MG/L)	10.000	AG	0	16	0.00
		1.000	AS	0	16	0.00
		0.050	AAC	0	16	0.00
		0.500	AB	0	16	0.00
215	SULFATE (MG/L)	250.000	AS	13	16	81.25

SOURCE CODES:
AB = AQUATIC BIOTA
ABC = AQUATIC BIOTA (COLD)
ABW = AQUATIC BIOTA (WARM)
ABL1 = AQUATIC BIOTA (TOTAL HARDNESS, LESS THAN 100)
ABL2 = AQUATIC BIOTA (TOTAL HARDNESS, 100-200)
AB23 = AQUATIC BIOTA (TOTAL HARDNESS, 200-300)
AB34 = AQUATIC BIOTA (TOTAL HARDNESS, 300-400)
ABG4 = AQUATIC BIOTA (TOTAL HARDNESS, GREATER THAN 400)
AG = AGRICULTURE
AS = CLASS 2 RAW WATER SUPPLY

85

Table 40. Comparison of water quality data with proposed Colorado water quality standards, La Plata River at Farmington, May 1977 – August 1978.

CODE	CONSTITUENT	STANDARD	SOURCE	NUMBER EXCEEDING	NUMBER OF SAMPLES	PERCENT EXCEEDING
101	ALUMINUM, DISSOLVED (UG/L)	100,000	AB	14	14	100,00
104	BARIUM, TOTAL (UG/L)	1000,000	WS	2	10	20,00
106	CADMIUM, TOTAL (UG/L)	10,000	AG	6	10	60,00
		10,000	WS	6	10	60,00
		0,400	ABL1	0	10	0,00
		1,000	AB12	0	10	0,00
		5,000	AB23	1	10	10,00
		10,000	AB34	2	10	20,00
		15,000	ABG4	1	10	10,00
109	CHROMIUM, TOTAL (UG/L)	100,000	AG	1	5	20,00
		50,000	WS	1	5	20,00
		100,000	AB	1	5	20,00
111	COPPER, TOTAL (UG/L)	200,000	AG	2	11	18,18
		1000,000	WS	0	11	0,00
		10,000	ABL1	1	11	9,09
		10,000	AB12	0	11	0,00
		10,000	AB23	2	11	18,18
		20,000	AB34	2	11	18,18
		40,000	ABG4	3	11	27,27
113	IRON, DISSOLVED (UG/L)	300,000	WS	1	13	7,69
114	IRON, TOTAL (UG/L)	1000,000	AB	9	14	64,29
116	LEAD, TOTAL (UG/L)	100,000	AG	0	3	0,00
		50,000	WS	0	3	0,00
		4,000	ABL1	0	3	0,00
		25,000	AB12	0	3	0,00
		50,000	AB23	0	3	0,00
		100,000	AB34	0	3	0,00
		150,000	ABG4	0	3	0,00
117	MAGNESIUM (MG/L)	125,000	WS	0	14	0,00
118	MANGANESE, DISSOLVED (UG/L)	50,000	WS	8	13	61,54
119	MANGANESE, TOTAL (UG/L)	200,000	AG	13	14	92,86
		1000,000	AB	2	14	14,29
121	MERCURY, TOTAL (UG/L)	2,000	WS	2	13	15,38
		0,050	AB	13	13	100,00
125	NICKEL, TOTAL (UG/L)	200,000	AG	1	10	10,00
		50,000	ANL1	0	10	0,00
		100,000	AB12	0	10	0,00
		200,000	AB23	1	10	10,00
		300,000	AB34	0	10	0,00
		400,000	ABG4	0	10	0,00
128	SELENIUM, TOTAL (UG/L)	20,000	AG	0	5	0,00
		10,000	WS	0	5	0,00
		50,000	AB	0	5	0,00
130	SILVER, TOTAL (UG/L)	50,000	WS	0	4	0,00
		0,100	ABL1	0	4	0,00
		0,100	AB12	0	4	0,00
		0,150	AB23	1	4	25,00
		0,200	AB34	0	4	0,00
		0,250	ABG4	3	4	75,00
133	ZINC, TOTAL (UG/L)	2000,000	AG	0	14	0,00
		5000,000	WS	0	14	0,00
		50,000	ABL1	1	14	7,14
		50,000	AB12	0	14	0,00
		100,000	AB23	2	14	14,29
		300,000	AB34	1	14	7,14
		600,000	ABG4	0	14	0,00
202	ARSENIC, DISSOLVED (UG/L)	100,000	AG	0	1	0,00
		50,000	WS	0	1	0,00
		50,000	AB	0	1	0,00
205	BORON (MG/L)	750,000	AG	0	7	0,00
207	CHLORIDE (MG/L)	250,000	WS	1	14	7,14
208	CYANIDE (MG/L)	0,200	AG	0	8	0,00
		0,200	WS	0	8	0,00
		0,005	AB	8	8	100,00
209	FLUORIDE (MG/L)	2,400	WS	0	13	0,00
210	NITROGEN, NITRATE (MG/L)	100,000	AG	0	1	0,00
		10,000	WS	0	1	0,00
211	NITROGEN, NITRITE (MG/L)	10,000	AG	0	14	0,00
		1,000	WS	0	14	0,00
		0,050	ABC	0	14	0,00
		0,500	ABW	0	14	0,00
215	SULFATE (MG/L)	250,000	WS	12	14	85,71

SOURCE CODES: AB = AQUATIC BIOTA
ABC = AQUATIC BIOTA (COLD)
ABW = AQUATIC BIOTA (WARM)
ABL1 = AQUATIC BIOTA (TOTAL HARDNESS LESS THAN 100)
AB12 = AQUATIC BIOTA (TOTAL HARDNESS 100-200)
AB23 = AQUATIC BIOTA (TOTAL HARDNESS 200-300)
AB34 = AQUATIC BIOTA (TOTAL HARDNESS 300-400)
ABG4 = AQUATIC BIOTA (TOTAL HARDNESS GREATER THAN 400)
AG = AGRICULTURE
WS = CLASS 2 RAW WATER SUPPLY

APPENDIX F

USBR TEMPERATURE SIMULATION FOR THE PROPOSED
RIDGES BASIN RESERVOIR

(Note: Source is USBR Durango Field Office, 1977 data used in simulation.)

Table 41. Day 130.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	85.10 M	SURFACE AIR TEMP	13.90 C
DEPTH OF SURFACE ELEMENT	5.65 M	TOTAL SYSTEM OUTFLOW	7.11 CMS
THERMOCLINE DISTANCE FROM BOTTOM	73.2 M	TOTAL SYSTEM INFLOW	11.93 CMS
SURFACE WATER TEMP	7.42 C	EQUILIBRIUM TEMP	8.11 C
CUML EVAPORATION	.018 M	EVAPORATION RATE	2.09E-01 CMS
COMPUTED DOWNSTREAM TEMP	5.94 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONENTS

QNS	8.238E-02	KC/M2/S
QNA	3.773E-02	KC/M2/S
QW	6.240E-02	KC/M2/S
QE	1.510E-02	KC/M2/S
QC	-1.444E-02	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	11.93	10.00	82.30	14

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	0.00	4.45	4.57	2	0.0	0.0
2	7.11	5.94	70.10	12	97.5	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

SUMMARY OF OUTPUT FOR 10 MAY 1977 (130)   EXECUTION INTERVAL ENDING 2400 HRS

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	4.4454	40.0018	0.0000	0.0000	999.99828	0.	0.
6.1	4.4454	40.0018	0.0000	0.0000	999.99828	4.7146E-14	8.0000E-02
12.2	4.4454	40.0018	0.0000	0.0000	999.99828	2.8287E-13	8.0000E-02
18.3	4.4454	40.0018	0.0000	0.0000	999.99828	1.4723E-12	8.0000E-02
24.4	4.4455	40.0018	0.0000	0.0000	999.99828	5.4409E-12	8.0000E-02
30.5	4.4455	40.0019	0.0000	0.0000	999.99827	2.9491E-11	8.0000E-02
36.6	4.4458	40.0025	0.0000	0.0000	999.99827	1.7346E-10	8.0000E-02
42.7	4.4474	40.0054	0.0000	0.0000	999.99826	9.9048E-10	8.0000E-02
48.8	4.4551	40.0191	0.0000	0.0000	999.99820	5.2769E-09	8.0000E-02
54.9	4.4872	40.0769	0.0000	0.0000	999.99795	2.5542E-08	8.0000E-02
61.0	4.6074	40.2932	0.0000	0.0000	999.99687	1.1833E-07	8.0000E-02
67.1	4.9978	40.9960	.5722	0.0000	999.99180	5.7855E-07	8.0000E-02
73.2	6.0660	42.9189	1.0756	5.8089	999.96593	3.1693E-06	8.0000E-02
79.2	7.4168	45.3503	1.4997	6.1239	999.90878	8.4074E-06	1.2391E-01

