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CHERRY CREEK RESERVOIR

CLEAN LAKES STUDY

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ABSTRACT

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ABSTRACT: This report discusses the present and future water quality conditions of Cherry Creek Reservoir, with emphasis on eutrophication, phosphorus and chlorophyll a. Methods to control the eutrophication process are discussed and costs to control the process are identified. Recommendations are made on limits of phosphorus and chlorophyll a which will protect the beneficial uses of the reservoir.

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EXECUTIVE SUMMARY

Cherry Creek Reservoir is a valuable flood control structure and recreational resource for the Denver metropolitan area. It has prevented millions of dollars in flood damages and is used by well over a million people each year for fishing, swimming, boating, picnicking, and sight-seeing and other recreational pursuits.

The reservoir was included in the National Eutrophication Survey (NES) conducted by the U.S. Environmental Protection Agency (EPA) between 1972 and 1975. It was determined in the NES that Cherry Creek Reservoir was in a slightly eutrophic, or "aged," state. However, the present water quality of the reservoir is adequate for its designated uses and only minor concerns have arisen regarding water quality. The reservoir is presently classified for the following designated uses. Class I Warm Water Aquatic Life, Class I Recreation (swimming), agriculture, and water supply.

Since the reservoir basin is presently relatively undeveloped, the reservoir water quality is a result of natural causes. However, Cherry Creek Reservoir is situated in the quickly growing, southern Denver area and tremendous growth is projected to occur in its vicinity. Along with this growth come increased amounts of pollutants and a greater potential for water quality degradation. Because of the large value of this resource, signs that it is already aging significantly, and the great growth potential in its basin, Cherry Creek Reservoir was identified as a candidate for a Clean Lakes Study.

The purpose of the Cherry Creek Reservoir Clean Lakes Study was to recommend water quality goals and standards related to eutrophication as well as treatment levels to achieve those standards which would protect the existing water quality and beneficial uses. This is different from the purpose of most Clean Lakes Studies in that it attempted to prevent an adverse situation from occurring, instead of studying how to resolve an already existing one.

The recommended water quality goals and standards in this study are related to eutrophication and will supplement those standards already adopted by the Colorado Water Quality Control Commission (WQCC) to protect the reservoir. There are presently no federal or state standards for variables which are related to lake eutrophication such as the nutrient phosphorus or chlorophyll a (a plant pigment found in algae cells which is commonly used to measure the degree of eutrophication). Such standards are needed for Cherry Creek Reservoir due to the potential for magnified nutrient enrichment from development which will accelerate eutrophication. Also needed are recommended treatment elvels for both point and nonpoint source pollution. The recommendations and information from this study will be forwarded to the WQCC for consideration in adopting additional standards for Cherry Creek Reservoir. The standards and treatment levels adopted will be used in a subsequent Basin Master Plan for the Cherry Creek Basin. This Basin Management Plan will identify special treatment facilities and institutions for implementation and management.

The Cherry Creek Reservoir Clean Lakes Study was coordinated by the Denver Regional Council of Governments (DRCOG), EPA, and the Colorado Department of Health, and lasted two years. The study involved several data gathering and sampling efforts which were conducted by DRCOG, the Colorado Department of Health and the U.S. Geological Survey. Study activities and guidance were provided by a Clean Lakes Task Force consisting of representatives from these agencies along with local governments and water and sanitation districts in the reservoir basin.

Data was collected on present reservoir and tributary water quality and on basin characteristics including land use, population, and wastewater treatment systems. Projections of future basin characteristics were developed and future reservoir water quality was predicted using a model based upon these projections and an array of treatment systems analyzed. This data and information addressed the specific objectives of the study which were to: 1) determine the present trophic status of the reservoir; 2) determine the source and magnitude of nutrient and pollutant loading to the reservoir; 3) evaluate present and future basin characteristics and effects of growth on reservoir water quality; and, 4) identify and recommend acceptable reservoir standards related to eutrophication and treatment systems to achieve them.

