Development of Water Quality Management Program for the Rawhide Electric Generating Station Cooling Impoundment: A Domestic Wastewater Reuse Project

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DEVELOPMENT OF WATER QUALITY MANAGEMENT PROGRAM FOR THE RAWHIDE ELECTRIC GENERATING STATION COOLING IMPOUNDMENT: A DOMESTIC WASTEWATER REUSE PROJECT

R. Anne Jones and G. Fred Lee

ABSTRACT

The Platte River Power Authority is constructing a 250 MW coal-fired electric generating station 22 miles (35 km) north of the city of Fort Collins, Colorado. The make-up water for the cooling impoundment created for this facility will be secondarily treated domestic wastewater treatment plant effluent from Fort Collins. The Platte River Power Authority wishes to make this waterbody available to the public for recreation. This paper discusses the potential water quality problems that may be faced in trying to use a waterbody consisting primarily of domestic wastewater for recreation, the approximate magnitude of the problems, and the degree of contaminant control necessary for maintaining desired quality in the waterbody.

With no further treatment of the make-up water, the eutrophication-related water quality of the cooling impoundment is predicted to be very poor; it would be highly undesirable for recreational use because of unsightly algal growths and obnoxious odors. Controlling the phosphorus input to the impoundment is predicted to improve this aspect of water quality. If the P in the make-up water is reduced to 0.1 mg P/l, which represents state-of-the-art in P control technology, good water quality could be achieved in the cooling impoundment. It is predicted, using the OECD eutrophication modeling approach, that with this degree of treatment, mean summer chlorophyll concentrations would be about 7.5 μg/l (maximum of 13 μg/l) and mean summer Secchi depth about 1.6 m.

It was predicted that even with the state-of-the-art in phosphorus removal, the bottom waters of the impoundment would be depleted of oxygen by mid-summer, not only because of the decomposition of algae, but also because of the high nitrogen input. This would preclude sustaining populations of cold water fish in this impoundment.

Another major concern in using domestic wastewater treatment plant effluent as the primary source of make-up water for a recreational-use cooling lake is toxicity to fish caused by ammonia and nitrite in the wastewater, and chlorine in the condenser discharge waters. Domestic wastewaters typically contain on the order of 20 mg N/l total ammonia; especially with elevated pH induced by algal photosynthesis, sufficient amounts of un-ionized ammonia could be present to cause toxicity.

There is also a potential for toxicity in the Rawhide cooling impoundment due to nitrite. This could be a substantial problem during colder periods and if the make-up waters were partially nitrified.

Chlorine added to the cooling waters to prevent condenser tube fouling may cause acute or chronic toxicity to fish in the area of the cooling water discharge.

The wholesomeness of the fish caught in the Rawhide cooling impoundment is also of concern in assessing water quality since fishing will be one of the points of attraction to the waterbody. There are some chemicals pres-

ent in some domestic wastewaters which can bioaccumulate-bioconcentrate in fish flesh causing them to have an off-flavor, or to be unsafe for use as food.

From an overall point of view, it appears that there is a potential for developing a highly successful joint domestic wastewater reuse facility involving waste heat dissipation for electric power generation and a warm water sports fishery. The successful development of this project will be dependent on using state-of-the-art phosphorus removal from the domestic wastewaters and will likely require selective ammonia removal at certain times of the year to avoid potential ammonia toxicity to aquatic organisms.

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INTRODUCTION

The Platte River Power Authority (PRPA) of Fort Collins, Colorado is developing a 279 MW (gross) (250 MW net) , coal-fired electric generating unit, Rawhide Energy Project Unit I, scheduled to begin power production in April, 1984. The general grounds layout of this plant, which is located about 20 miles north of Fort Collins, CO is shown in Figure 1. The condenser cooling water for this plant will be obtained from an on-site impoundment, Rawhide cooling impoundment, being constructed by PRPA (see Figure 1). The make-up water for this impoundment will be the secondarily treated effluent of the Fort Collins Wastewater Treatment Plant No. 2.

The Platte River Power Authority Board of Directors, because of the scarcity of water in the Front Range of Colorado, has an interest in maintaining the water quality in this cooling impoundment so that it would be a recreational asset to the region. This paper presents a discussion of the water quality problems that could arise in the Rawhide cooling impoundment that could affect its recreational utility. It is based on a report submitted by the authors to the PRPA (1). Additional information on this topic can be obtained from that report.

Water quality should be judged in terms of the desired beneficial uses of a waterbody. It is largely a subjective assessment which depends to some extent on the availability of alternate waterbodies in the region to which the residents of the area can go to pursue the recreational activities of interest. The water quality in waterbodies in the Fort Collins region varies significantly from highly deteriorated waterbodies such as Timnath and Fossil Creek Reservoirs, to the good water quality in Horsetooth Reservoir.

The first and foremost consideration for water quality management in this impoundment is the water's suitability for use in cooling the condensers in the electric power generating station. Because of the design of the condensers, except for potential problems of scale due to calcium carbonate deposition in the condenser tubes, there should not be problems with using the impoundment water for condenser cooling. With this requirement apparently satisfied, the next priority should be given to management of water quality for recreational purposes. Aesthetic enjoyment, fishing and boating are the recreational activities which will be allowed on and around the waterbody, which directs control efforts to three areas of concern in the Rawhide cooling impoundment: eutrophication (excessive growths of algae and other aquatic plants), fish toxicity, and wholesomeness of the fish for use as food.

Characteristics of Rawhide Cooling Impoundment

Black & Veatch (2) summarized the mean monthly air temperatures and other meteorological data over the period 1930 to 1975 for the Rawhide

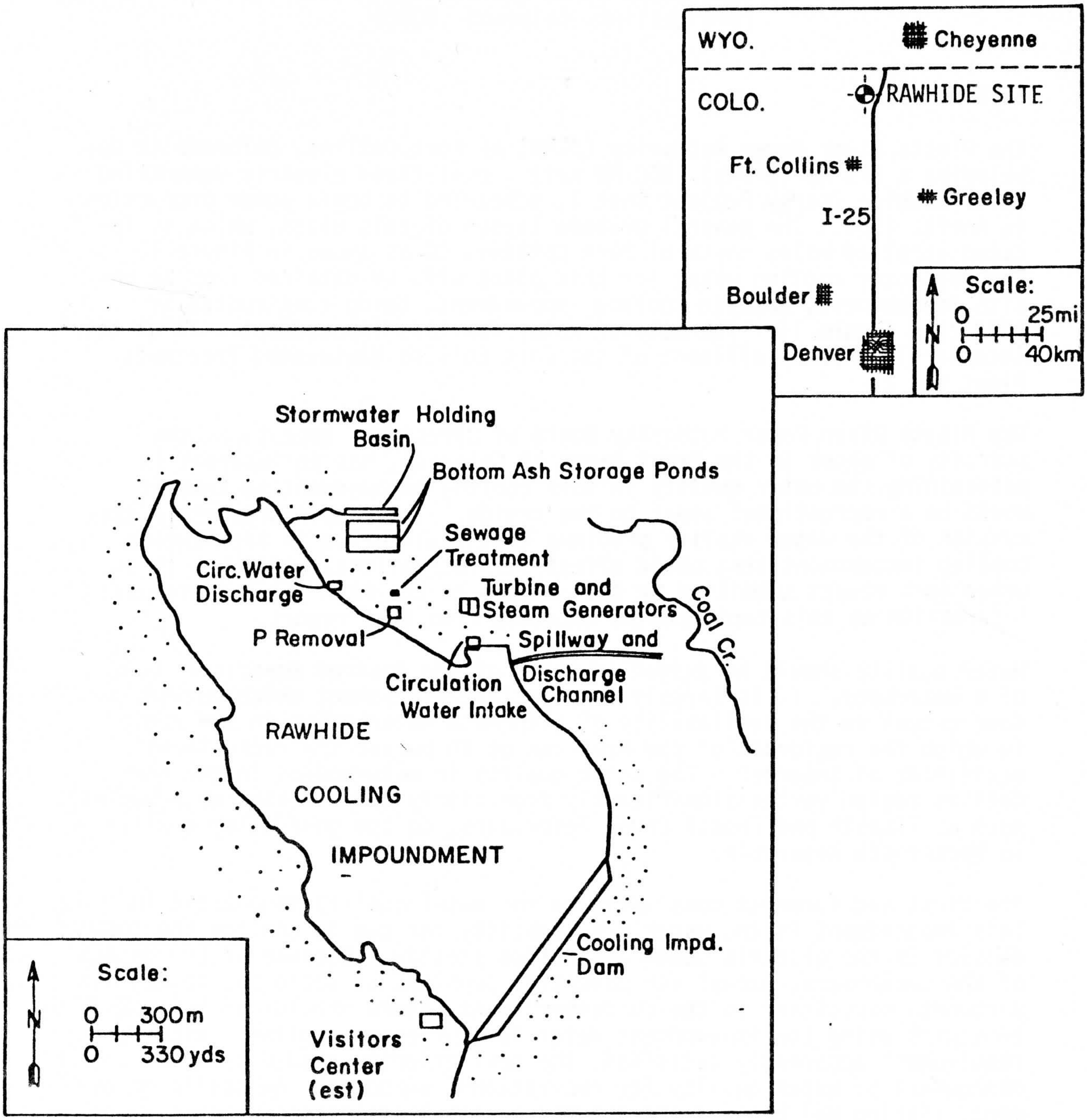


Figure 1. Rawhide Energy Project Location - Grounds and Cooling Impoundment Layout

area. Temperatures varied from a mean of 26.6° F (-3° C) in January to a mean of 71° F (22° C) for July. Annual precipitation is on the order of 12 to 15 inches (30 to 40 cm).

The Rawhide cooling impoundment will be a 500 acre (202 hectare) waterbody having a volume at full pool of approximately 15,000 ac ft (1.85×10^7 m^3). Average depth at full pool will be about 30 ft (9 m) and maximum depth near the dam will be about 70 ft (21 m) (Black & Veatch (2)).

Table 1 presents the water balances for the Rawhide cooling impoundment under conditions where no power is being generated, and where 250 MW are being generated, with and without on-site irrigation. As noted by Black & Veatch (2), the generation of power will increase the make-up water demand to 3,675 ac ft/yr (4.5×10^6 m^3/yr) primarily because of the increase in evaporation caused by condenser cooling, and to offset consumptive losses and downstream discharges. It was believed that adding on-site irrigation would have the potential for limiting dissolved solids build up in the impoundment. While this strategy is not without problems, this water budget was included in the water quality evaluation. Estimates of the water requirements under conditions of 279 MW gross power generation have been made by the authors (Table 1). These were made by linear extrapolation from the requirements for 250 MW gross production given by Black & Veatch (2). In addition to the water inputs from rainfall and the wastewater treatment plant, the Platte River Power Authority has a very junior right to water from the Poudre River. During periods of water abundance, PRPA would be able to utilize water from the Poudre River as make-up water for the cooling impoundment. This condition has not been directly considered in the estimations of water quality in the cooling impoundment made in this study. However, when this water is available, it would most likely serve to improve the overall quality of the impoundment.