Table 42.   Day 140.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	84.48 M	SURFACE AIR TEMP	9.40 C
DEPTH OF SURFACE ELEMENT	5.23 M	TOTAL SYSTEM OUTFLOW	8.64 CMS
THERMOCLINE DISTANCE FROM BOTTOM	73.2 M	TOTAL SYSTEM INFLOW	0.00 CMS
SURFACE WATER TEMP	7.81 C	EQUILIBRIUM TEMP	5.72 C
CUML EVAPORATION	.045 M	EVAPORATION RATE	2.93E-01 CMS
COMPUTED DOWNSTREAM TEMP	6.44 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	8.558E-02	KC/M2/S
QNA	3.123E-02	KC/M2/S
QW	8.277E-02	KC/M2/S
QE	2.139E-02	KC/M2/S
QC	-4.057E-03	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP -DEG C	DIST. FROM BOTTOM (M)	ELEM
1	0.00	9.44	0.00	0

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	1.53	4.46	4.57	2	48.8	0.0
2	7.11	6.86	70.10	12	91.4	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	4.4450	40.0021	0.0000	0.0000	999.99827	0.	0.
5.1	4.4458	40.0025	.1191	0.0000	999.99827	1.3066E-10	8.0000E-02
12.2	4.4464	40.0035	.2438	0.0000	999.99827	4.3311E-10	8.0000E-02
18.3	4.4477	40.0058	.2546	0.0000	999.99826	1.1173E-09	8.0000E-02
24.4	4.4500	40.0100	.2637	0.0000	999.99824	2.0713E-09	8.0000E-02
30.5	4.4556	40.0218	.2654	0.0000	999.99819	6.0795E-09	8.0000E-02
36.6	4.4753	40.0555	.2416	0.0000	999.99805	1.8469E-08	8.0000E-02
42.7	4.5243	40.1437	.1467	0.0000	999.99764	5.3897E-08	8.0000E-02
48.8	4.6406	40.3531	0.0000	0.0000	999.99653	1.5360E-07	8.0000E-02
54.9	4.8325	40.7885	0.0000	0.0000	999.99355	4.2910E-07	8.0000E-02
61.0	5.3272	41.5890	0.0000	0.0000	999.98568	1.1765E-06	8.0000E-02
67.1	6.0462	42.8832	.6223	0.0000	999.96657	2.9075E-06	8.0000E-02
73.2	6.9799	44.5638	1.1438	0.0000	999.93019	5.6694E-06	9.4041E-02
79.2	7.8136	46.0645	1.5504	0.0000	999.88695	7.7059E-06	1.1658E-01

89

Table 43.   Day 150.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	83.67 M	SURFACE AIR TEMP	14.40 C
DEPTH OF SURFACE ELEMENT	10.52 M	TOTAL SYSTEM OUTFLOW	7.11 CMS
THERMOCLINE DISTANCE FROM BOTTOM	67.1 M	TOTAL SYSTEM INFLOW	5.29 CMS
SURFACE WATER TEMP	8.32 C	EQUILIBRIUM TEMP	9.08 C
CUML EVAPORATION	.060 M	EVAPORATION RATE	1.72E-01 CMS
COMPUTED DOWNSTREAM TEMP	8.02 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	8.674E-02	KC/M2/S
QNA	3.764E-02	KC/M2/S
QW	8.318E-02	KC/M2/S
QE	1.265E-02	KC/M2/S
QC	-1.216E-02	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	5.29	11.67	76.20	13

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	0.00	4.45	4.57	2	0.0	0.0
2	7.11	8.02	70.10	12	91.4	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	4.4528	40.0150	0.0000	0.0000	999.99822	0.	0.
6.1	4.4558	40.0205	0.0000	0.0000	999.99820	3.2987E-09	8.0000E-02
12.2	4.4636	40.0344	0.0000	0.0000	999.99814	8.1659E-09	8.0000E-02
18.3	4.4777	40.0599	0.0000	0.0000	999.99803	1.5016E-08	8.0000E-02
24.4	4.4947	40.0905	0.0000	0.0000	999.99789	1.9433E-08	8.0000E-02
30.5	4.5307	40.1552	0.0000	0.0000	999.99759	4.3866E-08	8.0000E-02
36.6	4.6065	40.2917	0.0000	0.0000	999.99688	1.0316E-07	8.0000E-02
42.7	4.7540	40.5572	0.0000	0.0000	999.99525	2.3962E-07	8.0000E-02
48.8	5.0233	41.0401	0.0000	0.0000	999.99140	5.6554E-07	8.0000E-02
54.9	5.4778	41.8600	0.0000	0.0000	999.98233	1.3478E-06	8.0000E-02
61.0	6.2200	43.1960	0.0000	0.0000	999.96078	3.2800E-06	8.0000E-02
67.1	7.1560	44.8808	.6223	1.7568	999.92190	5.9428E-06	9.7193E-02
73.2	8.3248	46.9846	1.1438	3.5256	999.85552	1.1003E-05	1.4959E-01
79.2	8.3248	46.9846	1.5504	0.0000	999.85552	0.	0.

90

Table 44. Day 160.

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          SUMMARY OF OUTPUT FOR  9 JUN 1977  (160)    EXECUTION INTERVAL ENDING 2400 HRS


                        GENERAL SYSTEM INFORMATION

                    ELEVATION BOTTOM OF POOL   2029.97 M


        END OF TIME INTERVAL                    AVERAGE OVER TIME INTERVAL

                    POOL DEPTH    83.46 M           SURFACE AIR TEMP      20.60 C
           DEPTH OF SURFACE ELEMENT   10.30 M    TOTAL SYSTEM OUTFLOW    14.63 CMS
   THERMOCLINE DISTANCE FROM BOTTOM   67.1 M     TOTAL SYSTEM INFLOW     11.93 CMS
              SURFACE WATER TEMP   9.96 C         EQUILIBRIUM TEMP       14.01 C
                 CUML EVAPORATION    .064 M       EVAPORATION RATE    0.      CMS
           COMPUTED DOWNSTREAM TEMP   9.32 C         OBJECTIVE TEMP       4.44 C



                        SURFACE HEAT COMPONETS

                        QNS    8.587E-02 KC/M2/S
                        QNA    3.948E-02 KC/M2/S
                        QW     8.522E-02 KC/M2/S
                        QE     0.        KC/M2/S
                        QC     0.        KC/M2/S



                        INFLOWS AND POSITIONS

              TRIB    FLOW    TEMP   DIST. FROM   ELEM
               NO      CMS    DEG C  BOTTOM (M)
                1     11.93   11.67     76.20      13



                        OUTFLOWS AND LEVELS

        OUTLET   FLOW    TEMP   DIST. FROM  ELEM   WITHDRAWAL LIMITS
          NO      CMS    DEG C  BOTTOM (M)         UPPER    - LOWER
           1     0.00    4.49      4.57      2      0.0       0.0
           2    14.63    9.32     70.10     12     91.4      61.0

        NOTE:
        WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.
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         SUMMARY OF OUTPUT FOR  9 JUN 1977  (160)     EXECUTION INTERVAL ENDING 2400 HRS
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DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	4.4901	40.0421	0.0000	0.0000	999.99793	0.	0.
6.1	4.5017	40.1030	0.0000	0.0000	999.99783	1.3820E-08	8.0000E-02
12.2	4.5301	40.1542	0.0000	0.0000	999.99759	3.5282E-08	8.0000E-02
18.3	4.5755	40.2359	0.0000	0.0000	999.99718	6.0510E-08	8.0000E-02
24.4	4.6197	40.3154	0.0000	0.0000	999.99675	6.3930E-08	8.0000E-02
30.5	4.7039	40.4671	0.0000	0.0000	999.99584	1.3425E-07	8.0000E-02
36.6	4.8679	40.7622	0.0000	0.0000	999.99375	3.0639E-07	8.0000E-02
42.7	5.1697	41.3054	0.0000	0.0000	999.98882	7.1700E-07	8.0000E-02
48.8	5.7192	42.2788	0.0000	0.0000	999.97647	1.7803E-06	8.0000E-02
54.9	6.6330	43.9394	0.0000	0.0000	999.94522	4.6230E-06	8.1525E-02
61.0	7.6514	45.7733	0.0000	0.0000	999.89612	7.7949E-06	1.1752E-01
67.1	8.7209	47.6976	1.2805	4.0413	999.82864	1.0966E-05	1.4828E-01
73.2	9.9638	49.9349	2.3538	7.8915	999.73025	1.5903E-05	1.9358E-01
79.2	9.9638	49.9349	3.1904	0.0000	999.73025	0.	0.