Water Quality Goals

In order to evaluate treatment systems and reservoir water quality and, ultimately, recommend a reservoir standard, it was necessary to establish water quality goals. This was difficult at study conception due to the paucity of data on reservoir water quality which made it impossible to state that water quality should be either maintained or improved. Because of the limited data available, three general water quality goals were established for this study and refined throughout the study as information became available. The three general goals were to:

1. Allow no further water quality degradation by maintaining levels of pollutants as close to current (1982) monitored conditions as possible;

2. Define an acceptable trophic status (water quality) difficult from present conditions which would protect the existing use classification of the reservoir; and,

3. Change the use classification of the reservoir if necessary based upon other agencies' goals.

These goals were evaluated using technical information and the results of a users' perception study completed as a part of this study. Technical information was related to defining an acceptable trophic status (amount of "aging") based upon chlorophyll a concentration. This was extremely tedious as scant information exists on the relationship between chlorophyll a and beneficial uses. However, using data available on other lakes in the region along with that collected during 1982, it was determined that an acceptable range of chlorophyll a would be 11-40 micrograms per liter (ug/L). From this, a specific goal was to be selected.

A study of users' perceptions was conducted as a part of this study and its results were used to evaluate water quality goals. This proved to be difficult as users were found to perceive pollution from an aesthetic viewpoint, and the pollutants they identified as being present and affecting their use of the reservoir were mainly caused by the users themselves (e.g., litter, gas, grease, oil) and are not directly related to eutrophication or the water quality parameters studied.

It was concluded by the study Task Force that the use classification of the reservoir should not be changed and that a specific standard be defined using the 11-40 ug/L chlorophyll a range to protect these uses. Chlorophyll a levels out of this range were concluded to be too high and too low by the Task Force. Goals were refined by the Task Force which were used to evaluate future water quality conditions, select treatment options and further evaluate water quality standards. These goals are as follows:

1. Maintain the present use classification of the reservoir;

2. Maintain the existing numeric water quality standards for the reservoir;

3. Maintain the water quality as close to current conditions as economically and practically feasible;

4. Maintain the existing use classification and identify a trophic state and standard of total phosphorus related to chlorophyll a which would protect the present uses; and,

5. Define treatment systems for point and nonpoint sources necessary to achieve the recommended trophic state and standards.

This set of goals acted as a vehicle for direction of the study and evaluation of specific treatment systems and standards.

Present Reservoir Water Quality and Basin Characteristics

Cherry Creek Reservoir water quality was sampled by the Colorado Department of Health from November 1981 through October 1982 as a part of the study. Basin characteristics and tributary water quality were studied by DRCOG and the U.S. Geological Survey, respectively, in order to fully understand the relationship between the present reservoir water quality and basin characteristics.

Cherry Creek Reservoir was found to be typical of plans reservoirs in the region in that it is shallow, well mixed, and its water has relatively high amounts of inorganic suspended solids. The reservoir was determined to be in a slightly eutrophic or "aged" state and had a mean growing season (July-September) chlorophyll a level of 10.7 ug/L. No major water quality problems were identified in the reservoir and the water quality met the adopted state standards. Concentrations of ammonia and nitrate-plus-nitrate nitrogen were found to be very low on the average. Levels of total phosphorus were moderate, but soluble orthophosphate was very low. Concentrations of metals were below the adopted state standards and were not thought to pose any problems. The reservoir was found to be well mixed throughout most of the year with only brief periods of stratification occurring during late summer. A study of limiting nutrients concluded that both nitrogen and phosphorus limit algal growth at different times of the year, but that only phosphorus should be targeted for control due to feasibility and effectiveness.

The reservoir basin is largely undeveloped at this time so that the present reservoir water quality is mainly due to natural sources. It was found that only slightly more than 17,200 acres or about 7 percent of the total basin area was developed in 1982. Most of this development was medium to large lot, single-family housing. Also, total basin wastewater flows in 1982 were only slightly more than 1.0 million gallons per day, and all effluent was land applied so that this source was an insignificant contributor of phosphorus to the reservoir.

The major source of phosphorus to the reservoir in 1982 was from storm runoff. This source was found to contribute approximately 77 percent of the phosphorus load that year. Storm runoff and direct precipitation onto the reservoir surface accounted for over 92 percent of the estimated water entering the reservoir. Baseflows from tributaries contributed small amounts of water and phosphorus to the reservoir. This and the finding that nearly 10 percent of the water in the reservoir was lost to groundwater point to the generally dry nature of the basin.