Table 2 presents characteristics of the Fort Collins Wastewater Treatment Plant No. 2 effluent used by Black & Veatch in their "water quality" model to predict a number of water quality characteristics of the Rawhide cooling impoundment. These data were based in large part on 1977 plant operating records. More recent monthly average data were obtained from M. Grimes, operator of the Fort Collins Wastewater Treatment Plant No. 2 and are presented in Table 3. Soluble orthophosphate concentrations were in general higher in 1979 and 1980 than those reported by Black & Veatch. Total ammonia appeared to be more or less the same in the two data sets although in the 1979-80 data pH values were higher.

PREVIOUS STUDIES PERTINENT TO WATER QUALITY MANAGEMENT IN THE RAWHIDE COOLING IMPOUNDMENT

There are a number of projects currently in use in the U.S. in which treated domestic wastewaters are being directly re-used for cooling water and/or recreation. These include the Apollo Project, Antelope Valley, California; Indian Creek Reservoir, Alpine County, California; and Comanche Station near Lawton, Oklahoma. It is of interest to review the water quality experience at these facilities as part of evaluating the potential water quality and water quality problems in the Rawhide cooling impoundment to become aware of potential problems that may develop and to draw on the experience of others in averting or remedying problems that may occur.

Apollo County Park Wastewater Reclamation Project

The Apollo County Park Wastewater Reclamation Project (Apollo Project)

Table 1. Average Flow Inputs and Withdrawals Simulated for Rawhide Cooling Impoundment

	Simulation Condition			
	No Generation ac ft/yr	250 MW Generation ac ft/yr	250 MW Generation With Onsite Irrigation ac ft/yr	279 MW Generation*** ac ft/yr
Inputs				
Rainfall*	593	593	593	593
STP Supply	2,241	3,675	4,044	3,841
Total	2,834	4,268	4,637	4,434
Withdrawals				
Evaporation**	2,092	3,242	3,242	- not estimated -
Exfiltration	742	742	742	- not estimated -
Consumptive Station Uses	0	184	184	- not estimated -
Downstream Releases	0	100	100	- not estimated -
Irrigation	0	0	369	- not estimated -
Total	2,834	4,268	4,637	

*Includes pond drainage area runoff of 50 ac ft/yr.

**Computed by model.

***Based on linear extrapolation from 250 MW generation requirements as per C. Lucy, PRPA Environmental Planner

After Black & Veatch (2)

Table 2. Monthly Average Characteristics of Fort Collins Wastewater Treatment Plant No. 2 Effluent - 1977

	Month											
Constituent	J	F	M	A	M	J	J	A	S	O	N	D
Dissolved Oxygen (mg/l)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
5-Day BOD (mg/l)	20	20	20	20	20	20	20	20	20	20	20	20
Coliform (/100 ML)	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Suspended Solids (mg/l)	20	20	20	20	20	20	20	20	20	20	20	20
Ammonia (mg/l-N)	18	18	18	15	15	13	9	10	12	12	12	12
Nitrate (mg/l-N)	1	1	1	1	1	1	1	1	1	1	1	1
Orthophosphate (mg/l-P)	3.5	3.5	3.5	3.5	3.5	2	2	2	3.5	3.5	3.5	3.5
Total Dissolved Solids (mg/l)	400	400	400	400	400	400	400	400	400	400	400	400
Alkalinity (mg/l-$CaCO_3$)	125	125	150	150	190	200	200	210	190	150	125	125
pH (units)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Temperature (degrees C)	13	13	13	15	16	18	18	19	19	17	14	13

After Black & Veatch (2).

Table 3. Chemical Characteristics of Fort Collins' Wastewater Treatment Plant No. 2 Effluent*
Monthly Averages for Samples Collected**

	1979								1980				
Constituent	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Mar	Apr	May	Jun	Jul
Dissolved oxygen (mg/l)	-	-	-	-	-	-	-	-	2.4	2.1	3.8	1.8	1.2
Suspended Solids (mg/l)	5.4	4.6	3.5	2	8	7.5	3	3	-	-	-	-	-
Total Ammonia (mg N/l)	19	21.3	21.5	18.8	15.2	16.3	10.5	3.0	9.2	4.8	10.1	6.1	8.1
Nitrate (mg N/l)	1.3	1	0.7	0.4	1.1	0.9	1.9	2.2	8.6	8.9	2.4	1.9	0.54
Nitrite (mg N/l)	-	-	-	-	-	-	-	-	0.6	0.4	0.2	0.64	0.43
Soluble Orthophosphate (mg P/l)	8	8.6	8	5.8	5.1	6.4	4.6	3.7	7.0	4.5	3.3	2.8	2.3
Total Solids (mg/l)	310	286	299	324	370	374	408	394	-	-	-	-	-
Alkalinity (mg/l $CaCO_3$)	186	191	193	196	212	199	212	194	144	164	144	190	224
pH	7.6	7.8	7.7	7.5	7.6	7.9	8.1	7.9	6.9	6.9	7.1	7.3	7.4
Temperature (°C)	11	12	13.5	13	14	17	18	18	13	12	14	15	16.5
Calcium (mg/l Ca)	44.2	41.8	44.2	53	59	62	93	78	-	-	111	128	-

*Data provided by M. Grimes, Operator.

**Based on samples collected once or twice per month, except January through March 1979 which were based on approximately weekly samples.

Dash (-) indicates data not available.

near Lancaster, California is a full-scale demonstration project to document the economics and feasibility of reclaiming domestic wastewater for recreational use in a semi-arid area. Brandt and Kuhns (3) reported the results of the investigations of the project which had been shown to be promising as fishing and boating assets based on a pilot-scale project (Los Angeles County Department of County Engineer (4)). There was, however, an initial problem in the lakes with a fish kill due to high ammonia levels and elevated pH related to algal growth. This problem in the Apollo lakes was remedied by altering water circulation, and operating the secondary treatment oxidation ponds to achieve as low an ammonia concentration as possible. The latter was accomplished by storing excess oxidation pond waters during the warm autumn months, with treatment and release during colder months. No further problems of this type were experienced. The planted fish, including the rainbow trout, reproduced and survived year-round; bottom water in all three lakes remained oxic during the 1972 12-month monitoring study.

A problem with fish wholesomeness was encountered when it was determined that a trout which had been in the lakes for 14 months had mercury concentrations in its flesh of 2 mg/kg, which was well above the 0.5 mg/kg FDA allowable limit. Upon further investigation, other trout were found to have similar levels of mercury, so that all fish had to be destroyed. The mercury appears to be from natural sources (the sediments of the region) rather than from any pollution source. The Los Angeles County Sanitation District is now maintaining a put-and-take trout fishery in the lakes rather than maintaining a self-sustaining fishery. The trout do not stay in the lakes for more than a few weeks before they are caught; therefore, they do not accumulate excessive mercury within their flesh.

In terms of aquatic plant growth, objectionable amounts of the aquatic plant Zannichellia, filamentous algae - Spirogyra, and Anabaena were produced which formed rotting mats in the lakes (Brandt and Kuhns (3)). Most profuse growths of Zannichellia occurred in July and October and were especially noted in more shallow areas and in areas more protected from the wind. Chlorella and Chlamydomonas were the most common planktonic algae found. Overall, however, the water quality of these lakes has been acceptable and public response has been very good. Mr. Kuhns (personal communication to G. Fred Lee) indicated that the only real problem they are now having with the Apollo Lakes is the build-up of dissolved solids concentrations due to evaporation. As the result of the fact that this is a highly arid-desert region, there is need to discharge waters from the lakes in order to eliminate or at least reduce the rate of salt build-up.

Indian Creek Reservoir

Indian Creek Reservoir (ICR), located near Lake Tahoe in Alpine County, California, was designed to retain the treated domestic wastewaters from the South Tahoe Public Utility District (STPUD) during the winter and to release water for irrigation during the summer, redirecting the water so it would not enter Lake Tahoe. Since its completion in 1968, this 160 acre (65 hectare), 3.9 x 10^6 m^3 reservoir has also become an important recreational asset to the county, providing a trout fishery and boating opportunity. Trout of various ages are regularly stocked in the lake; those which are not caught generally survive the winter (Wood (5)).

It has been estimated (Wood (5)) that in 1974, 70% of ICR water was treated domestic wastewater. The primary water quality problem encountered in this waterbody has been the periodic fish (trout) kills which, according to Wood (5) have occurred since the formation of the reservoir. They have been both local and expansive and have occurred primarily in the early spring and summer. The trout kills have been largely attributed to high concentrations of un-ionized ammonia induced by elevated pH values resulting from algal growth in the reservoir. Wood (5) suggested that there should be no problem of ammonia toxicity if the total ammonia levels in the reservoir were kept below 3 mg/l. According to Cofer (6), there has not been a reported fish kill in ICR since 1977.

There was a fish kill in ICR during the first year after an ice cover formed on the reservoir which resulted in oxygen depletion. The reservoir is now aerated to, among other things, control the ice cover (Porcella et al. (7)).

Wood (5) reported that there have always been extensive growths of aquatic plants in Indian Creek Reservoir. As of his writing, there were Chlorophyta, Cyanophyta, Chrysophyta, and Englenophyta groups present. Massive growths of Oscillatoria were observed in 1970 which caused fish flesh tainting and earthy odors in the area (Wood (5)).

From an overall point of view, Indian Creek Reservoir is providing a valuable recreational asset to the area. However, there are severe water quality problems associated with eutrophication of this waterbody which have caused fish kills during spring algal blooms and tainting of fish flesh during the summer.

Comanche Station and Others

Black & Veatch (2) cited the Public Service Company of Oklahoma (PSO) Comanche Station as the only facility known to them where a cooling pond is supplied solely by treated domestic wastewater treatment plant effluent. They indicated that the cooling pond waters are characterized by high pH, especially during the summer, and high nutrient, alkalinity, and total dissolved solids concentrations. Calcium carbonate scaling in the condenser tubing at the station is reported by them to be significant and to be causing operational problems.

The authors (Lee and Jones) have discussed the Comanche Station situation with P. Allison, plant superintendent. He indicated that the principal water quality problems were those of dislodging of attached algae and macrophytes which clog the intake works for the power plant cooling water. Mr. Allison also indicated that they have discontinued recreational use of the cooling pond because the public would not stop littering the area.

Summary of Water Quality Problems

A limited amount of information is available on water quality characteristics of recreational and/or cooling water waterbodies for which the principal source of water is domestic wastewater. It appears, however, that the major problems relate to aesthetics, and fish toxicity and wholesomeness. Because the wastewaters are rich in aquatic plant nutrients these waterbodies tend to be highly productive, to the extent that nuisance algal growths appear. These growths can not only be aesthetically displeasing but also result in tainted fish flesh. In a number of instances the high load of ammonia in conjunction with algal growth-induced pH increases has caused un-ionized ammonia toxicity to fish.