Table 45. Day 170.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	82.95 M	SURFACE AIR TEMP	20.60 C
DEPTH OF SURFACE ELEMENT	9.80 M	TOTAL SYSTEM OUTFLOW	14.63 CMS
THERMOCLINE DISTANCE FROM BOTTOM	67.1 M	TOTAL SYSTEM INFLOW	5.52 CMS
SURFACE WATER TEMP	11.16 C	EQUILIBRIUM TEMP	12.57 C
CUML EVAPORATION	.085 M	EVAPORATION RATE	2.39E-01 CMS
COMPUTED DOWNSTREAM TEMP	10.61 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONENTS

QNS	8.786E-02	KC/M2/S
QNA	4.375E-02	KC/M2/S
QW	8.664E-02	KC/M2/S
QE	1.773E-02	KC/M2/S
QC	-1.789E-02	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	5.52	13.61	76.20	13

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	0.00	4.61	4.57	2	0.0	0.0
2	14.63	10.61	70.10	12	91.4	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	4.5954	40.2735	0.0000	0.0000	999.99698	0.	0.
6.1	4.6245	40.3241	0.0000	0.0000	999.99670	4.1468E-08	8.0000E-02
12.2	4.6910	40.4437	0.0000	0.0000	999.99569	1.0507E-07	8.0000E-02
18.3	4.7920	40.6256	0.0000	0.0000	999.99477	1.7669E-07	8.0000E-02
24.4	4.8861	40.7950	0.0000	0.0000	999.99349	1.8745E-07	8.0000E-02
30.5	5.0621	41.1117	0.0000	0.0000	999.99074	4.0448E-07	8.0000E-02
36.6	5.3982	41.7169	0.0000	0.0000	999.98415	9.6566E-07	8.0000E-02
42.7	6.0019	42.8033	0.0000	0.0000	999.96798	2.3501E-06	8.0000E-02
48.8	6.9229	44.4612	0.0000	0.0000	999.93278	5.4414E-06	9.1377E-02
54.9	7.8987	46.2176	0.0000	0.0000	999.88197	8.0415E-06	1.2011E-01
61.0	8.9070	48.0326	0.0000	0.0000	999.81525	1.0780E-05	1.4746E-01
67.1	9.9315	49.8767	1.2805	1.9341	999.73308	1.3348E-05	1.7125E-01
73.2	11.1575	52.0835	2.3538	3.5820	999.61625	1.7908E-05	2.1036E-01
79.2	11.1575	52.0835	3.1905	0.0000	999.61625	0.	0.

Table 46. Day 180.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	81.56 M	SURFACE AIR TEMP	22.80 C
DEPTH OF SURFACE ELEMENT	8.40 M	TOTAL SYSTEM OUTFLOW	14.63 CMS
THERMOCLINE DISTANCE FROM BOTTOM	48.8 M	TOTAL SYSTEM INFLOW	0.00 CMS
SURFACE WATER TEMP	11.56 C	EQUILIBRIUM TEMP	14.16 C
CUML EVAPORATION	.093 M	EVAPORATION RATE	0. CMS
COMPUTED DOWNSTREAM TEMP	11.34 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	8.519E-02	KC/M2/S
QNA	3.123E-02	KC/M2/S
QW	8.705E-02	KC/M2/S
QE	0.	KC/M2/S
QC	0.	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	0.00	15.56	0.00	0

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	LOWER
1	0.00	4.85	4.57	2	0.0	0.0
2	14.63	11.34	70.10	12	91.4	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	4.8301	40.6942	0.0000	0.0000	999.99427	0.	0.
6.1	4.8896	40.7995	0.0000	0.0000	999.99346	1.1978E-07	8.0000E-02
12.2	5.0247	41.0444	0.0000	0.0000	999.99136	3.0859E-07	8.0000E-02
18.3	5.2256	41.4060	0.0000	0.0000	999.98775	5.3322E-07	8.0000E-02
24.4	5.4047	41.7284	0.0000	0.0000	999.98400	5.5385E-07	8.0000E-02
30.5	5.7292	42.3125	0.0000	0.0000	999.97596	1.1899E-06	8.0000E-02
36.6	6.3260	43.3868	0.0000	0.0000	999.95703	2.8208E-06	8.0000E-02
42.7	7.1737	44.9127	0.0000	0.0000	999.92104	5.7042E-06	9.4444E-02
48.8	8.0733	46.5319	0.0000	0.0000	999.87144	8.0239E-06	1.1993E-01
54.9	8.9698	48.1456	0.0000	0.0000	999.81063	1.0050E-05	1.4040E-01
61.0	9.8405	49.7130	0.0000	0.0000	999.74095	1.1688E-05	1.5586E-01
67.1	10.6745	51.2141	1.2605	0.0000	999.66464	1.2739E-05	1.6574E-01
73.2	11.5594	52.8070	2.3538	0.0000	999.57366	1.4530E-05	1.8173E-01
79.2	11.5594	52.8070	3.1905	0.0000	999.57366	0.	0.

93

Table 47. Day 190.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL 2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	79.71 M	SURFACE AIR TEMP	20.60 C
DEPTH OF SURFACE ELEMENT	5.56 M	TOTAL SYSTEM OUTFLOW	17.61 CMS
THERMOCLINE DISTANCE FROM BOTTOM	67.1 M	TOTAL SYSTEM INFLOW	0.00 CMS
SURFACE WATER TEMP	12.79 C	EQUILIBRIUM TEMP	14.76 C
CUML EVAPORATION	.098 M	EVAPORATION RATE	9.42E-02 CMS
COMPUTED DOWNSTREAM TEMP	11.07 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	8.571E-02 KC/M2/S
QNA	4.491E-02 KC/M2/S
QW	8.861E-02 KC/M2/S
QE	7.352E-03 KC/M2/S
QC	-1.365E-02 KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	0.00	16.89	0.00	0

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	1.64	5.91	4.57	2	36.6	0.0
2	15.97	11.60	70.10	12	91.4	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	5.4205	41.7569	0.0000	0.0000	999.98365	0.	0.
5.1	5.5663	42.0194	.2419	0.0000	999.98020	4.8785E-07	8.0000E-02
12.2	5.7714	42.3886	.4659	0.0000	999.97480	8.1528E-07	8.0000E-02
18.3	6.0143	42.8258	.4221	0.0000	999.96758	1.1351E-06	8.0000E-02
24.4	6.2676	43.2817	.3395	0.0000	999.95912	1.3022E-06	8.0000E-02
30.5	6.7146	44.0863	.1673	0.0000	999.94184	2.6564E-06	8.0000E-02
36.6	7.4047	45.3284	0.0000	0.0000	999.90941	5.1587E-06	8.8027E-02
42.7	8.1828	46.7290	0.0000	0.0000	999.86462	7.1762E-06	1.1091E-01
48.8	9.0159	48.2287	0.0000	0.0000	999.80719	9.2597E-06	1.3257E-01
54.9	9.8776	49.7798	0.0000	0.0000	999.73775	1.1195E-05	1.5141E-01
61.0	10.7725	51.3905	0.0000	0.0000	999.65507	1.3255E-05	1.7042E-01
67.1	11.7146	53.0863	1.3935	0.0000	999.55667	1.5499E-05	1.9013E-01
73.2	12.7906	55.0232	2.5708	0.0000	999.43039	1.8162E-05	2.1245E-01
79.2	12.7906	55.0232	3.4845	0.0000	999.43039	0.	0.

Table 48. Day 200.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	77.82 M	SURFACE AIR TEMP	22.20 C
DEPTH OF SURFACE ELEMENT	4.67 M	TOTAL SYSTEM OUTFLOW	11.77 CMS
THERMOCLINE DISTANCE FROM BOTTOM	67.1 M	TOTAL SYSTEM INFLOW	0.00 CMS
SURFACE WATER TEMP	13.61 C	EQUILIBRIUM TEMP	15.96 C
CUML EVAPORATION	.106 M	EVAPORATION RATE	0. CMS
COMPUTED DOWNSTREAM TEMP	12.59 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	8.272E-02	KC/M2/S
QNA	3.764E-02	KC/M2/S
QW	8.974E-02	KC/M2/S
QE	0.	KC/M2/S
QC	0.	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	0.00	16.94	0.00	0

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	.65	6.84	4.57	2	30.5	0.0
2	11.13	12.93	70.10	12	85.3	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	6.4180	43.5524	0.0000	0.0000	999.95363	0.	0.
6.1	6.6002	43.8804	.1247	0.0000	999.94654	1.1872E-06	8.0000E-02
12.2	6.8275	44.2895	.2372	0.0000	999.93701	1.4904E-06	8.0000E-02
18.3	7.0942	44.7695	.1876	0.0000	999.92486	1.8270E-06	8.0000E-02
24.4	7.3904	45.3028	.0961	0.0000	999.91015	2.2422E-06	8.0000E-02
30.5	7.9090	46.2362	0.0000	0.0000	999.88136	4.5326E-06	8.0405E-02
36.6	8.5595	47.4072	0.0000	0.0000	999.83965	6.6814E-06	1.0550E-01
42.7	9.3046	48.7482	0.0000	0.0000	999.78506	8.8630E-06	1.2857E-01
48.8	10.1084	50.1951	0.0000	0.0000	999.71745	1.1019E-05	1.4975E-01
54.9	10.9366	51.6859	0.0000	0.0000	999.63876	1.2454E-05	1.6679E-01
61.0	11.8007	53.2412	0.0000	0.0000	999.54711	1.4556E-05	1.8195E-01
67.1	12.7363	54.9254	2.6375	0.0000	999.43712	1.6938E-05	2.0232E-01
73.2	13.6061	56.4910	2.7355	0.0000	999.32507	1.9122E-05	2.2025E-01