Future Reservoir Water Quality and Basin Characteristics

Future reservoir water quality was estimated upon present conditions and projections of basin development for the years 1985, 1990, 2000, and 2010. This was done by estimating increases in nutrients to the reservoir in the future and using these as inputs into a series of simple, empirical models. These models provided predictions of future chlorophyll a and phosphorus concentrations, and of water clarity.

Substantial growth is projected to occur in the Cherry Creek Reservoir basin. Two sets of population, land use and wastewater flow projections were developed using DRCOG and developer data. These projections indicate the following percent increases in the year 2010 compared to 1982 (depending upon which projections were used): 320 through 460 percent increases in developed acreage; 1400 through 2700 percent increases in wastewater flows; and, as high as 4900 and 6500 percent increases in phosphorus loading, depending on the treatment level. Nearly all the development is to occur in the lower half of the basin near the reservoir.

Treatment Options

In predicting future reservoir water quality, five different treatment systems for point source and two levels of nonpoint source control were investigated. These treatment systems and levels represent state-of-the-art technology and require advanced forms of phosphorus removal. The following point source, wastewater treatment systems were identified:

- Secondary treatment with direct discharge
- Secondary treatment with slow rate land application
- Advanced treatment with phosphorus removal (no filtration)
- Advanced treatment with phosphorus removal (filtration)
- Treated Effluent Transmission Line (ETL)

Also, secondary treatment with rapid infiltration basins was not directly evaluated but was considered to produce effluent the equivalent of advanced treatment with phorphorus removal and filtration. These wastewater treatment systems were evaluated in combination with the following nonpoint, storm-runoff control systems:

- Detention basins and wetlands to achieve 25 percent basin-wide phosphorus removal
- Rapid infiltration and detention to achieve 50 percent basin-wide phosphorus removal

All combinations of the point and nonpoint source treatment systems were evaluated through the year 2010 in the modeling. This represented 30 possible scenarios, 15 with each set of projections. Equivalent annual costs for each system were determined and compared to model results of water quality and the water quality goals.

Future Reservoir Water Quality

The highest levels of chlorophyll a and total phosphorus in the future were predicted to occur using secondary treatment of wastewater with direct discharge and no nonpoint control. Even 50 percent control of nonpoint with this point source treatment option resulted in a chlorophyll a level of

92.1 ug/L in the year 2010. The lowest predicted chlorophyll *a* in 2010 was found with the Effluent Transmission Line (ETL). Predicted chlorophyll *a* using this point source control ranged from 31.1 ug/L with no nonpoint control to 15.8 ug/L with 50 percent of nonpoint control in 2010. Advanced treatment with filtration, slow-rate land application, and the ETL all were predicted to produce chlorophyll *a* levels of less than the upper limit of 40 ug/L in 2010, even without nonpoint control. No treatment system evaluated in this study could maintain the chlorophyll *a* level at the measured 1982 condition.

It is important to note that only chlorophyll *a*, total phosphorus and water clarity as measured by Secchi disc depth were modeled. These parameters are related to eutrophication and no standards presently exist for them. The predicted levels of these based on the treatment system combinations identified were compared to system cost and water quality goals to arrive at recommendations.

Evaluation of Treatment Systems

Wastewater and nonpoint treatment systems were evaluated with regard to effects on reservoir water quality, system cost, and feasibility. Because of the primary concern for water quality, treatment system combinations were first evaluated with regard to the water quality goals established, especially the 11-40 ug/L acceptable range of chlorophyll *a*. Based upon this range, secondary treatment with direct discharge and advanced treatment with phosphorus removal and no filtration were dropped from further consideration because these systems were predicted to produce chlorophyll *a* levels greater than 40 ug/L even with 50 percent nonpoint control in the year 2010.

Next, costs were used to evaluate the remaining systems. The lowest chlorophyll *a* level was predicted using the ETL and 50 percent nonpoint source control. This resulted in chlorophyll *a* levels of 15.8 and 21.2 ug/L in 2010 using DRCOG and developer projections with equivalent annual costs of $23.06 and $34.44 million respectively. This represented the most expensive option considered and was determined to have prohibitive problems associated with water rights, downstream impacts, water resources management, and a host of other concerns--all of which most likely would further increase costs. For these reasons, this treatment option was eliminated.