Phosphorus, nitrogen, and carbon are the three major aquatic plant nutrients; in waterbodies suitable for recreation, it is generally phosphorus which limits the maximum planktonic algal biomass produced. This means that for the light available, algal biomass increases until the supply of phosphorus is no longer sufficiently available to the algae; if more available P were added to the water, more algae could be produced. Similarly, if the load of P to the water were reduced by a sufficient amount, less algal biomass could be produced. From the composition of the domestic wastewaters from the city of Fort Collins presented in Tables 2 and 3, it appears that without further treatment there will undoubtedly be problems associated with excessive algal and macrophyte growth based on the level of aquatic plant nutrients being introduced. These domestic wastewaters, as is typical, contain about 1,000 times more phosphorus than is necessary to grow excessive amounts of algae in a lake or impoundment. As discussed by Lee et al. (8), however, it is not possible as a rule to set numeric standards for the concentrations of P in the target waterbody or in input waters because the extent to which planktonic algae utilize a P load is dependent on a variety of factors besides P load. The approach that has become recognized as the reliable approach for assessing and developing control programs for eutrophication was that developed through the OECD (Organization for Economic Cooperation and Development) Eutrophication Study Program. This work emphasized that one should proceed to assess eutrophication-related water quality based on parameters characteristic of waterbody response to nutrient loads and parameters to which people can respond, such as planktonic algal chlorophyll concentration ("greenness"), Secchi depth (water clarity), maintenance of oxygen in the hypolimnion in the waterbody, etc. (Rast and Lee (9); Jones and Lee (10)). In the case of the Rawhide cooling impoundment, the primary consideration must be given to planktonic algal chlorophyll and Secchi depth. In an impoundment such as the Rawhide cooling impoundment in which there is expected to be a limited amount of inorganic turbidity due either to stirring of the sediments into the water column or addition of erosional material to the waterbody from tributaries, these relationships would be expected to hold true.

The OECD Eutrophication Modeling Approach

About seven years ago a five year study was undertaken under the auspices of the Organization for Economic Cooperation and Development (OECD) to investigate the relationships between the nutrient (P) load to a waterbody and the waterbody's planktonic algal - related water quality response. Vollenweider (11)(12), based on a limited number of waterbodies, had found that there was a relationship between the coupling of areal annual P load to a waterbody with its morphologic and hydrologic characteristics, and the relative, qualitative recreational use suitability of the waterbody. He had also defined a quantitative relationship between the P load normalized by mean depth and hydraulic residence time, and the mean chlorophyll concentration. In the OECD eutrophication study, the data base with which to evaluate these concepts was greatly expanded; load and response information was collected for about 200 waterbodies located in 22 countries in Western Europe, North America, Japan, and Australia. A synthesis report discussing the relationships between nutrient load and response for the 34 US OECD waterbodies has been published by the US EPA (Rast and Lee (9)).

Using the concepts originally developed by Vollenweider (11)(12)(13) and the US OECD data, Rast and Lee defined correlations between the P load to a waterbody normalized by the waterbody's mean depth and hydraulic residence time, and mean summer chlorophyll for the US OECD waterbodies. They also extended this concept to develop a correlation between the normalized P load and mean summer Secchi depth (water clarity), and hypolimnetic oxygen depletion rate.

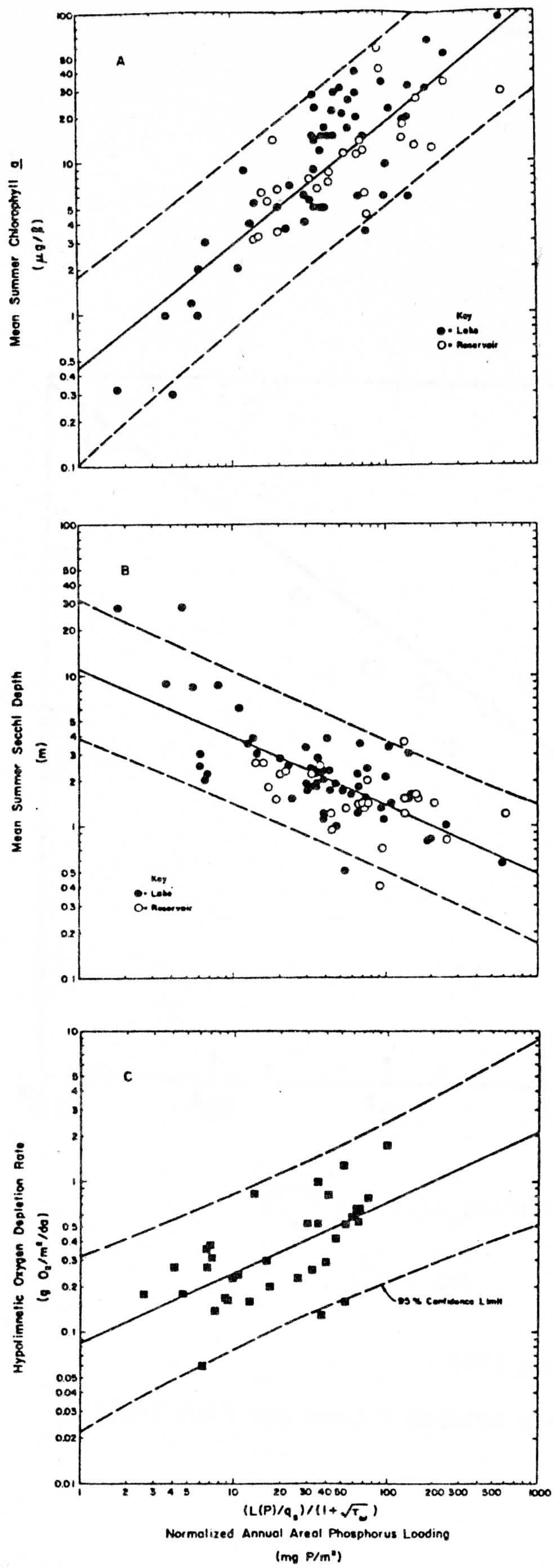
Subsequent to completion of the Rast and Lee report, it has been found that the non-US OECD waterbodies have essentially the same load-response correlations as the US OECD waterbodies. Further, Lee and his associates have evaluated this approach for an additional approximately 40 U.S. lakes and impoundments (Jones and Lee (10)); these waterbodies also obeyed the same relationships. Figure 2 shows the load-response relationships based on the U.S. waterbodies. Rast et al. (14) have demonstrated the predictive capability of this modeling approach by applying it to waterbodies for which the P load and chlorophyll concentrations were known for both before and after a major P load alteration had taken place. They found for the 10 waterbodies on which they could find sufficient data, that this modeling approach provided good predictions for management purposes, of the change in chlorophyll that would result from a given change in P load.

Lee and Jones (15) further extended the Vollenweider - Rast and Lee concepts and defined a correlation between normalized P load and fish yield (Figure 3). It is now possible, given a waterbody's P load, mean depth, and hydraulic residence time, to estimate the amount of fish biomass that the system should support based on the amount of primary production. It does not, at this state of development, however, provide information regarding the types or size of the fish. It is possible, however, by using a combination of hypolimnetic oxygen depletion rate and hypolimnion characteristics, to determine if cold water fish could likely be sustained. It is also known, as discussed by Lee and Jones (15), that highly eutrophic waterbodies often support large populations of stunted pan fish, which, while producing large amounts of overall biomass, are less desirable to sports fishermen. Lee and Jones (15) have estimated that in many waterbodies, pan fish are found to have stunted growth when the average summer chlorophyll concentrations are in the order of 30 to 50 μg/l or greater.

A number of ancillary relationships have also been quantified, which are useful in applying the OECD modeling approach. One is the relationship between the summer mean chlorophyll concentration and the summer maximum chlorophyll concentration defined by Jones et al. (16) (Figure 4). It is useful in this context because while the OECD model provides an estimate of the summer mean chlorophyll concentration, it is generally the peak bloom or worst case to which the public responds adversely.

Application of the OECD Eutrophication Modeling Approach to Rawhide Cooling Impoundment

Table 4 presents the various power generation and treatment conditions assumed in applying the OECD eutrophication modeling approach to the Rawhide cooling impoundment. As discussed previously and as shown in Tables 1 and 5, the power generation-irrigation options affect the amount of inflow water as well as the hydraulic residence time of the waterbody. The degree of P removal from the make-up water before it is discharged to the impoundment, which has been considered at no removal and removal to 1 mg P/l, 0.1 mg P/l, and 0.5 mg P/l, affects the P loading rate. Removal of P in domestic wastewater to 1 mg P/l is readily and generally inexpensively accomplished by precipitation of P with iron or aluminum salts. P removal to 0.1 mg P/l represents the state-of-the-art in P removal technology and is considerably more costly to achieve. The design



KEY

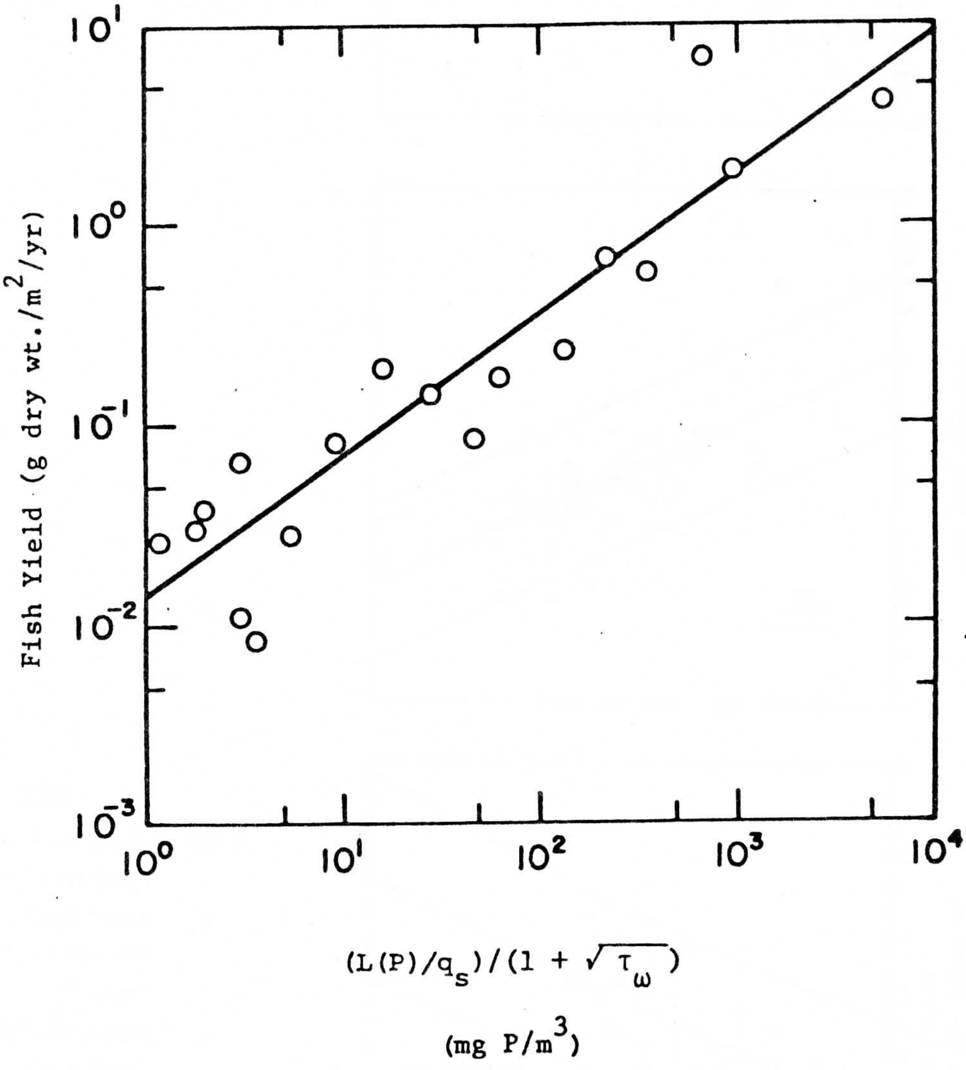
$L(P)$ = Areal Annual Phosphorus Load (mg P/m²/yr)

q_s = Mean Depth ÷ Hydraulic Residence Time = $\bar{z}/\tau_\omega$ (m/yr)