Table 49.   Day 210.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	77.37 M	SURFACE AIR TEMP	18.60 C
DEPTH OF SURFACE ELEMENT	10.31 M	TOTAL SYSTEM OUTFLOW	9.01 CMS
THERMOCLINE DISTANCE FROM BOTTOM	61.0 M	TOTAL SYSTEM INFLOW	9.11 CMS
SURFACE WATER TEMP	13.40 C	EQUILIBRIUM TEMP	12.58 C
CUML EVAPORATION	.110 M	EVAPORATION RATE	3.60E-02 CMS
COMPUTED DOWNSTREAM TEMP	13.29 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	8.075E-02	KC/M2/S
QNA	3.385E-02	KC/M2/S
QW	8.931E-02	KC/M2/S
QE	2.923E-03	KC/M2/S
QC	-6.123E-03	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	9.11	15.56	70.10	12

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	0.00	7.27	4.57	2	0.0	0.0
2	9.01	13.29	70.10	12	85.3	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	7.2025	44.9645	0.0000	0.0000	999.91963	0.	0.
6.1	7.3597	45.2475	0.0000	0.0000	999.91174	1.2136E-06	8.0000E-02
12.2	7.7099	45.8777	0.0000	0.0000	999.89287	2.9151E-06	8.0000E-02
18.3	8.1839	46.7310	0.0000	0.0000	999.86455	4.4369E-06	8.0000E-02
24.4	8.5433	47.3779	0.0000	0.0000	999.84096	3.7804E-06	8.0000E-02
30.5	9.0222	48.2400	0.0000	0.0000	999.80672	5.6036E-06	9.3276E-02
36.6	9.6005	49.2810	0.0000	0.0000	999.76118	7.4678E-06	1.1426E-01
42.7	10.2492	50.4485	0.0000	0.0000	999.70471	9.2991E-06	1.3297E-01
48.8	10.9422	51.6960	0.0000	0.0000	999.63819	1.0899E-05	1.4860E-01
54.9	11.6683	53.0029	0.0000	0.0000	999.56177	1.2198E-05	1.6078E-01
61.0	12.4521	54.4138	0.0000	3.0441	999.47170	1.4097E-05	1.7792E-01
67.1	13.3975	56.1156	2.1361	6.0683	999.35279	1.9418E-05	2.2263E-01
73.2	13.3975	56.1156	2.2154	0.0000	999.35279	0.	0.

Table 50. Day 220.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	76.70 M	SURFACE AIR TEMP	21.10 C
DEPTH OF SURFACE ELEMENT	9.64 M	TOTAL SYSTEM OUTFLOW	6.03 CMS
THERMOCLINE DISTANCE FROM BOTTOM	61.0 M	TOTAL SYSTEM INFLOW	0.00 CMS
SURFACE WATER TEMP	14.15 C	EQUILIBRIUM TEMP	21.37 C
CUML EVAPORATION	.114 M	EVAPORATION RATE 0.	CMS
COMPUTED DOWNSTREAM TEMP	13.93 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	7.373E-02	KC/M2/S
QHA	4.957E-02	KC/M2/S
QW	6.031E-02	KC/M2/S
QE	0.	KC/M2/S
QC	0.	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	0.00	16.67	0.00	0

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	. LOWER
1	0.00	8.29	4.57	2	0.0	0.0
2	6.03	13.93	70.10	12	85.3	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	8.2074	46.7733	0.0000	0.0000	999.86306	0.	0.
5.1	8.4000	47.1200	0.0000	0.0000	999.85058	1.9925E-06	8.0000E-02
12.2	8.8070	47.8525	0.0000	0.0000	999.82250	4.5057E-06	8.0070E-02
13.3	9.2510	48.6519	0.0000	0.0000	999.78925	5.4036E-06	9.0932E-02
24.4	9.5893	49.2608	0.0000	0.0000	999.76211	4.3921E-06	8.0000E-02
30.5	10.0140	50.0251	0.0000	0.0000	999.72584	5.9200E-06	9.6932E-02
36.6	10.5370	50.9666	0.0000	0.0000	999.67785	7.8661E-06	1.1827E-01
42.7	11.1351	52.0432	0.0000	0.0000	999.61856	9.7734E-06	1.3768E-01
48.8	11.7802	53.2043	0.0000	0.0000	999.54934	1.1449E-05	1.5380E-01
54.9	12.4469	54.4045	0.0000	0.0000	999.47231	1.2638E-05	1.6482E-01
61.0	13.1630	55.6933	0.0000	0.0000	999.38332	1.3670E-05	1.7413E-01
67.1	14.1516	57.4728	1.4299	0.0000	999.25009	1.8923E-05	2.1864E-01
73.2	14.1516	57.4728	1.4830	0.0000	999.25009	0.	0.

Table 51. Day 230.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	76.48 M	SURFACE AIR TEMP	20.00 C
DEPTH OF SURFACE ELEMENT	9.42 M	TOTAL SYSTEM OUTFLOW	5.47 CMS
THERMOCLINE DISTANCE FROM BOTTOM	61.0 M	TOTAL SYSTEM INFLOW	11.93 CMS
SURFACE WATER TEMP	14.47 C	EQUILIBRIUM TEMP	16.23 C
CUML EVAPORATION	.117 M	EVAPORATION RATE	0. CMS
COMPUTED DOWNSTREAM TEMP	14.34 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	7.359E-02	KC/M2/S
QNA	4.423E-02	KC/M2/S
QW	9.056E-02	KC/M2/S
QE	0.	KC/M2/S
QC	0.	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	11.93	15.83	70.10	12

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	0.00	9.38	4.57	2	0.0	0.0
2	5.47	14.34	70.10	12	85.3	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	9.2925	48.7265	0.0000	0.0000	999.78601	0.	0.
6.1	9.4835	49.0705	0.0000	0.0000	999.77076	2.4732E-06	8.0000E-02
12.2	9.8522	49.7340	0.0000	0.0000	999.73994	5.0264E-06	8.6441E-02
18.3	10.2534	50.4561	0.0000	0.0000	999.70433	5.8139E-06	9.5712E-02
24.4	10.5615	51.0108	0.0000	0.0000	999.67552	4.7225E-06	8.2749E-02
30.5	10.9413	51.6944	0.0000	0.0000	999.63828	6.1449E-06	9.9495E-02
36.6	11.4057	52.5302	0.0000	0.0000	999.59020	7.9774E-06	1.1944E-01
42.7	11.9335	53.4803	0.0000	0.0000	999.53217	9.6375E-06	1.3634E-01
48.8	12.5016	54.5028	0.0000	0.0000	999.46575	1.1018E-05	1.4973E-01
54.9	13.0869	55.5565	0.0000	0.0000	999.39308	1.1964E-05	1.5862E-01
61.0	13.7054	56.6697	0.0000	4.2447	999.31169	1.2799E-05	1.6629E-01
67.1	14.4742	58.0536	1.2963	7.6881	999.20405	1.6125E-05	1.9547E-01
73.2	14.4742	58.0536	1.3444	0.0000	999.20405	0.	0.

98

Table 52. Day 240.

GENERAL SYSTEM INFORMATION

ELEVATION BOTTOM OF POOL   2029.97 M

END OF TIME INTERVAL		AVERAGE OVER TIME INTERVAL	
POOL DEPTH	76.85 M	SURFACE AIR TEMP	20.00 C
DEPTH OF SURFACE ELEMENT	9.80 M	TOTAL SYSTEM OUTFLOW	6.18 CMS
THERMOCLINE DISTANCE FROM BOTTOM	61.0 M	TOTAL SYSTEM INFLOW	6.67 CMS
SURFACE WATER TEMP	15.24 C	EQUILIBRIUM TEMP	15.61 C
CUML EVAPORATION	.123 M	EVAPORATION RATE	0. CMS
COMPUTED DOWNSTREAM TEMP	15.19 C	OBJECTIVE TEMP	4.44 C

SURFACE HEAT COMPONETS

QNS	6.953E-02	KC/M2/S
QNA	4.423E-02	KC/M2/S
QW	9.146E-02	KC/M2/S
QE	0.	KC/M2/S
QC	0.	KC/M2/S

INFLOWS AND POSITIONS

TRIB NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM
1	6.67	15.00	70.10	12

OUTFLOWS AND LEVELS

OUTLET NO	FLOW CMS	TEMP DEG C	DIST. FROM BOTTOM (M)	ELEM	WITHDRAWAL LIMITS UPPER	WITHDRAWAL LIMITS LOWER
1	0.00	10.38	4.57	2	0.0	0.0
2	6.18	15.19	70.10	12	85.3	61.0

NOTE:
WITHDRAWAL ZONE WAS COMPUTED USING WES METHOD.