The remaining two wastewater treatment systems evaluated -- advanced treatment with filtration and slow-rate land application -- produced chlorophyll a levels within the 11-40 ug/L range at equivalent annual costs of between $14.50 and $28.06 million, depending upon projections used and the degree of nonpoint control. The least costly system evaluated had an equivalent annual cost of $13.00 million. Specifically, slow-rate land application with 50 percent nonpoint control resulted in a range of chlorophyll a of 16.3-21.4 yg/L in 2010 at equivalent annual costs of $18.96 and $28.06 million, respectively. Advanced treatment with filtration resulted in higher chlorophyll a levels of 18.6-26.5 ug/L but at substantially less cost ($15.66 and $22.98 million, respectively). Rapid infiltration of wastewater with 50 percent nonpoint control was assumed to produce comparable results to advanced treatment.

An analysis of the effectiveness versus cost of using nonpoint controls concluded that, if such controls were needed to meet the specific water quality standard, control of 50 percent nonpoint source phosphorus was more cost-effective than 25 percent control. The cost difference between the two levels was less than $100,000 annually in the year 2010, but the additional reduction in chlorophyll a was more than 5.0 ug/L in some cases using 50 percent control.

Further evaluation of treatment systems and the need for nonpoint control could not be accomplished without specifically defining water quality goals and standards for the reservoir. With such standards defined, further refinement of the analysis of treatment systems needed to achieve them could be made, and such systems recommended in the Basin Management Plan.

Recommendations and Conclusions

Recommended Reservoir Standard

Chlorophyll a concentrations can vary greatly within a water body due to wind, water mixing, shading and other factors which affect algae productivity. Because of this, and the fact that chlorophyll a is not a constituent of wastewater, it was decided that a limit of chlorophyll a be set in the reservoir, but the standard be based on total phosphorus. This chlorophyll a limit would be based on the mean growing season concentration and could be related to a concentration of total phosphorus in the reservoir. This concentration of phosphorus should vary less than its associated level of chlorophyll a and is relatable to wastewater discharges and nonpoint source contributions.

The chlorophyll a limit and phosphorus standard were established using the water quality goals previously set and based upon a literature search and consultation with states and experts on the relationship between chlorophyll a levels and beneficial uses, and an evaluation of treatment systems. This limit and standard should consider the time frame for standards reviewed by the WQCC which will occur in 1984 and 1987 for the South Platte River Basin.

Little specific information was found in the literature on the relationship between chlorophyll a and beneficial uses. This relationship depends upon the water body. However, valuable information was gathered from other states and consultation with experts. Two findings became apparent from this search: 1) a limit of chlorophyll a in the area of 20 ug/L was cited as an acceptable upper limit target in many cases, and 2) people most likely would not perceive a difference in chlorophyll a levels of 10-20 ug/L. It was found that a level of 20 ug/L would most likely create a more productive fishery without impairing other uses. It was also emphasized that the effects of phosphorus loading on reservoirs such as Cherry Creek, which have high amounts of suspended solids in them, would be diminished due to phosphorus absorption into particle surfaces.

Based upon this information, it is recommended that the chlorophyll a limit for Cherry Creek Reservoir be set at 20 ug/L (mean growing season).

A level of 20 ug/L chlorophyll a was determined to relate to a reservoir total phosphorus concentration of 44 ug/L through the modeling. Therefore, it is recommended that a reservoir total phosphorus standard (limit) be set at 44 ug/L (mean growing season).

It is felt that this total phosphorus standard will further protect Cherry Creek Reservoir and its designated beneficial uses. With the criteria that reservoir water quality should be kept as close as possible to present conditions (1982) and the fact that this study is based upon present known technologies which may change in the future, it is realized that this standard may need to be periodically reviewed. This will be accomplished by the triennial review of standards already adopted by the WQCC.