τ_ω = Hydraulic Residence Time (yr)

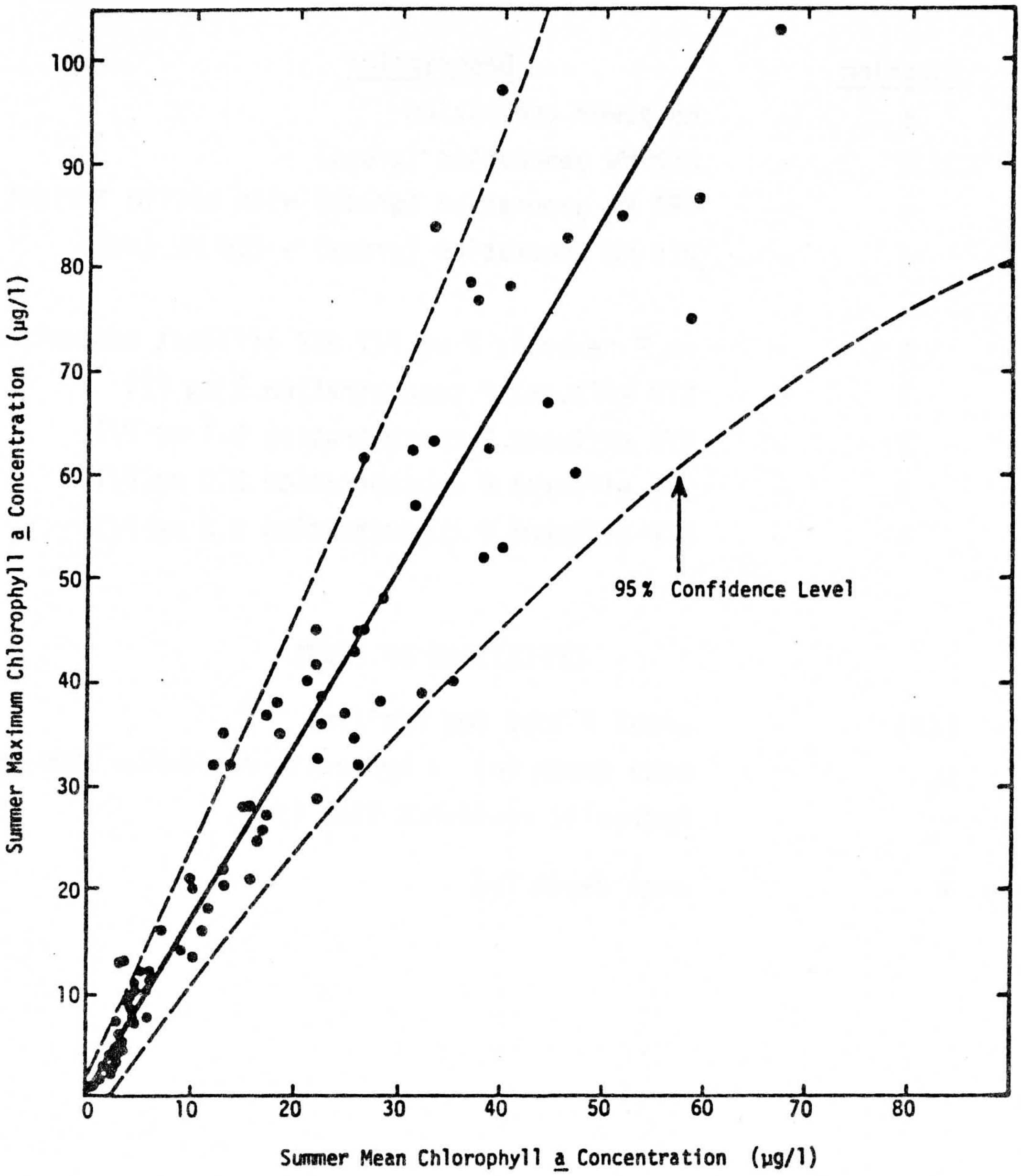
After Jones and Lee (10).

Figure 2. Nutrient Load-response Relationships for U.S. Waterbodies



After Lee and Jones (15).

Figure 3. Relationship between P Load and Fish Yield



After Jones *et al.* (16).

Figure 4. Relationship between Mean and Maximum Summer Chlorophyll a in Surface Waters

Table 4. Description Of Conditions Considered

Notation		Description
a	-	no power generation
b	-	250 MW generation (gross)
c	-	250 MW generation (gross) with onsite irrigation
d	-	279 MW generation (gross) - 250 MW (net)
N	-	no P removal; 7 mg P/l STP effluent concentration
1	-	STP effluent P concentration 1 mg P/l
2	-	STP effluent P concentration 0.1 mg P/l
3	-	STP effluent P concentration 0.5 mg P/l
4	-	STP effluent P concentration 0.2 mg P/l

DEFINITION OF TERMS

L(P)	areal P load (mg $P/m^2/yr$)
q_s	mean depth (m) ÷ hydraulic residence time (yr)
τ_ω	hydraulic residence time (yr)
$\bar{z}$	mean depth (m)

criterion for the Rawhide P removal facility treating the make-up water is 0.2 mg P/l although an attempt will be made to achieve 0.1 mg P/l in the make-up water. In order to quantify the eutrophication-related water quality that could be achieved in the Rawhide cooling impoundment under various P removal scenarios, the OECD eutrophication models were applied.

Table 5 presents the physical and chemical characteristics of the cooling impoundment and make-up water assumed in the modeling. Figure 5 and Table 6 show the predicted summer average chlorophyll concentrations under the various conditions described in Table 4. With no P removal from the make-up water, mean summer chlorophyll concentrations would be expected to be on the order of 225 μg/l based on an extrapolation of the line of best fit shown in Figure 2. At this P loading level, it might be expected that some factor other than P, such as nitrogen or light, would be limiting algal biomass within the impoundment. If the P concentration in the make-up water were reduced to 1 mg P/l, mean chlorophyll concentrations would be on the order of 40 to 50 μg/l which is still indicative of poor water quality for essentially all beneficial uses. With P removal to 0.1 mg P/l, mean summer chlorophyll concentrations would be on the order of 6.5 to 8 μg/l. This corresponds to maximum chlorophyll levels of 11 to 13 μg/l.

With make-up water treatment to 0.1 mg P/l, it would appear that eutrophication-related water quality would be generally good, except for the peak bloom periods. Typically any time chlorophyll levels are above about 10 μg/l, people tend to object to some aspect of water quality. With make-up water treatment to 0.1 mg P/l, the Rawhide cooling impoundment would be classified as mesotrophic. In general the generation of power or on-site irrigation would not significantly affect the expected chlorophyll concentrations in the Rawhide cooling impoundment.

It is likely that even if the 0.1 mg P/l treatment level were achieved (design criterion is 0.2 mg P/l), peak algal biomass periods may elicit some complaints about the recreational water quality of the waterbody. However, in comparison to the eutrophication-related water quality characteristics of two Front Range irrigation reservoirs nearby, the expected water quality with P removal to 0.1 mg P/l in the make-up water, would be considered quite good.

As discussed previously, Rast and Lee (9) developed a relationship between normalized P load and Secchi depth (water clarity) for waterbodies in which the only substantial factor interfering with light penetration was planktonic algae. Figure 6 shows that under conditions of no P removal from the make-up water, mean summer Secchi depth would be on the order of 0.3 to 0.4 m (see Table 6). With treatment to 1 mg P/l, Secchi depth would be increased to 0.8 to 0.9 m, and with treatment to 0.1 mg P/l, mean summer Secchi depth would be 2 to 2.5 m. The Rawhide cooling impoundment, with make-up water treatment to 0.1 mg P/l, will have noticeably greater water clarity than other reservoirs of the region. The generation of power and the on-site irrigation would not significantly affect the mean Secchi depth of the waterbody.

Figure 7 and Table 6 show the predicted hypolimnetic oxygen depletion rates for the Rawhide cooling impoundment under conditions of P removal to 1 mg P/l, 0.1 mg P/l, and 0.2 mg P/l, based on the relationship developed by Rast and Lee (9). To translate the oxygen depletion rates into the durations of persistence of oxygen in hypolimnetic waters, estimates had to be made of the hypolimnion volume and dissolved oxygen concentration in Rawhide cooling impoundment at the onset of thermal stratification in the spring. Based on a review of the Black & Veatch (2) pre-

Table 5. Characteristics of Rawhide Cooling Impoundment

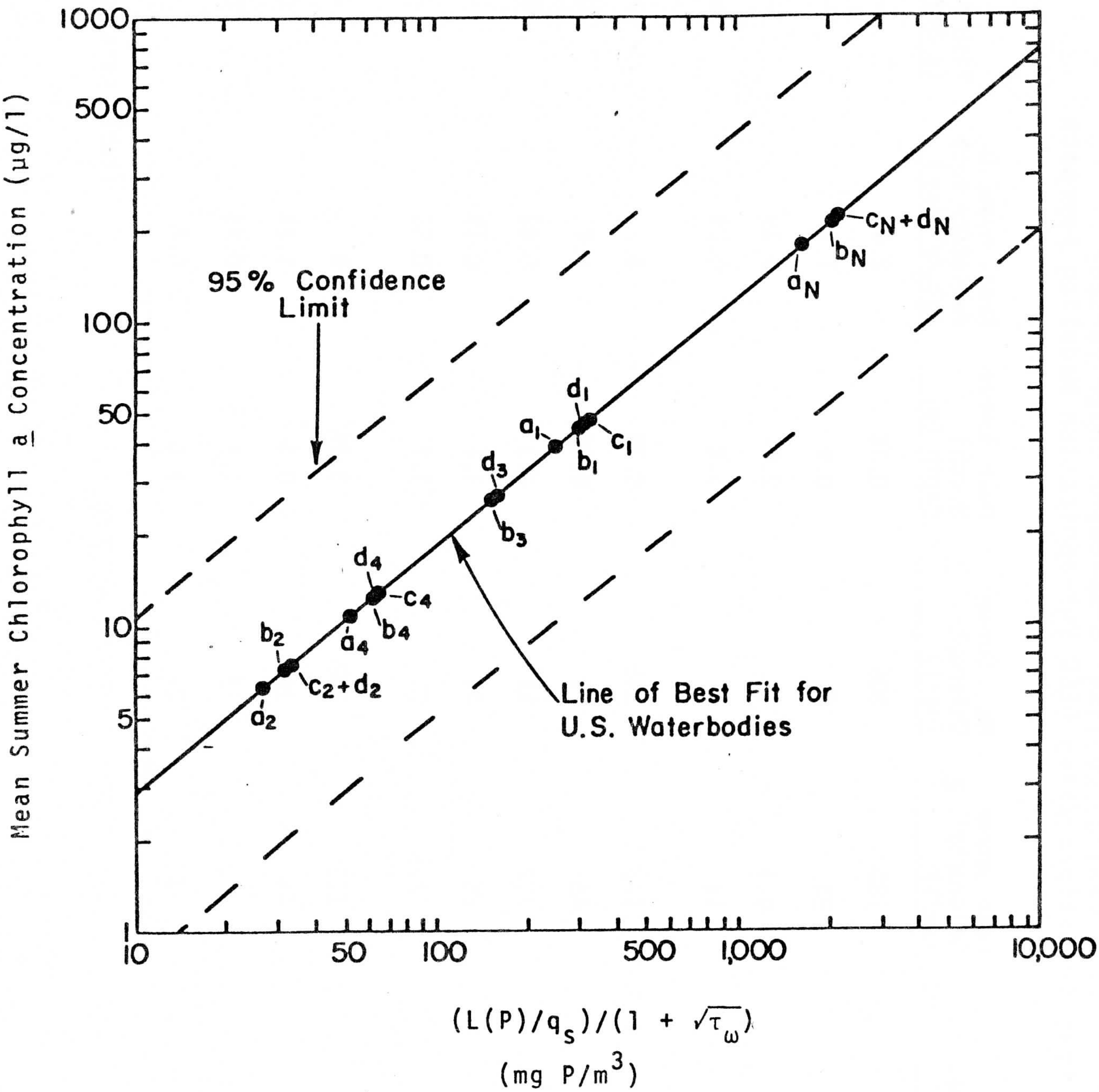
Parameter	Original Units	Metric* Units	Reference
Mean depth	30 ft.	9.1m(9.16 calc.)	(2)
Volume	15,000 acre ft.	1.85×10^7 m^3	(22)
Area	500 acres	2.02×10^6 m^2	(22)
P concentration Make-up water- no treatment	-	7 mg P/l	(23)
Atmospheric P export (per watershed area)	-	0.02 $gP/m^2/yr$	(24)
D.O. at onset of thermocline	-	9.4 mg/l	(25)
For thermocline at 15m: Surface area:	86 acres	3.48×10^5 m^2	
Volume	840 acre ft.	1.04×10^6 m^3	(2)