SUMMARY OF OUTPUT FOR 28 AUG 1977 (240)   EXECUTION INTERVAL ENDING 2400 HRS

DISTANCE FROM BOTTOM	TEMP DEG. C.	TEMP DEG. F.	HORZ OUT CMS	HORZ IN CMS	DENSITY KG/CM	STABILITY	DIFFUSION COEFFICIENT
0.0	10.3048	50.5486	0.0000	0.0000	999.69961	0.	0.
6.1	10.4723	50.8501	0.0000	0.0000	999.68399	2.5749E-06	8.0000E-02
12.2	10.7898	51.4217	0.0000	0.0000	999.65336	5.0331E-06	8.6522E-02
18.3	11.1366	52.0459	0.0000	0.0000	999.61840	5.7311E-06	9.4756E-02
24.4	11.4056	52.5300	0.0000	0.0000	999.59021	4.6042E-06	8.1293E-02
30.5	11.7441	53.1394	0.0000	0.0000	999.55340	6.0055E-06	9.7910E-02
36.6	12.1711	53.9080	0.0000	0.0000	999.50488	7.9189E-06	1.1882E-01
42.7	12.6747	54.8145	0.0000	0.0000	999.44470	9.8328E-06	1.3827E-01
48.8	13.2384	55.8291	0.0000	0.0000	999.37358	1.1634E-05	1.5554E-01
54.9	13.8416	56.9148	0.0000	0.0000	999.29315	1.3159E-05	1.6955E-01
61.0	14.4791	58.0624	0.0000	2.3091	999.20335	1.4728E-05	1.8346E-01
67.1	15.2435	59.4383	1.4661	4.3595	999.08928	1.8960E-05	2.1895E-01
73.2	15.2435	59.4383	1.5206	0.0000	999.08928	0.	0.

99

APPENDIX G

OXYGEN SIMULATION MODEL FOR RIDGES BASIN RESERVOIR

Table 53.   Variable names for "OXYHYP".

Variable	Computer Code	Units
Sediment oxygen demand at 20°C	500	g/m^2-day
Time interval of segments	J	days
Number of intervals	N	dimensionless
Day (starting May 1)	Day	dimensionless
Temperature of bottom	TEMBOT	°C
Temperature of surface	TEMSUR	°C
Diffusion coefficient	DIFCOF	m^2/sec
D.O. saturation value at surface temperature	O2SAT	mg/ℓ
D.O. saturation at surface temperature, corrected for altitude	SATO2	mg/ℓ
D.O. of hypolimnion	DOHYP	mg/ℓ
Area of thermocline	AREAHP	m^2
Area of sediment under thermocline	AREABT	m^2
Volume of hypolimnion	VOLHYP	m^3
Hypolimnetic outflow	FLOWOT	m^3/sec
Rate of oxygen utilization by sediment	MO2BOT	kg/day
Rate of oxygen transfer by diffusion	MO2DIF	kg/day
Rate of loss of oxygen to outflow	MO2OUT	kg/day
Overall rate of change of mass of oxygen in hypolimnion per unit area	DELTO2	kg/m^2-day

Table 54. "OXYHYP" computer model.

```
            F6700    F O R T R A N    C O M P I L A T I O N    M A R K    2.5.150

                                          O X Y H Y P
                                          = = = = = =

C  N=NO. OF TIME INTERVALS
C  J=TIME INTERVAL(DAYS)
C  SOD(I)=SEDIMENT OXYGEN DEMAND AT 20C
C  SOUT=SEDIMENT O2 UTILIZATION,G/M2/DAY (ADJUSTED FOR TEMP.)
C  MO2BOT(I)=MASS OF O2 UTILIZED BY SEDIMENT DURING TIME INTERVAL I
C  MO2OUT(I)=MASS OF O2 LEAVING HYPOLIMNION VIA OUTFLOW DURING INTERVAL I
C  MO2DIFF(I)=MASSOF O2 DIFFUSING INTO HYPOLIMNION DURING INTERVAL I.
C  ELSUR(I)=EL. OF SURFACE(M FROM SEA LEVEL)
C  TEMSUR(I)=TEMP(C) OF SURFACE
C  TEMPBOT(I)=TEMP(C) OF BOTTOM
C  DIFCOF(I)=DIFFUSION COEFFICIENT AT THERMOCLINE, DAY(-1)
C  AREABT(I)=AREA OF BOTTOM UNDER HYPOLIMNION
C  AREAHP(I)=AREA OF THERMOCLINE
C  FLOWOT(I)=DISCHARGE
C  VOLHYP(I)=VOLUME OF HYPOLIMNION(CUBIC METERS)
C  DAY(I)=DAY OF YEAR
C  DOHYP=CONC. OF O2 IN THE HYPOLIMNION (A CSTR.)
C  O2SAT(I)=OXYGEN SAT. AT TIME INTERVAL I

        DIMENSION SOUT(12),MO2BOT(12),MO2OUT(12),MO2DIF(12),ELSUR(12),
       /TEMSUR(12),TEMPOT(12),DIFCOF(12),AREABT(12),AREAHP(12),FLOWOT(12),
       /VOLHYP(12),DAY(12),DOHYP(12),O2SAT(12),SATO2(12)
        WRITE(6,40)
40      FORMAT('1',T32,'OXYGEN BALANCE FOR THE HYPOLIMNION OF RIDGES BASIN
       / RESERVOIR')
        WRITE(6,42)
42      FORMAT('0',T32,'UPPER VALUES FOR DIFFUSION USED')
        WRITE(6,44)
44      FORMAT(' ',T32'SOD=4.00(MIDDLE VALUE)')
        WRITE(6,50)
50      FORMAT('0',T15,'CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY')
        WRITE(6,60)
60      FORMAT(' ',' DAY', T15,'BOTTOM',T31,'OUTLET',T47,'DIFFUSION',T65,'H
       /YPOLIMNETIC D.O., MG/L')
        READ(5,70)SOD,N,J
70      FORMAT(F5.3,I3,I3)
        DO 100 I=1,N
        READ(5,80)TEMSUR(I),TEMPOT(I),AREABT(I),AREAHP(I),VOLHYP(I),FLOWOT
       /(I),DAY(I),O2SAT(I),DIFCOF(I),ELSUR(I)
80      FORMAT(F5.2,F5.2,1X,I7,1X,I7,1X,I9,F4.2,I3,F4.1,F8.7,F6.1)
100     CONTINUE
        SATO2(1)=O2SAT(1)*10**(((-273)*ELSUR(1))/(18421*(TEMSUR(1)+273+.00
       /25*ELSUR(1))))
        SOUT(1)=SOD*2.302**(.062*(TEMPOT(1)-10))
        MO2BOT(1)=0
        MO2OUT(1)=0
        MO2DIF(1)=0
        DOHYP(1)=SATO2(1)
        DO 300 I=1,N-1
C       CALCULATION OF MASS O2 UTILIZED BY SEDIMENT
        SOUT(I+1)=SOD*2.302**(.062*(TEMPOT(I)-10))
        MO2BOT(I+1)=(SOUT(I)*AREABT(I)/1000)*(-1)
C       MASS OF O2 GAINED BY DIFFUSION
        SATO2(I+1)=O2SAT(I)*10**(((-273)*ELSUR(I))/(18421*(TEMSUR(I)+273+.
```

102

Table 54.   Continued.

```
      /0025*ELSUR(I))))
C       MASS CF C2 LOST THROUGH OUTFLOW
      MO2DIF(I+1)=DTFCCF(J)*AREAPP(I)*(PATO2(I)-CCHYP(I))/14.2
      MO2OUT(I+1)=((CCHYP(I)+FLOWCT(I)*86400)*(-1))/1000
      OCHYP(I+1)=CCHYP(I)+J*1000*(MO2OUT(I)+MO2DIF(I)+MO2ECT(I))/VCLHYP(
     /I)
300   CONTINUE
      DO 400 I=1,N
      WRITE(6,310)DAY(I),MO2ECT(I),MO2OUT(I),MO2DIF(I),CCHYP(I)
310   FORMAT('0',I3,TI5,F10.0,T31,F10.0,T47,F10.0,T65,F5.2)
400   CONTINUE
C     LIST OF INPUT DATA
      WRITE(6,410)
410   FORMAT('1',T40,'INPUT DAT FOR STORE BASIN RESERVOIR')
      WRITE(6,412)
412   FORMAT(' ','DAY',T6,'TEMSUR, C.',T18,'TEMHCT, C.',T30,'ELSUR, M',T
     /41,'VCLHYP, CLB. M.',T57,'AREAPP, SG. M.',T73,'AREAET, SG. M.',T90
     /,'DTFCCF, SG. M./SEC.')
      DO 420 I=1,N
      WRITE(6,416)DAY(I),TEMSUR(I),TEMHCT(I),ELSUR(I),VCLHYP(I),AREAPP(I
     /),AREAET(I),DTFCCF(I)
416   FORMAT(' ',I3,T6,F5.2,T18,F5.2,T34,F6.1,T41,I5,T57,I7,T73,I7,T90,F
     /8.7)
420   CONTINUE
      WRITE(6,430)
430   FORMAT('1','O2SAT, MG./L.',T16,'FLOWCT, CLB. M./SEC.')
      DO 460 I=1,N
      WRITE(6,440)O2SAT(I),FLOWCT(I)
440   FORMAT(' ',F4.1,T16,F4.2)
460   CONTINUE
      STOP
      END
```

Table 55. Oxygen balance for the hypolimnion of Ridges Basin Reservoir.