Recommended Treatment Levels

An analysis of the effectiveness of nonpoint control measures showed that the use of these controls may substantially decrease total phosphorus to the reservoir and delay the eutrophication process. It was also determined that 50 percent control was more cost-effective than 25 percent control. For example, 50 percent removal reduces chlorophyll a in the year 2010 by 15 to 30 percent. This would be the equivalent of reducing wastewater flows by 6 to 10 million gallons per year, and reservoir chlorophyll a by over 5 ug/L. Twenty-five percent nonpoint removal would cost about $100,000 less, but would decrease chlorophyll a by less than 2 ug/L. Because of the benefit of nonpoint control and the increased cost-effectiveness of 50 percent removal, it is recommended that the Basin Master Plan develop a staging plan for implementation of nonpoint control programs capable of removing fifty percent of the annual phosphorus load from nonpoint sources and identify the methods for implementing these programs.

Table 1 shows the predicted dates that certain chlorophyll a levels would be reached using the three treatment levels consistent with the water quality goals and cost analysis -- slow-rate land application, advanced treatment with phosphorus removal and filtration, and rapid infiltration -- all with 50 percent nonpoint control.

Table 1
Relationship Between Treatment Systems and Chlorophyll a Levels

Chlorophyll a level (ug/L	Expected Period When Level Will be Reached* — With Land Application	With AWT** or Rapid Infiltration
10.7	1982	1982
15	1991 - 2004***	1987 - 1988
20	2005 - post-2010	1995 - 2006
25	past 2010	2007 - post-2010

* - with 50 percent nonpoint control
** - AWT = advanced wastewater treatment with phosphorus removal and filtration
*** - Range represents difference between DRCOG and developer growth projection

This table shows that the chlorophyll a limit of 20 ug/L would not be exceeded by these treatment systems until after 1995 under either growth scenario. This means that these systems will adequately protect the reservoir through the next four water quality standards reviews by the WQCC which will be in 1984, 1987, 1990 and 1993. Therefore, it is recommented that these three treatment methods, or any other equivalent systems, be identified in the Basin Master Plan as appropriate techniques for meeting a phosphorus effluent limit of 0.2 mg/L or better in the basin. The 0.2 mg/L of total phosphorus represents the highest level of this nutrient in effluent produced by these three systems.

It is believed that these recommended treatment systems will sufficiently protect the standards and beneficial uses of Cherry Creek Reservoir. However, the projections of growth in the basin indicate that sometime after 1995, the wastewater flows with nonpoint controls would cause the water quality to exceed the 20 ug/L chlorophyll a limit. This allows reasonable time for additional study of lake conditions, control technologies and growth implications. Therefore, it is recommended that between 1984 and 1995, the water quality in the basin and in the reservoir should be regularly monitored and the findings, recommendations, chlorophyll a limit, and in-lake phosphorus standard presented in the Clean Lakes Study should be regularly evaluated.

The recommendations from this study will be forwarded to the WQCC for its consideration during its standards setting process. The reservoir standards adopted by the WQCC and action taken on recommended treatment levels will be incorporated into the Cherry Creek Basin Master Plan. When the Basin Master Plan is completed and all standards are adopted, the Clean Water Plan will be amended.

I. INTRODUCTION

BACKGROUND

Cherry Creek Reservoir was identified as being eutrophic through the National Eutrophication Survey conducted in 1974-75 by the U.S. Environmental Protection Agency (EPA) based on total phosphorus and chlorophyll a.[1] The reservoir is a valuable regional recreation resource although its primary function is a flood control facility. Because of the high recreational value and the concern over future water quality problems, the Denver Regional Council of Governments (DRCOG) and the Colorado Department of Health applied for and received a grant from the U.S. EPA to conduct a Clean Lakes Study on the reservoir. The two-year study was initiated in 1981 and water quality goals designed to protect the beneficial uses of the reservoir will be implemented as the Cherry Creek basin becomes developed. Additional funding was supplied by seven water and sanitation districts in the Basin. The districts participated to gather additional water quality information on the reservoir, and information on feasible treatment alternatives, and other data which could be used in designing, developing, and ultimately issuing permits for new wastewater treatment facilities in the Basin.