	Condition** a	b	c	d	
Total inflow (m^3/yr)	3,495,740	5,264,578	5,719,740	5,469,339	(2)
$\tau_\omega(\frac{vol}{inflow})$ yrs	5.3	3.5	3.2	3.4	Calculated
P load (mg P/yr)***					
N	1.93×10^{10}	3.17×10^{10}	3.50×10^{10}	3.32×10^{10}	Calculated*
1	2.80×10^9	4.57×10^9	5.03×10^9	4.78×10^9	
2	3.13×10^8	4.90×10^8	5.36×10^8	5.11×10^8	
3	-	2.31×10^9	-	2.41×10^9	
4	5.90×10^8	9.44×10^8	1.04×10^9	9.85×10^8	

** See Table 5 for description of conditions

*** Black & Veatch (2) inflow (see Table 1); M. Grimes (23) for treatment level STP P concentrations. Atmospheric export coefficient multiplied by lake area.

Dash (-) indicates not applicable or not calculated



See Table 4 for Key

After Jones and Lee (10).

Figure 5. Estimation of Mean Summer Chlorophyll Concentrations in Rawhide Cooling Impoundment

Table 6. Summary Of Water Quality Characteristics Of Rawhide Cooling Impoundment Under Various Load Conditions Using OECD Eutrophication Modeling Approach

Conditions Assumed*	Mean Summer Chlorophyll *a* (μg/l)	Max. Summer Chlorophyll *a* (μg/l)	Mean Summer Secchi Depth (m)	Areal hypol. O_2 depletion rate ($gO_2/m^2/day$)	Fish Yield (g dry $wt/m^2/yr$)
a_N	180	306	0.38	2.6	-
a_1	38	65	0.9	1.1	-
a_2	6.3	11	2.4	0.39	-
a_4	11	19	1.8	0.53	-
b_N	215	366	0.34	3	-
b_1	45	76	0.82	1.2	0.8
b_2	7.2	12	2.3	0.42	0.2
b_3	26	44	1.1	0.89	-
b_4	12.5	21	1.7	0.58	-
c_N	225	282	0.34	3	-
c_1	46	78	0.8	1.25	0.8
c_2	7.5	13	2.2	0.43	0.2
c_4	13	22	1.6	0.6	-

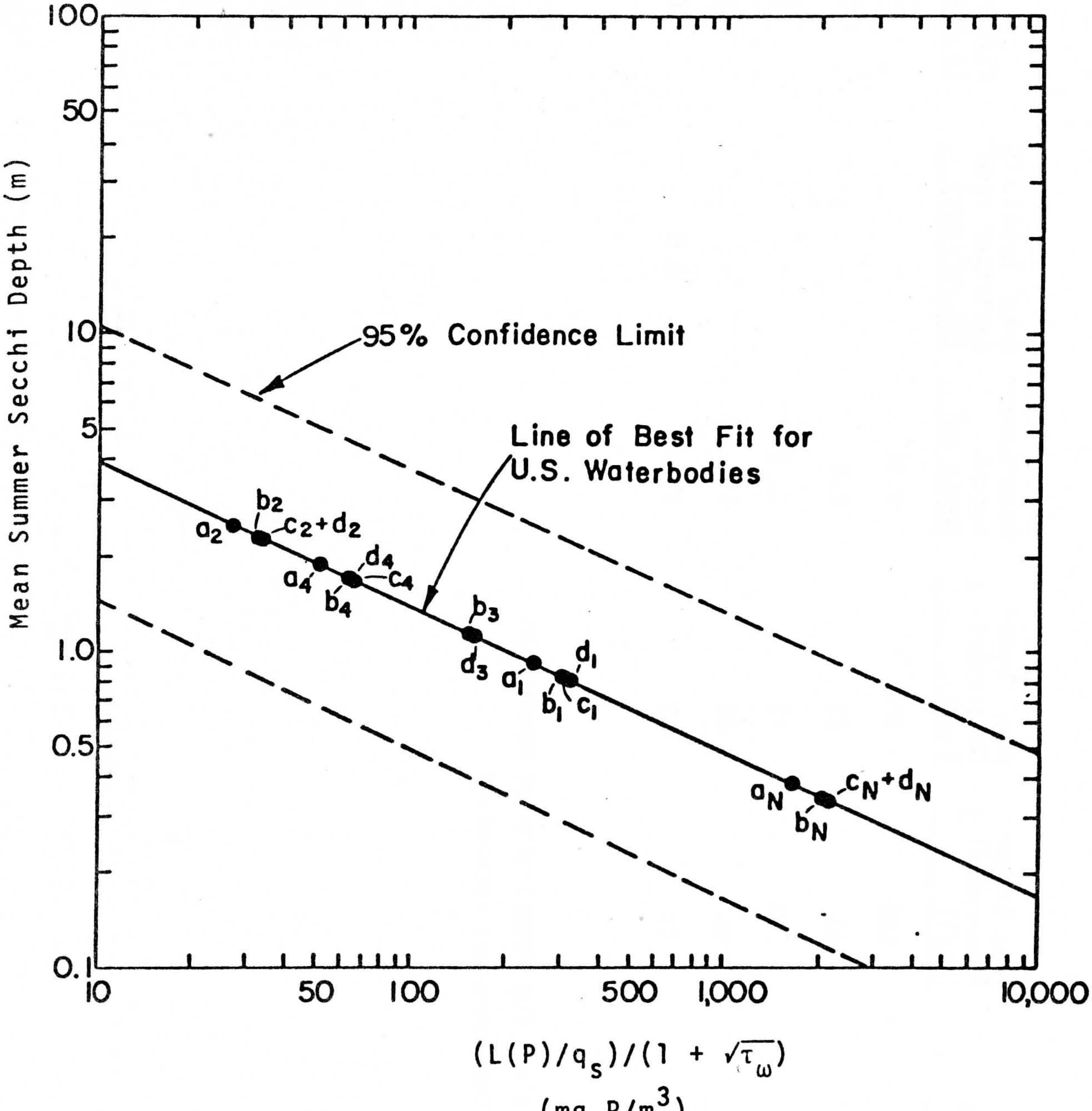
(table continued)

Table 6. (continued)

Conditions Assumed*	Mean Summer Chlorophyll *a* (µg/l)	Max. Summer Chlorophyll *a* (µg/l)	Mean Summer Secchi Depth (m)	Areal hypol. O_2 depletion rate ($gO_2/m^2/day$)	Fish Yield (g dry wt/m^2/yr)
d_N	225	382	0.34	-	-
d_1	47	80	0.8	-	0.8
d_2	7.5	13	2.2	-	0.2
d_3	26	44	1.1	-	-
d_4	13	22	1.65	0.6	0.3

* See Table 4 for description of conditions

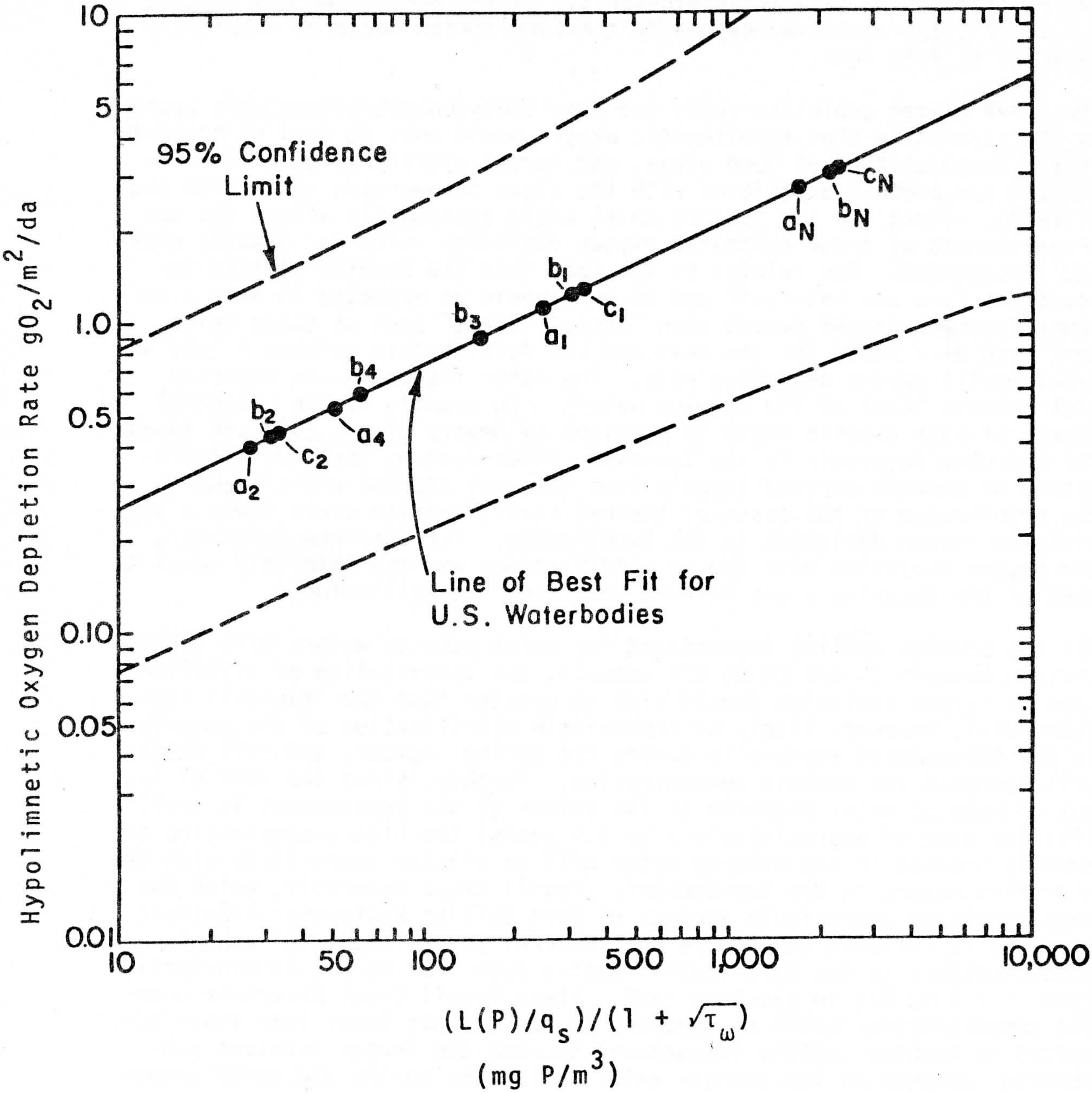
(-) dash indicates not determined



See Table 4 for Key

After Jones and Lee (10).