UPPER VALUES FOR DIFFUSION USED
SOD=2.00 (LOW VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-939.	0.	0.	9.39
150	-939.	-1241.	0.	9.34
160	-837.	0.	-1.	9.20
170	-837.	0.	0.	9.14
180	-840.	0.	-2.	9.09
190	-530.	0.	-4.	8.95
200	-859.	-1267.	-3.	8.91
210	-895.	-500.	-4.	8.77
220	-843.	0.	-4.	8.68
230	-889.	0.	-3.	8.62
240	-952.	0.	-4.	8.56

LOWER VALUES FOR DIFFUSION USED
SOD=4.00 (MIDDLE VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-1879.	0.	0.	9.39
150	-1879.	-1241.	0.	9.29
160	-1675.	0.	0.	9.09
170	-1675.	0.	0.	8.97
180	-1680.	0.	0.	8.86
190	-1060.	0.	0.	8.58
200	-1719.	-1216.	0.	8.51
210	-1790.	-478.	0.	8.32
220	-1686.	0.	0.	8.17
230	-1778.	0.	0.	8.06
240	-1904.	0.	0.	7.94

Table 55. Continued.

LOWER VALUES FOR DIFFUSION USED
SOD=2.0 (LOW VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-939.	0.	0.	9.39
150	-939.	-1291.	0.	9.34
160	-837.	0.	0.	9.20
170	-837.	0.	0.	9.14
180	-840.	0.	0.	9.09
190	-530.	0.	0.	8.95
200	-859.	-1267.	0.	8.91
210	-895.	-500.	0.	8.77
220	-843.	0.	0.	8.68
230	-889.	0.	0.	8.62
240	-952.	0.	0.	8.56

MIDDLE VALUES FOR DIFFUSION USED
SOD=2.0 (LOW VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-939.	0.	0.	9.39
150	-939.	-1291.	0.	9.34
160	-837.	0.	0.	9.20
170	-837.	0.	0.	9.14
180	-840.	0.	-1.	9.09
190	-530.	0.	-2.	8.95
200	-859.	-1267.	-1.	8.91
210	-895.	-500.	-2.	8.77
220	-843.	0.	-2.	8.68
230	-889.	0.	-1.	8.62
240	-952.	0.	-2.	8.56

Table 55.   Continued.

MIDDLE VALUES FOR DIFFUSION USED
SCD=4.00(MIDDLE VALUE)

	CHANGE IN MASS OF HYPOLIMNETIC D.C., KG/DAY			
DAY	BOTTOM	OUTLET	DIFFUSION	HYPOLIMNETIC D.C., MG/L
130	0.	0.	0.	9.35
140	-1879.	0.	0.	9.39
150	-1879.	-1241.	0.	9.29
160	-1675.	0.	0.	9.05
170	-1675.	0.	0.	8.97
180	-1680.	0.	0.	8.86
190	-1760.	0.	-1.	8.58
200	-1719.	-1216.	0.	8.51
210	-1790.	-478.	0.	8.32
220	-1686.	0.	0.	8.17
230	-1778.	0.	0.	8.06
240	-1904.	0.	0.	7.94

UPPER VALUES FOR DIFFUSION USED
SCD=4.00(MIDDLE VALUE)

	CHANGE IN MASS OF HYPOLIMNETIC D.C., KG/DAY			
DAY	BOTTOM	OUTLET	DIFFUSION	HYPOLIMNETIC D.C., MG/L
130	0.	0.	0.	9.35
140	-1879.	0.	0.	9.39
150	-1879.	-1241.	0.	9.29
160	-1675.	0.	0.	9.05
170	-1675.	0.	0.	8.97
180	-1680.	0.	-1.	8.86
190	-1060.	0.	-2.	8.58
200	-1719.	-1216.	0.	8.51
210	-1790.	-478.	-1.	8.32
220	-1686.	0.	0.	8.17
230	-1778.	0.	0.	8.05
240	-1504.	0.	0.	7.94

Table 55. Continued.

LOWER VALUES FOR DIFFUSION USED
SED=6.0^(HIGH VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-2619.	0.	0.	9.39
150	-2619.	-1241.	0.	9.24
160	-2513.	0.	0.	8.97
170	-2513.	0.	0.	8.81
180	-2520.	0.	0.	8.64
190	-1591.	0.	0.	8.22
200	-2579.	-1168.	0.	8.11
210	-2685.	-455.	0.	7.87
220	-2529.	0.	0.	7.66
230	-2667.	0.	0.	7.49
240	-2856.	0.	0.	7.31

MIDDLE VALUES FOR DIFFUSION USED
SED=6.0^(HIGH VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-2619.	0.	0.	9.39
150	-2619.	-1241.	0.	9.24
160	-2513.	0.	0.	8.97
170	-2513.	0.	0.	8.81
180	-2520.	0.	0.	8.64
190	-1591.	0.	0.	8.22
200	-2579.	-1168.	1.	8.11
210	-2685.	-455.	1.	7.87
220	-2529.	0.	1.	7.66
230	-2667.	0.	2.	7.49
240	-2856.	0.	2.	7.31

Table 55. Continued.

UPPER VALUES FOR DIFFUSION USED
SOD=8.00(HIGH VALUE)

DAY	CHANGE IN MASS OF HYPOLIMNETIC D.O., KG/DAY			HYPOLIMNETIC D.O., MG/L
---	BOTTOM	OUTLET	DIFFUSION	
130	0.	0.	0.	9.39
140	-2819.	0.	0.	9.39
150	-2919.	-1241.	0.	9.24
160	-2513.	0.	0.	8.97
170	-2513.	0.	1.	8.81
180	-2520.	0.	0.	8.64
190	-1591.	0.	0.	8.22
200	-2579.	-1164.	1.	8.11
210	-2685.	-458.	1.	7.87
220	-2529.	0.	2.	7.66
230	-2667.	0.	3.	7.49
240	-2856.	0.	4.	7.31

Metal Retention Data from Literature

To determine values for V_m in Equation 27 data on metal retention coefficients and areal loading from a number of lakes were needed. Data on metal retention were extracted from the literature for a number of lakes for which metals loadings (inflow and outflow) were presented or for which the available data permitted computations of metals loadings. Data from six lakes and reservoirs were used: Bighorn Lake (Montana), Pueblo Reservoir (Colorado), Lake Washington (Washington), Coeur D'Alene Lake (Idaho), Derwent Reservoir (England), and Alpnachersee (Switzerland). In some cases more than one year's data existed and several data points could be generated for a single water body. The methods used to obtain data and a description of each water body studied follows.

Pueblo Reservoir, Colorado

Pueblo Reservoir is a 535,269 A.F. (6.58 x 10^8 m^3) impoundment located on the Arkansas River in Pueblo County, Colorado. The reservoir was created by an earthfill dam whose crest extends 200 ft (61 m) above the streambed (el. 4,725 ft). The reservoir formed is long (approx. 10 mi) and narrow (max. width approx. 1.5 mi) and covers 8,027 acres when filled. The primary purposes of the reservoir are flood control and irrigation. The hydraulic residence time for the time period studied was very short, less than 0.1 yr. Filling began on January 9, 1974.

In a study performed by Herrmann and Mahan (1977), water quality data were collected from the Arkansas River above the pool of the reservoir, from several locations in the pool, and from the Arkansas River immediately below the dam site. Concentrations of most suspended and dissolved inorganic constituents were measured on a monthly basis from June 1974 through March 1976. Data on metals concentrations were collected during this study, but the absence of the study period precludes use of these data. Data were compiled for iron, zinc, and lead in the inflow and outflow for the study period (see Tables 56 and 57). For dates on which data are missing, an estimate of the concentration was made by averaging the data from the preceding and following months. The incompleteness of data during 1976 made loading calculations impossible. The data were divided into two time segments: June - September 1974 and October 1974 - September 1975. During the entire period, data for iron were missing four times, for zinc once, and for lead once. Since two of the missing data points for iron were in the first time segment, loading calculations for iron

were possible only during the second time segment. Thus, for loading calculations, the data were always more than 80 percent complete.

Flow data were obtained from the USBR Pueblo, Co. Office (W. C. Kregger, per. comm.). The hydraulic retention times for Pueblo Reservoir were calculated on a monthly basis using the hydraulic data provided by Mr. Kregger (Table 58). The average hydraulic retention time and total areal water load for each study period (June - September 1974 and October 1974 - September 1975) are presented in Table 23. Loadings (input and output) were calculated for each month using the reported concentration of each constituent and the total monthly discharge. Data on monthly loadings of Zn, Fe, and Pb for the entire period are presented in Tables 56 and 57. The loading of each constituent (inflow and outflow) and the calculated retention coefficient (Equation 22) are presented for the June - September, 1974 and the October, 1974 - September, 1975 sample periods in Table 66.