Figure 6. Estimation of Mean Summer Secchi Depth in Rawhide Cooling Impoundment



See Table 4 for Key

After Rast and Lee (9).

Figure 7. Estimation of Hypolimnetic Oxygen Depletion Rate in Rawhide Cooling Impoundment

dicted thermal structure in the Rawhide cooling impoundment, it appears that under conditions of 250 MW power generation, by mid-April of each year, a thermocline will be developed which will prevent mixing of surface with bottom waters. In the absence of power generation, such as would occur during filling, this was predicted to occur about a month later.

For the purpose of this evaluation, it is assumed that the thermocline will become established on April 15 at the depth of 15 m and that the dissolved oxygen concentration in the hypolimnion will be at 9.4 mg/l, which is saturation for a temperature of 10^{o} C at 5000 ft (1524 m) elevation. If make-up waters are treated to 1 mg P/l, complete depletion of dissolved oxygen in the hypolimnion is estimated to occur by late May if the thermocline sets in in mid-April. If the make-up waters contain 0.1 mg P/l, the dissolved oxygen in the hypolimnion would be completely depleted by late June.

The above oxygen depletion rates and resultant concentrations were based on the assumption that hypolimnetic oxygen would only be used by bacteria in the decomposition of dead algae, and normal nitrification of the organic N and ammonia associated with the algae (conversion to nitrite and nitrate). There are two factors which would appreciably affect the appropriateness of these estimated oxygen depletion rates for Rawhide cooling impoundment. One relates to the fact that the Rawhide cooling impoundment is a new reservoir and as such would be expected to have a much lower sediment oxygen demand than "typical lakes" such as those which were used as a basis for the Rast and Lee relationship between P load and hypolimnetic oxygen depletion rate. The other factor is the expected high ammonia level of the make-up waters. An example of the potential impact of high ammonia input is provided by Newbry et al. (17) who found for Cherokee Reservoir in the Tennessee River system, that the nitrification of ammonia derived largely from external sources and present in the hypolimnion at the onset of thermal stratification could cause a significant oxygen depletion in the hypolimnion. For Cherokee Reservoir, the oxygen depletion rate due to nitrification was approximately equal to that of the decaying algae raining down from the epilimnion.

For the Rawhide cooling impoundment, for which make-up waters will likely contain between 15 and 20 mg N/l ammonia, the contribution of nitrification to oxygen depletion should also be greater than the "typical" lake. There will, however, likely be appreciable nitrification of the ammonia in the impoundment especially during the spring, summer, and fall which will decrease the ammonia concentration. Further, since the rate of input of make-up water compared to the volume of the impoundment is small (filling time of approximately 3 to 3.5 years) the high concentration of ammonia present in the make-up water will be diluted appreciably with the nitrified waters in the impoundment. Fossil Creek Reservoir, which has been receiving appreciable amounts of Fort Collins Wastewater Treatment Plant No. 2 effluent during the past several years, had total ammonia concentrations in its hypolimnion ranging from 0.27 mg N/l in mid-April 1980 to 1.7 mg N/l in mid-June 1980. These Fossil Creek Reservoir ammonia concentrations would be expected to be somewhat lower than those expected in Rawhide cooling impoundment because the former receives substantial amounts of low ammonia water during the spring and early summer.

It is expected that the BOD (biochemical oxygen demand) added to the impoundment from the wastewater treatment plant effluent would have a minimal impact on the hypolimnetic oxygen depletion rate because of the high degree of BOD removal achieved at the Fort Collins Wastewater Treatment Plant No. 2.

While the estimates of hypolimnetic oxygen depletion rate made above are in general somewhat crude, it is clear that the hypolimnetic waters of the Rawhide cooling impoundment will become anoxic during each summer. This will, without hypolimnetic aeration, limit the possibility of developing a cold water fishery in this waterbody because of elevated temperatures expected in the epilimnion (21 to 23^{o} C, Black & Veatch (2)). Further, as discussed in a subsequent section, anoxic hypolimnetic conditions could lead to hydrogen sulfide production in the hypolimnion through sulfate reduction.

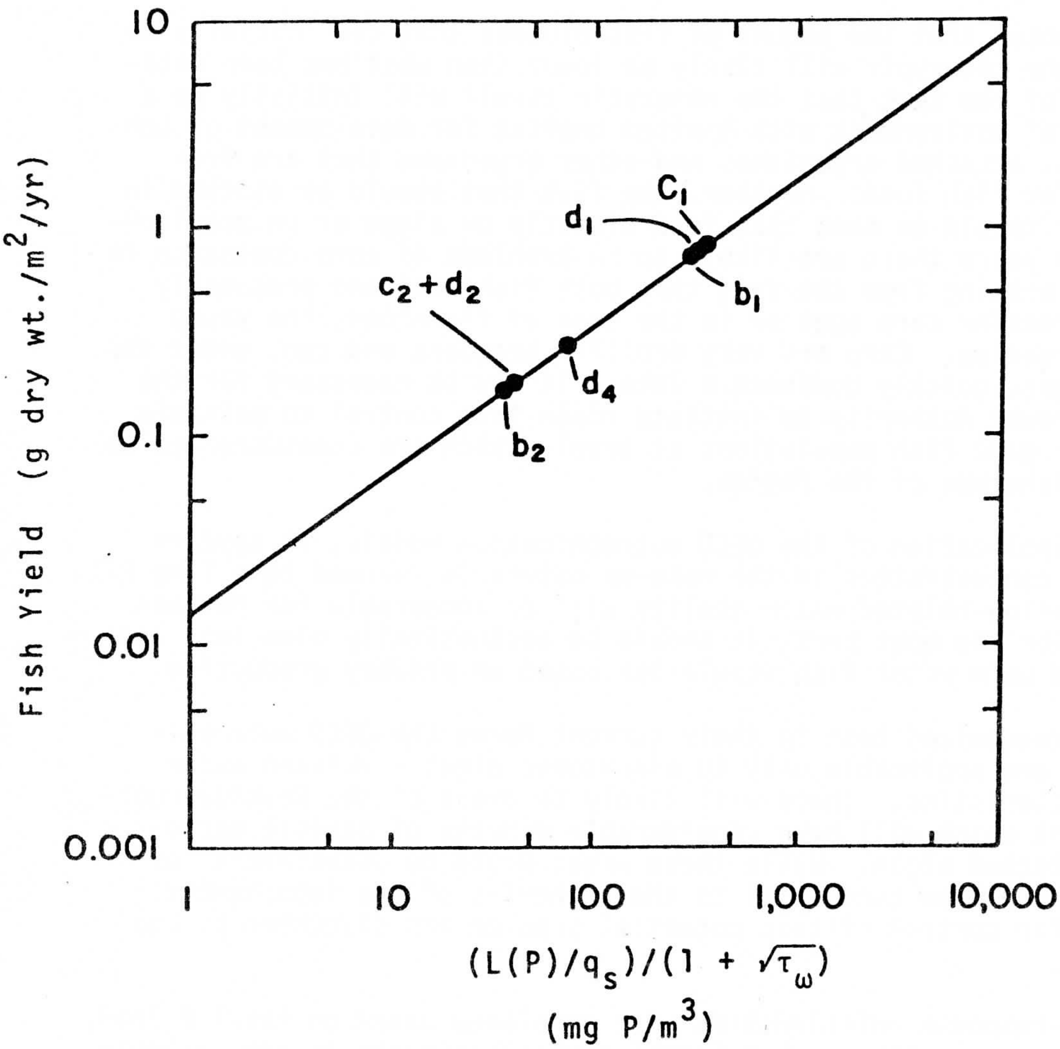
The final eutrophication-related water quality indicator of concern in the Rawhide cooling impoundment for which predictions can readily be made, is the overall fish yield that can be sustained in the impoundment. Figure 8 shows that based on the nutrients available, the waterbody could develop a good warm water fishery with make-up water P concentrations between 0.1 mg P/l and 1 mg P/l.

It should be noted that the amount of fish biomass that can initially be sustained in the reservoir will likely be lower than what has been estimated because of the fact that the reservoir itself will initially be a rather "sterile" environment with limited habitat for development of benthic organisms, attached organisms, and other organisms that are frequently used for fish food. Further, the fish that should be stocked in this reservoir should be ones that feed directly on algae or on zooplankton. In a few years there are likely to be problems of carp dominance in the waterbody arising from the fact that both fishermen and presumably birds would transfer carp eggs or in the case of fishermen, the young carp, to waterbodies. Carp are very prolific breeders and can, under the right conditions, quickly dominate a lake. It may be necessary for the Platte River Power Authority to initiate rough fish control to maintain the warm water game fish populations at levels which are considered to be optimum for fishermen of the region.

Based on the application of the OECD eutrophication models, it appears that if the P concentration in the make-up waters is reduced to 0.1 mg P/l, the eutrophication-related water quality will be acceptable for recreational use. For the most part, it should be aesthetically pleasing, and support a good warm water fish population based on primary production.

It should be recognized that in their current forms the OECD eutrophication models are applicable only to planktonic algal - related water quality characteristics. There will likely be areas of the Rawhide cooling impoundment which will have considerable growths of aquatic macrophytes and attached algae. While these areas would be undesirable for boating, they would be beneficial to the fisheries of the impoundment. Alternatives for control of this potential problem are discussed by Lee and Jones (1).

The OECD load-response relationships were developed based on total P load. They have inherent in them a normalization which accounts to some extent for the fact that only a portion of the total P load to a waterbody is in forms which are or will become available to stimulate algal growth. The P load-response calculations made herein for the Rawhide cooling impoundment were based on the assumptions that the percent available P entering the cooling impoundment was similar to that for the waterbodies upon which the relationships were based, and that the P removal scenarios will cause more or less consistent reductions in the percent available P. The make-up waters for the Rawhide cooling impoundment will contain phosphorus of a markedly different form and ratio between available P and total P compared to most of the OECD eutrophication study waterbodies; there will



After Lee and Jones (15).

Figure 8. Relationship between Phosphorus Load and Fish Yield and Predicted Fish Yield for Rawhide Cooling Impoundment

likely be a slightly different relationship that will prevail between the total phosphorus load and the algal biomass as measured by Secchi depth and chlorophyll concentration. The treatment of domestic wastewaters for P removal to 1 mg P/l removes large amounts of available P. Lee et al. (18) have pointed out that domestic wastewaters which have been treated for phosphorus removal (to 1 mg P/l) have the remaining phosphorus largely in the form of either iron or aluminum hydrous oxide floc (depending on which of the metals is used as the precipitating agent). It is likely that this phosphorus is unavailable or less readily available to support planktonic algal growth. This means that the typically very expensive filtration of the effluent to decrease the total P concentrations beyond 1 mg P/l to 0.1 mg P/l may not result in an improvement in eutrophication-related water quality beyond that predicted for 1 mg P/l, as it is removing unavailable P forms. It also means, however, that P removal to 1 mg P/l may have the same impact on eutrophication-related water quality as that calculated for 0.1 mg P/l, since the treatment renders less available, P remaining after treatment.

At this time the algal availability of iron and aluminum hydrous oxide floc - associated P is not well known. The impact of using the correlations between P load and response developed for U.S. waterbodies, for a waterbody receiving 100% treated domestic wastewaters is also not known although it is expected that these correlations provide adequate accuracy for management decisions to be made. Studies are needed to determine for situations such as this, the value of using the ultimate "state-of-the-art" in sedimentation and filtration for removal of this particulate phosphorus.

Eutrophication-Related Water Quality Criteria for Rawhide Cooling Impoundment

For any waterbody for which there are multiple beneficial uses, such as Rawhide cooling impoundment, the selection of the "ideal" eutrophication-related water quality characteristics (such as Secchi depth or planktonic algal chlorophyll concentration) is difficult. Generally the recreational users would like to have the clearest water possible, i.e., have as few planktonic algae as possible, yet have a highly productive waterbody which would support a wide variety of rapidly growing pan fish. As was discussed previously in this report, these two concepts are to some extent mutually incompatible. The primary production of a waterbody is dominated in most cases by the planktonic algal biomass which grows to the extent possible based on the loading of the limiting nutrient, usually P. This biomass, in turn, serves as food for zooplankton, which are both consumed by fish in the normal aquatic trophic food web. Within limits, the more phosphorus, the more algae, the more fish. Therefore, since the Rawhide cooling impoundment will be used for boating-aesthetics where water clarity would be a primary desirable quality, and fishing where fish growth rate would be important, it is necessary to choose a compromise in establishing the "ideal" water quality characteristics in the waterbody. Based on the experience of the authors as well as others, it is thought that summer average planktonic algal chlorophyll concentrations in the 5 to 10 mg/l range, corresponding to average Secchi depths on the order of 2 to 3 m, represent acceptable water quality and yet still will allow production of a moderate biomass of rapid growing fish.

It is important to reemphasize that "water quality" assessment for recreational uses is highly subjective, depending on the public's response to a particular waterbody. This response is conditioned by many factors, such as the availability of other waterbodies in the region with "higher" water quality, social conditioning, the particular recreational pursuit that the public wishes to undertake, and alternative waterbodies allowing that use. A sport fisherman who wants to catch a large number of pan fish might find a "pea soup" green water perfectly acceptable, while someone who is more interested in the overall aesthetic qualities of a waterbody would find that "pea soup" water somewhat objectionable. In the case of the Colorado Front Range, there are a few waterbodies which have good warm water fisheries. Almost none of these, however, would be judged to have good aesthetic water quality. Since it is possible with the Rawhide cooling impoundment to design water quality to some extent, it is felt that an overall water quality which is on the edge of being occasionally objectionable to some individuals who might focus on aesthetic quality, is probably the right blend between the fishermen who desire the production of game fish, and the avoidance of obnoxious algal blooms which would even be a deterent to fishing.

With respect to the fisheries-related water quality, it should be noted that the Rawhide cooling impoundment is going to be approximately 25 miles from the population centers at Fort Collins and Loveland. Located within these centers is Horsetooth Reservoir, which has a very high aesthetic water quality. It is likely that those who will recreate at the Rawhide cooling impoundment will in general be die-hard fishermen, rather than those interested in just boating. The Colorado Front Range boaters will probably go to Horsetooth Reservoir, since water skiing and other water contact sports will not be allowed in the Rawhide cooling impoundment because of potential public health problems and the liability of the Platte River Power Authority in the event that any user of this water should contract a waterborne disease. The Fort Collins water skiers will also continue to use Fossil Creek Reservoir and Timnath Reservoir through their ski clubs, or Horsetooth Reservoir during the warm parts of the summer. Rawhide cooling impoundment will likely also serve as an important overall recreational asset for the people in south central Wyoming.

FISH TOXICITY

Introduction

The second major concern with regard to water quality in Rawhide cooling impoundment is the toxicity of components of the make-up water or recycle water, or their transformation products, to fish in the impoundment. Ammonia, nitrite, and chlorine are the three chemicals of greatest potential water quality significance in this regard.

Ammonia

Ammonia exists in aquatic systems in two different forms, un-ionized ammonia (NH_3), and the ammonium ion (NH_4^+). The un-ionized form is highly toxic to fish; the ammonium ion is not. The distribution of the total ammonia ($NH_4^+ + NH_3$) between these two species in a water is primarily dependent on the pH and the temperature of the water. The higher the pH and the higher the temperature, the greater the percentage of un-ionized ammonia. Chronic (generally life-time or critical life stage) exposure safe concentrations of un-ionized ammonia for warm water fish are generally considered to be on the order of 50 µg/l NH_3. Many fish can survive for extended periods of time in water containing a few tenths of a mg/l un-ionized ammonia, but such exposure, while not acutely lethal, is likely to be adverse to fish growth, overall health, resistance to disease, etc. Fish are known to be able to acclimatize to higher levels of un-ionized ammonia, and apparently grow and reproduce in waters having concentrations considerably above those which have been found to be adverse to fish under laboratory conditions. At this time the concentration - duration of exposure - adverse impact relationships for ammonia are poorly defined.

Typical domestic wastewaters contain on the order of 20 mg N/l of total ammonia. The waters which Fort Collins will provide to the Platte River Power Authority will likely have concentrations of total ammonia in this order of magnitude. This level is somewhat higher than that indicated in Table 3 for 1980, as a result of the fact that the Fort Collins Wastewater Treatment Plant No. 2 is achieving partial nitrification of the wastewater. The water provided to the PRPA will not likely be treated to the same degree. In natural waters, ammonia is nitrified (converted to nitrite by the bacterium Nitrosomonas and then to nitrate by the bacterium Nitrobacter) under oxic conditions. It is therefore expected that the approximately 20 mg/l of total ammonia added in the make-up water will result in an ammonia concentration in the cooling impoundment considerably lower than that amount. There is a possibility of appreciable ammonia build-up over the winter as was found in Indian Creek Reservoir, however, since the rate of conversion of ammonia to nitrite is considerably slower during colder weather. While it is impossible to accurately predict the total ammonia concentrations that will be present in the Rawhide cooling impoundment, it is estimated by the authors that they will be on the order of 0.5 to 2 mg N/l at various times during the year. This is consistent with the concentrations of total ammonia found in Fossil Creek Reservoir during the early to mid-summer 1980. It should be noted, however, that with the increased pH and temperature associated with periods of rapid algal growth and high biomass in the spring and summer, the un-ionized ammonia concentrations in the Rawhide cooling impoundment could become sufficiently great so as to be toxic to fish. For example, as discussed in a previous section, Indian Creek Reservoir, which receives the treated domestic wastewater effluents from South Lake Tahoe, California has periodically had fish kills which have been attributed to the high concentrations of un-ionized ammonia arising from photosynthetic algal-induced pH increases. Similar problems have been encountered in other impoundments such as the Apollo Project impoundments, filled primarily with domestic wastewater treatment plant effluents.

Black & Veatch (2) predicted, using an unverified deterministic model, that the maximum - month un-ionized ammonia concentration in Rawhide cooling impoundment would be 0.3 mg/l when 2-stage phosphate removal is practiced. This means that according to this model output, there could be fish toxicity problems in the Rawhide cooling impoundment due to ammonia.

In the Indian Creek situation it appears that the ammonia problem can be solved by short-term measures such as temporarily removing ammonia. Since year-round ammonia removal might not be needed for the Rawhide cooling impoundment, it is felt that it would be better to postpone any decisions regarding ammonia removal by PRPA until a better assessment can be made of the potential for an ammonia problem in its cooling impoundment.

Nitrite

Another nitrogen species which could cause fish toxicity problems in the Rawhide cooling impoundment is nitrite. Nitrite is the intermediate product in the nitrification of ammonia to nitrate. The activity of the Nitrobacter which mediate the conversion of nitrite to the non-toxic nitrate, is highly temperature dependent. There is therefore a potential to have a build-up of nitrite in the cooling impoundment waters especially during colder weather from the partial nitrification of the ammonia in the make-up waters. Depending on the operation of the Fort Collins Wastewater Treatment Plant No. 2, the make-up waters themselves may contain substantial amounts of nitrite. In the late spring through early summer 1980, nitrite concentrations in the Fort Collins Wastewater Treatment Plant No. 2 effluent ranged from 0.2 to 0.65 mg N/l. These values are likely to be higher than those which would be in the Rawhide make-up water since the treatment plant was partially nitrifying its effluent during this period. Nitrite concentrations in Fossil Creek Reservoir during this period of time ranged from 0.05 to 0.21 mg N/l.

It appears that concentrations of nitrite above a few tenths of a mg N/l would be chronically toxic to some forms of aquatic life. At the present time there is insufficient information available to determine the critical concentrations of nitrite to warm water fish.

As in the case of ammonia, it is unclear whether or not nitrite will be a problem in the Rawhide cooling impoundment. It should be closely watched as part of the monitoring established for this waterbody. If the concentrations exceed a few tenths of a mg/l as N then studies should be conducted to determine the potential significance of the nitrite levels to the fish in the impoundment.

Chlorine

The use of chlorine to eliminate condenser tube fouling in the electric generating station introduces a toxicant into Rawhide cooling impoundment which could have an adverse impact on its fisheries. According to Black & Veatch (2), the Rawhide electric generating station will practice shock chlorination for 20-to 30-minute periods, two to three times a day. The impact of this widely accepted practice of shock chlorination used in electric power generating stations on fisheries is unknown at this time.

Chlorine, both in its elemental state and combined state in the form of chloramines, is highly toxic to fish. While Black & Veatch (2) did not indicate the level of chlorine that would be present in the discharge waters, it is likely to be on the order of a few tenths of a mg/l Cl. Chronic exposure safe concentrations for fish are on the order of 5 µg/l Cl. The rapid dilution that will occur almost immediately after discharge of the condenser cooling waters to the cooling impoundment, should significantly reduce the chlorine concentrations in the vicinity of the discharge to values which are not acutely toxic to fish. Even so, however, there is a potential for chronic toxicity, especially if there tends to be appreciable shortcircuiting between the condenser intake and discharge waters.