Derwent Reservoir, England

Derwent Reservoir is a 5.06 x 10^6 m^3 impoundment located in Durham (Consett Co.), England. It was constructed between 1960 and 1966 to provide water for domestic and industrial purposes. It is also used for sailing and trout fishing. The inflow water is soft and frequently contains humic substances that often cause a brown color (Harding and Whitton 1978).

Harding and Whitton (1978) studied Derwent Reservoir in 1976 with respect to the movement of zinc, lead, and cadmium in the reservoir. They sampled the Derwent River above the reservoir from March - December, 1976 (50 collections) and the Derwent River below the reservoir during March, 1976 (daily collections). The authors conclude, apparently on the basis of these sketchy data, that zinc, lead, and cadmium concentrations decreased by 70.3 percent, 98.3 percent, and 89.2 percent, respectively. Assuming evaporation to be negligible, a decrease in concentration equals a decrease in loading (continuity equation).

Area loading (q_s) was calculated using Figure 4 from Harding and Whitton (1978), a plot of depth vs. time, and Table 2 from Harding and Whitton (1978), a compilation of area vs. depth. The outflow was estimated to be 1.2 m^3/sec (Harding and Whitton 1978). Thus, areal loading was calculated on the basis of the average surface area and the average outflow for 1976. The hydraulic

Table 56. Loading of Fe, Zn, and Pb into Pueblo Reservoir, June 1974 - September 1975.

Date	Flow[a] (1000 ac ft)	$[Zn]^b$ (mg/ℓ)	$[Fe]^b$ (mg/ℓ)	$[Pb]^b$ (mg/ℓ)	Zn (kg)	Fe (kg)	Pb (kg)
6/27/74	86.3	0.039	0.546	0.0	4,152	58,132	0
7/11	71.7	0.056	0.520	0.0	4,954	45,997	0
8/8	37.8	0.036	–	0.026	1,679	–	1,212
9/7	18.5	0.035	–	0.023	799	–	524
10/19	13.4	0.011	0.514	0.0	182	8,497	0
11/16	17.3	0.030	1.204	0.003	640	25,697	64
12/6	14.6	0.010	0.372	0.0	180	6,700	0
1/01/75	14.6	0.020 est.	0.400 est.	0.0 est.	360	7,205	0
2/02/75	12.7	0.028	0.431	0.0	439	6,753	0
3/17	15.4	0.012	0.174	0.0	228	3,306	0
4/19	20.2	0.354	1.086 est.	0.052	8,822	27,064	1,296
5/23	43.4	0.166	1.998	0.002	8,888	106,978	107
6/18	131.1	0.073	1.247	0.002	11,807	201,687	323
7/28	169.2	0.017	0.257	0.000	3,549	53,647	0
8/09	61.2	0.019	0.242	0.000	1,435	18,272	0
9/26	27.7	0.005	0.011	0.000	171	376	0

[a] W.C. Kregger, USBR (personal communication).

[b] Metals data: *Herrmann and Mahan* (1977).

Table 57. Discharge loading of Fe, Zn, and Pb from Pueblo Reservoir, June 1974 - September 1975.

Date	Flow[a] (1000 ac ft)	$[Zn]^b$ (mg/ℓ)	$[Fe]^b$ (mg/ℓ)	$[Pb]^b$ (mg/ℓ)	Zn (kg)	Fe (kg)	Pb (kg)
6/27/74	86.5	0.006	0.168	0.0	640	17,928	0
7/11	71.7	0.017	0.130	0.0	1,504	11,499	0
8/8	38.0	0.008	0.310	0.0	375	14,533	0
9/7	18.4	0.000	0.112	0.0	0	2,542	0
10/19	13.5	0.002	0.492	0.0	33	8,194	0
11/16	17.2	0.001	0.232	0.003	21	4,923	64
12/6	14.6	0.000	0.132	0.0	0	2,378	0
1/1/75	14.4	0.004 est.	0.226 est.	0.0 est.	71	4,015	0
2/2	12.7	0.007	0.320	0.0	110	5,014	0
3/17	15.4	0.000	0.043	0.0	0	817	0
4/19	20.2	0.500	0.651	0.007	12,460	16,223	174
5/23	43.4	0.047	1.570	0.0	2,517	84,062	0
6/18	131.1	0.052	1.112	0.001	8,410	179,853	162
7/28	169.2	0.013 est.	0.246 est.	0.0 est.	2,714	51,350	0
8/9	61.3	0.010	0.196	0.001	756	14,823	76
9/26	27.6	0.007	0.146	0.0	238	4,971	0
				1975 W.Y. =	27,330	376,623	476

[a] W.C. Kregger, USBR (personal communication).

[b] Metals data: *Herrmann and Mahan* (1977).

Table 58. Hydraulic retention times for Pueblo, Colorado, by month.[a]

Period	Outflow (1000 ac-ft)	Volume (1000 ac-ft)	θ_h[b]	
			Yr.	Days
6/74	86.5	24.2	0.023	8.4
7/74	71.7	23.6	0.027	9.9
8/74	38.0	23.4	0.051	18.7
9/74	18.4	23.2	0.105	38.3
10/74	13.5	23.7	0.146	53.4
11/74	17.2	22.7	0.110	40.1
12/74	14.6	23.6	0.135	49.2
1/75	14.4	23.8	0.138	50.2
2/75	12.7	23.8	0.156	57.0
3/75	15.4	23.6	0.128	46.6
4/75	20.2	30.5	0.126	46.0
5/75	43.4	32.6	0.063	22.8
6/75	131.1	33.2	0.021	7.7
7/75	169.2	33.2	0.016	6.0
8/75	61.3	32.3	0.044	16.0
9/75	27.6	31.5	0.095	34.7

[a] Hydraulic data from W.C. Kregger, USBR (personal communication).

[b] $\theta_h = \dfrac{\text{end of month volume}}{\text{monthly discharge (12)}} = \text{yr.}$

Table 59. Retention of Fe, Zn, and Pb in Pueblo Reservoir, Colorado.[a,b]

June - September, 1974[c]

	Inflow (kg)	Outflow (kg)	% Retention
Fe	–	46,502	–
Zn	11,584	2,519	78.3
Pb	1,736	0	100.0

October, 1974 - September, 1975 (1975 W. Y.)[d]

	Inflow (kg)	Outflow (kg)	% Retention
Fe	466,182	376,623	19.6
Zn	36,701	27,330	25.5
Pb	1,790	476	73.4

[a] Data on metals concentrations from *Herrmann and Mahan* (1977).

[b] Flow data from W. C. Kregger, USGS (personal communication)

[c] Hydraulic retention time = 0.052 yr

[d] Hydraulic retention time = 0.098 yr

retention time was calculated on the basis of the average volume and the average discharge.

The data on metals retention, morphology, and hydraulic characteristics of Derwent Reservoir are presented in Table 23.

Alpnachersee, Switzerland

Alpnachersee is a natural, eutrophic lake located in the foothills of the Alps (el. = 430 m) near Luzern, Switzerland. The lake basin is roughly oval, with an area of 4.76 km^2 and a volume of 100 x 10^6 m^3. The lake is fed by two glacier-fed rivers and has a hydraulic retention time of 0.28 years (Baccini 1976).

Baccini (1976) studied the lake with respect to the fate of metals in the system. Samples of the inflow, outflow, freshly deposited sediment, plankton, and lake water were collected each month for a year. Based on the inflow and outflow loadings, retention times for Fe, Zn, Cu, and Cd were 92 percent, 50 percent, 42 percent, and 17 percent, respectively. The retention of each metal corresponded well with the fraction of that metal that was in particulate form in the inflow. Calculations of the hydrologic retention time and areal loading were made on the basis of reported values for hydraulic and morphological parameters. Data for Alpnachersee are summarized in Table 16.

Lake Washington

Lake Washington, adjacent to Seattle, Washington, is a large (2.91 x 10^9 m^3) lake that has a history of cultural eutrophication. In order to reverse the trend toward eutrophy, municipal sewage outfalls have been diverted from the lake.

Barnes and Schell (1972) composed a crude metals budget for the lake. The budget calculations included aeolian and fluvial inputs, a sedimentary sink, and fluvial output. It is unclear whether metals concentrations in the inflow and outflow were measured directly or calculated on the basis of sediment load and assumed composition of the sediment. Annual sedimentation was measured. Aeolian inputs were assumed to be insoluble and were calculated as the difference between net fluvial input and the annual sediment input.

The data used by Barnes and Schell are presented in Table 60 (adapted from Barnes and Schell 1972, Table 3) together with the calculated retention coefficient. For this lake, input was considered to be the sum of aeolian inputs and fluvial inputs. The data on aeolian inputs is probably inaccurate, as illustrated by a check on aeolian iron and sodium deposition using dustfall data. Barnes and Schell (1972) found on the basis of this check that their aeolian inputs were probably high by a factor of four but state that this error is still not large due to the relative magnitude of fluvial and aeolian inputs. Nevertheless, if this degree of error is associated with calculated aeolian inputs of the heavy metals, considerable error in calculated retention coefficients would occur, since aeolian inputs are relatively more important.