The Rawhide situation will be somewhat different from most other electric generating stations with regard to chlorine because of the fact that the waters will likely contain large amounts of ammonia which result in chloramine formation especially under winter conditions. The chloramines are substantially more stable - persistent than free (elemental) chlorine. It is possible that even with the intermittent nature of the chlorine additions, there might be an appreciable part of the waterbody which has chloramine concentrations in excess of those which have been found to be harmful to fish.

Fish behavior can also affect the impact of chlorine on water quality. It is well-known that fish tend to avoid areas having high levels of chlorine, and at least in the case of chlorination of sea water used for once-through cooling in electric generating stations, even slightly elevated levels of chlorine as well. Since the elevated chlorine concentrations in Rawhide cooling impoundment will be somewhat localized, it is possible that fish would tend to avoid the cooling water discharge area because of their avoidance reaction to chlorine. Fish are also known to avoid heated effluents in the summer, but they are attracted to them in the winter. While under summer chlorinating conditions the fish would tend to avoid both the chlorine and the heat in the effluent, in the winter they would tend to be attracted to the heated waters but repelled by the chlorine. The net result of this avoidance and attraction is unknown.

FISH WHOLESOMENESS

The third area that must be considered in connection with the Rawhide cooling impoundment's water quality, is the wholesomeness of the fish that are caught for use as food. A number of parameters which have caused the greatest environmental concern are those whose impacts are manifested through bioaccumulation-bioconcentration in fish to the point where the fish have an off-flavor or are rendered unsuitable for use as human food because of the contaminant concentration. PCBs, DDT, mercury, cadmium, kepone, and myrex are examples of chemicals which can cause problems of this type. These and similar chemicals are known to be present in some domestic wastewaters. However, some of these chemicals will be removed from the cooling impoundment make-up water during the chemical precipitation for P removal.

It is mandatory in any program designed to assess fisheries-related water quality, that representative samples of the fish be collected from the waterbody periodically, i.e., about twice a year, and the edible flesh analyzed for those contaminants for which the FDA (Food and Drug Administration) has established tolerance limits. These include mercury, cadmium, a number of chlorinated hydrocarbons such as DDT, kepone, and PCBs. The FDA has not yet established a tolerance limit for cadmium. There are some general guidelines, however, which can be used as an indication of potentially excessive amounts of cadmium in fish. The overall quality of the fish flesh with respect to taste should be assessed by discussions with fishermen who make extensive use of the fish derived from the cooling impoundment as food. If off-flavored fish are being frequently encountered, then attempts should be made to determine the cause of the off-flavors.

OTHER POTENTIAL WATER QUALITY PROBLEMS IN RAWHIDE COOLING IMPOUNDMENT

Dissolved Gas Supersaturation

A problem encountered in some electric generating station cooling ponds is related to supersaturation of the cooling water discharge with dissolved gases, especially nitrogen. This condition can lead to embolism ("the bends") in fish. It is not expected that this would be a problem with the Rawhide cooling impoundment because of the design of the cooling water intake and discharge which allows for rapid mixing of the discharge waters with the surface waters of the waterbody.

Mechanical Harvesting

The passage of water through the pumps and condenser tubes in an electric generating station results in the destruction of larval fish, fish eggs, fish food organisms such as zooplankton, etc. The amount of kill depends on the design of the system; it is typical that on the order of 5 to 15% of the organisms passing through the condensers are killed. A substantial part of this kill is due to mechanical damage rather than the heat in the cooling water. The impact of this "mechanical harvesting" on the fisheries in the waterbody is, at this time, difficult to predict. It is generally thought that such "harvesting" does not significantly impact the fisheries of a waterbody and that significant adverse impacts can be readily compensated for by stocking of the reservoir with additional fish.

Dissolved Solids Build-up

According to the Black & Veatch (2) model, the total dissolved solids concentration in the Rawhide cooling impoundment will increase over the first approximately 10 years of operation until an equilibrium is established. This will occur because one of the impoundment operation modes does not allow any discharge of water. According to Black & Veatch, the conservative dissolved solids concentration will have reached about 1400 mg/l, about 90% of the theoretical maximum, in this 10 year period. It is unclear from their calculations, however, whether or not they took into account the fact that calcium carbonate precipitation would likely be occurring before the equilibrium salt build-up occurred, which would likely retard the rate of total dissolved solids build-up.

Other than potential problems associated with scale formation in the condensers, the accumulation of salts to approximately 1400 mg/l within the Rawhide cooling impoundment does not appear at this time to represent a significant threat to beneficial uses. There are scattered reports in the literature that waterbodies which have higher concentrations of dissolved salts tend to favor the formation of blue-green algae. However, the information in this area is sparce and a cause-and-effect relationship is not well documented. It is doubtful at this time that this dissolved solids level would be of any great significance in determining the types of algae that will be produced in the Rawhide cooling impoundment or for that matter in influencing the growth and reproduction of fish within the waterbody.

Miscellaneous Parameters

pH

While federal water quality criteria and state of Colorado water quality guidelines-standards specify that for primary and secondary contact recreation the pH should be maintained between 6.5 and 9, pH values in excess of 9 have frequently been found to not have a significant adverse effect on fish. No attempt should be made to control pH within the cooling impoundment except for the purposes of minimizing the concentration of unionized ammonia.

Primary Contact

While primary contact recreation (swimming) will not be allowed in the Rawhide cooling impoundment, according to Black & Veatch (2) the Santee County Water District of Southern California is successfully operating lakes filled with reclaimed wastewater and allowing swimming, with no apparent problems. The District conducted a virology study which showed that while the wastewaters contained viruses, none were found in the treated lake waters (Black & Veatch (2)). However, virology studies of the Fort Collins Wastewater Treatment Plant No. 2 effluent showed that samples collected in late summer - early fall 1979 contained Coxsackie B-3 viruses in concentrations from 2 to 5 virus/liter (Carlson (19)). According to Carlson, this virus commonly causes colds and sore throats and is present in concentrations on the order of several hundred times above suggested limits for waters used for recreation (1 in 20 to 40 liters).

It is suggested that a fecal coliform standard for the Rawhide cooling impoundment be set at 200 organisms/100 ml, basically the same as the US EPA Red Book value (US EPA, (20)), to provide adequate user protection in the event of accidental body contact. The spring to mid-summer results of the authors' current cooperative study with the city of Fort Collins show that for the most part the Fort Collins Wastewater Treatment Plant No. 2 effluent has fecal coliform levels which are an order of magnitude below that level. Samples collected from the surface waters in Swede Lake and Fossil Creek Reservoir contained generally 10 fecal coliforms/100 ml, or less.

Hydrogen Sulfide Production

Because of the likelihood of anoxic conditions prevailing in the hypolimnetic waters of the Rawhide cooling impoundment during a substantial part of the summer, problems associated with hydrogen sulfide production may be encountered. The hydrogen sulfide would arise in the hypolimnion from the reduction of sulfate by sulfur-reducing bacteria. This hydrogen sulfide is of concern from several points of view. It is toxic to fish, exerts an oxygen demand on the surface waters, is malodorous, and is potentially corrosive.

The US EPA in its July 1976 water quality criteria, has established a suggested criterion for H_2S of 2 µg/l. This value relates to toxicity to aquatic life although the focal point of concern appears to be fish eggs. From the situation that will exist in the Rawhide cooling impoundment, it does not appear that a water quality criterion of 2 µg/l will be appropriate for any hydrogen sulfide that is discharged through the condensers as the result of the condenser intake location being at a point where it could obtain H_2S-containing waters in the hypolimnion during late summer, since H_2S, upon coming in contact with oxic waters, is rapidly oxidized to elemental sulfur and sulfate, both of which are relatively innocuous in aquatic systems. Fish that would come in contact with water in the discharge area would also likely be repelled by high concentrations of H_2S as is reported by US EPA (20) to occur. However, fish kills have been reported in the literature due to the upwelling of H_2S-containing waters (Serruya (21)). While elevated H_2S could cause harm to fish eggs which might be laid on the reservoir bottom, this is not likely to be of major significance, since primary spawning areas are expected to be in shallow nearshore regions.

The presence of H_2S in hypolimnetic waters could exert an oxygen demand on the waters at the bottom of the epilimnion. However, because of the large volume of water compared to the potential demand, it would not be expected that such an oxygen demand would be perceptible in the Rawhide cooling impoundment.

The presence of H_2S could also present problems in the use of the impoundment waters for condenser cooling. Not only would the presence of H_2S in the condenser cooling waters cause the cooling water discharge area of the impoundment to have a foul, "rotten egg" smell because of H_2S volatilization, rendering the discharge area essentially useless for recreation, it could also cause corrosion of the condenser tubes. However, the intake structure, according to Lucy (22) will be about 15 ft (4.6 m) in diameter and designed to take water over the depths of 4.6 to 15 m below the surface at full pool. Since the upper parts of this intake would always be taking some water with oxygen at or near saturation, this would greatly minimize the possibility of obtaining hydrogen sulfide-rich water which would cause water quality problems.

There are two factors which could limit the production and impact of H_2S production on impoundment water quality. The presence of high concentrations of nitrate in the cooling impoundment arising from the nitrification of ammonia, would tend to retard hydrogen sulfide formation. Further, as indicated previously, H_2S is unstable in oxic waters, being oxidized fairly rapidly (on the order of minutes) to elemental sulfur and sulfate. At this time it cannot be certain that hydrogen sulfide will be a problem; many waterbodies of this type in which anoxic hypolimnia develop during mid-summer as is predicted for this particular waterbody, do, however, develop several mg/l or more of hydrogen sulfide there.

CONCLUSIONS

1. Water quality in the Rawhide cooling impoundment will not be acceptable for desired recreational uses without removal of certain contaminants from the make-up water.

2. Based on the US OECD eutrophication models, removal of phosphorus to 0.1 mg/l total P in the cooling impoundment make-up water should minimize excessive growth of algae to acceptable levels and promote desirable warm water game fish production. It is possible that during periods of algal blooms, the pH of the impoundment water will be raised sufficiently to convert sufficient amounts of ionized ammonia to un-ionized ammonia to develop a potential for acute toxicity to fish.

3. Nitrite may accumulate under winter conditions to a sufficient extent in the Rawhide cooling impoundment to cause chronic toxicity to fish.

4. Chlorine used for the control of condenser fouling may be sufficiently persistent in the Rawhide cooling impoundment to cause chronic toxicity to fish in the region of the condenser water discharge.

5. In order to avert potential water quality problems in the cooling impoundment, an "active" water quality monitoring-evaluation program should be undertaken.

RECOMMENDATIONS

1. It is recommended that the Rawhide cooling impoundment make-up waters be treated for P removal to 0.1 mg P/l.

2. Platte River Power Authority should discuss with city of Fort Collins officials the possibility of obtaining nitrified or partially nitrified wastewaters if it appears that ammonia toxicity will be a problem in the cooling impoundment.

3. The ammonia and nitrite concentrations in the impoundment should be closely monitored to determine if either is present in "excessive" amounts and the impact of the concentrations on beneficial uses of the water.

4. Special caged fish studies should be conducted in the area of the cooling water discharge to evaluate the range and degree of toxicity associated with chlorination of cooling waters.

5. Consideration should be given to constructing the cooling water intake structure such that if necessary, the intake can be raised several meters to avoid taking anoxic hypolimnetic waters should they develop.

6. An "active" water quality monitoring - evaluation program should be followed to avoid the development of serious water quality problems in the cooling impoundment.

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