Coeur D'Alene Lake

Coeur D'Alene Lake, a natural lake, in northern Idaho is elongate (38.6 km), narrow (ave. width = 1.6 km), and shallow (ave. depth = 2.3 m) (USEPA 1975b). Inflows to Coeur D'Alene Lake include Coeur D'Alene River and the St. Joe River. The Coeur D'Alene River is polluted with heavy metals resulting from mining activity and smeltering in the Coeur D'Alene mining district. The St. Joe River is considered unpolluted with respect to mine waters but is affected to some extent by loading, farming, and sewage disposal (Funk et al. 1975).

Although abundant metals data exist for the Coeur D'Alene River above Coeur D'Alene Lake, there is little comparable data for the St. Joe River, making it difficult to calculate total loading of various constituents into Coeur d'Alene Lake. USEPA (1975b) presents data for zinc concentrations and flow for the St. Joe River, the Coeur D'Alene River at Rose Lake (~ 15-20 miles above Coeur D'Alene), and the Spokane River at Post Falls with the exception of January, in which there was a flood on the Coeur d'Alene River making flow measurement impossible. Loading of zinc into Coeur d'Alene Lake was calculated by month for 1974 (Table 61). Outflow loading of zinc was calculated for the Spokane River at Post Falls, immediately below the outlet of Coeur d'Alene Lake (Table 62).

Hydraulic residence time was computed using the flow data for February - December 1974 together with the average volume data presented in USEPA (1975b). This analysis indicates that 2,426,820 kg of Zn entered Coeur D'Alene Lake in the period February - December 1974 and that 2,002,574 kg left the lake via the Spokane River. Thus, 424,246 kg of Zn were trapped in the lake (17.5 percent of the total inflow load).

Data on lake morphology, hydraulic parameters, and zinc retention are presented in Table 16.

Yellowtail Reservoir

Bighorn Lake, formed by the Yellowtail Dam was completed in 1967 (filling began in 1965). The reservoir extends 61 miles along the Bighorn River and has a volume of 176 x 10^7 m^3.

The Bighorn River and the Shoshone River form the major tributaries into the reservoir, although numerous small tributaries enter the reservoir along its length.

Table 60. Trace metal budget for Lake Washington.[a]

Element	Annual Transport					
	Input	Fluvial Output	Net	Aeolian Input	Annual Deposition	Retention %
Fe, tons	2570	40	2530	2200[b]	4700	99.2
Na, tons	5420	5440	-20	180[c]	160	2.9
Pb, tons	1.3	1.0	0.3	29.8	30	96.8
Zn, tons	34	27	7	15	22	44.9
Cu, tons	5.7	3.5	2.2	2.8	5	58.8
Hg, kg	62	58	4	56	60	50.8

[a] Table and footnotes [b] and [c] adapted from *Barnes and Schell* (1972).

[b] Based on an average dustfall from Seattle of 38.92 U.S. tons/mi^2/mo. = 14.8×10^6 kg/yr over L. Washington, and using an iron concentration of 3,400 ppm iron for urban dust, the iron input for aeolian transport would be 500 tons/yr. (See references for dustfall data in *Barnes and Schell* 1972).

[c] Based on [b] above, Na output is 45 tons/yr from aeolian transport. Even if a higher Na concentration is assumed due to marine aerosols, the aeolian input is still very small compared to the fluvial.

[d] $R = \left(\dfrac{\text{aeolian input} + \text{fluvial input} - \text{fluvial output}}{\text{aeolian input} + \text{fluvial input}} \right) \times 100$

Table 61. Zinc loading into Coeur D'Alene Lake.[a]

	Coeur D'Alene River			St. Joe River		
	Flow	Conc.	Load	Flow (cfs)	Conc. (µg/ℓ)	Load[b]
Jan.	>100,000	1,800	--	6,000	0	0
Feb.	2,000	2,000	293,621	2,900	15	3,193
March	3,200	1,120	263,085	3,000	0	0
April	4,900	540	194,231	12,000	0	0
May	18,000	390	515,306	17,000	0	0
June	15,000	385	423,916	20,000	30	44,043
July	1,800	1,250	165,162	31,000	40	91,023
Aug.	900	2,000	132,130	1,000	9	661
Sept.	300	2,500	55,054	700	14	719
Oct.	310	2,533	57,640	800	0	0
Nov.	400	2,050	60,192	900	20	1,321
Dec.	900	1,900	125,523	700	0	0
Total[b]			2,285,860			140,960 kg
		Total:	2,426,820 (11 mo.)			

[a] Source: *USEPA* (1975b).

[b] January omitted from total loading calculation. See text for explanation.

Table 62. Zinc loading at Spokane River at Post Falls.[a]

Month	Flow (cfs)	Conc. (µg/ℓ)	Load (kg/mo)
Jan.	15,000	325	357,852
Feb.	10,000	345	253,249
March	8,000	370	217,280
April	21,000	405	624,313
May	23,000	227	383,250
June	26,000	160	305,367
July	2,500	130	23,857
Aug.	1,600	125	14,681
Sept.	1,600	125	14,681
Oct.	2,050	160	24,077
Nov.	2,100	715	110,218
Dec.	2,100	205	31,601
Total[b]			2,002,574

[a] Source: *USEPA* (1975b)

[b] January omitted from total loading calculation. See text for explanation.

Wright and Soltero (1973) sampled the Bighorn River and the Shoshone River (inflows), the reservoir outflow, and the reservoir water (6 stations) from February - December 1968 and from January - August 1969. Samples were analyzed for Zn, Fe, Mn, and Cu.

Since monthly data for metals were not available, loading of these metals was calculated by multiplying mean concentration of each metal (Tables VI and VII in Wright and Soltero 1973) for each sampling period by the total discharge during the sampling period for each year. For the 1968 sampling period 19 samples of inflow and outflow waters were collected (1 - 3 samples/month) and for the 1969 sampling period 27 samples were collected (2 - 5/month).

Data for average metals concentrations, total discharge, and total loading for the

Bighorn River, Shoshone River and reservoir outlet for the 1968 and 1969 sampling periods are presented for Fe, Mn, Zn, and Cu in Tables 63 and 64. The retention of iron, manganese, zinc, and copper were calculated for 1968 (Table 64) and 1969 (Table 65).

Average exchange rates (water renewal times) were calculated by dividing total reservoir outflow during the sampling period (Tables IV and V, Wright and Soltero 1973) by average reservoir volume during the sampling period. Average volume and surface area were calculated for each sampling period using the water surface vs. time graph (Figure 9, Wright and Soltero 1973) and Wright and Soltero's water surface elevation vs. volume and surface area plot (Figure 1, in Wright and Soltero 1973). These data are presented in Table 65.

Table 63. Metals loading data for Yellowtail Reservoir,[a] Feb. - Dec. 1968.

Stream	Ave. Discharge (m³/sec) Feb.-Dec.	[Fe]	Fe Loading (kg)	[Mn]	Mn Load (kg)	[Zn] (mg/ℓ)	Zn Load	[Cu⁺⁺] (µg/ℓ)	Cu Load (kg)
Bighorn R.	77.06	.138	335,134	.021	50,999	.094	228,281	1.60	3,886
Shoshone R.	29.01	.129	117,701	.025	22,810	.084	76,643	1.40	1,278
Discharge	116.6	.009	33,193	.004	14,754	.057	210,242	1.10	4,057
% Change (Inflow vs. Outflow)			92.7%		80.0%		31.1%		21.4%

[a] Source: *Wright and Soltero* (1973).

114

Table 64. Metals loading data for Yellowtail Reservoir,[a] Jan. - Aug. 1969.

Stream	Ave. Discharge (m^3/sec) Jan.-Aug.	[Fe] (mg/ℓ)	Fe Load (kg)	[Mn]	Mn Load (kg)	[Zn] (mg/ℓ)	Zn Load (kg)	[Cu] $(\mu g/\ell)$	Cu Load (kg)
Bighorn	65.68	1.290	2,677,895	0.265	548,056	0.048	99,271	3.1	6,411
Shoshone	28.34	1.390	1,244,203	0.182	162,909	0.038	34,014	2.6	2,327
Discharge	91.25	0.052	149,798	0.030	86,423	0.022	63,370	1.3	3,745
% Change			96.2%		87.8%		52.5%		57.1%

[a] Source: *Wright and Soltero* (1973).

Table 65. Morphological data for Yellowtail Reservoir.[a]

	Feb.-Dec., 1968	Jan.-Aug., 1969
Average Volume ($\times 10^6$ m^3)	970	1048
Average Area ($\times 10^6$ m^2)	30.2	37.9
Hydraulic Retention Time, θ_h (yr.)	0.313	0.407
Areal Water Load, q_s (m/yr.)	103	67.9
Average Water Surface Elevation (m)	1100	1104

[a] Source: *Wright and Soltero* (1973).