Most Clean Lakes Studies are conducted on lakes which have water quality problems resulting from an identifiable source such as septic tanks, shoreline development, or they receive large quantities of wastewater from municipal wastewater treatment plants. Techniques to restore the lake would focus on controlling these identifiable sources of nutrient loading. This is not the case with Cherry Creek Reservoir, as there is no shoreline development and no wastewater treatment plants discharge to the reservoir or its tributaries. Based on data collected in 1982, the nitrogen and phosphorus nutrients fueling the eutrophication process are carried into the reservoir by storm water runoff from the suburban areas on both sides of the reservoir and agricultural land to the south. The Clean Lakes Study for Cherry Creek Reservoir will focus on establishing water quality goals for the basin and reservoir to prevent any accelerated

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[1] U.S. Environmental Protection Agency, "Report on Cherry Creek Lake, Arapahoe County, Colorado," EPA Region VIII, Working Paper No. 768, U.S. EPA, June, 1977.

rate of eutrophication in the future as development does occur in the basin. By setting these water quality goals now, beneficial uses of the reservoir can be maintained and an undesirable future water quality condition can be avoided.

PURPOSE/SCOPE

The purpose of the Cherry Creek Reservoir Clean Lakes study was to recommend water quality goals and standards related to eutrophication and treatment levels to achieve them which would protect the existing water quality and beneficial uses. This information would serve as the basis for a Basin Master Plan. The Basin Master Plan will be completed following this study and will specify means to achieve water quality goals for the reservoir by an evaluation of recommended point and nonpoint source control measures.

The specific objectives of the Cherry Creek Reservoir Clean Lakes study were to:

1. Determine the present trophic condition of the reservoir;

2. Recommend water quality standards required for protection of the established uses of the reservoir;

3. Determine the quantity and quality of existing nonpoint flows tributary to the Cherry Creek basin;

4. Estimate future sources and quantity of point and nonpoint flows for the years 1990, 2000, and 2010 based on DRCOG and developer population projections;

5. Model the reservoir to predict effects of urbanization and wastewater discharges on reservoir water quality;

6. Develop alternative Best Management Practices (BMPs) for nonpoint sources and determine effects on the reservoir;

7. Develop treatment methods and recommend effluent standards for point source discharges and determine effects on the reservoir; and,

8. Use combined point and nonpoint source controls to determine the most cost effective means of maintaining acceptable water quality in the reservoir.

Many agencies have been concerned with the reservoir's water quality for a number of years. Therefore, the Cherry Creek Clean Lakes Study is a cooperative effort conducted by the U.S. EPA, Colorado Department of Health, and DRCOG, with assistance from seven water and sanitation districts located within Cherry Creek basin. Other agencies involved in the study include the U.S. Geological Survey (USGS), Metro Denver Sewage Disposal District #1 laboratory (MDSDD#1), Colorado Division of Parks and Outdoor Recreation, Colorado Division of Wildlife, Tri-County Health Department, and the U.S. Army Corps of Engineers. These agencies, along with representatives of local governments comprised the Clean Lakes Task Force which was the entity responsible for providing guidance and making recommendations on the study. The final decision regarding water quality standards for the basin is the responsibility of the Colorado Department of Health, Water Quality Control Commission.

GENERAL RESERVOIR AND BASIN CHARACTERISTICS

Cherry Creek Reservoir is located in southwestern Arapahoe County, Colorado, approximately 10 miles southeast of Denver, Colorado (Figure 1). The drainage basin is long and narrow, extending south from the reservoir through Douglas County and terminating in northern El Paso County. The total basin contains approximately 245,500 acres.

Cherry Creek Reservoir is the prominent feature in the basin. The reservoir occupies approximately 850 surface acres and is surrounded by Cherry Creek State Park, which contains 3,915 acres of multi-use recreation land managed by the Colorado Division of Parks and Outdoor Recreation. The reservoir itself is owned and operated by the U.S. Army Corps of Engineers. Only 7 percent of the basin has been developed to date and agriculture and agribusiness such as sod farming comprise the major land use in the basin. Developed land uses include high-moderate density suburban residential areas, large lot subdivisions, and office, commercial and light industrial parks. Developed land uses within the basin are expected to increase rapidly as the Denver Metropolitan area expands to the popular southeast sector. Table 1 lists the existing and proposed development areas which lie either partially or entirely within the basin. Along with the

Table 1

Development Areas Within Cherry Creek Basin

Development Area	Existing[1]	Proposed
Arapahoe W&S	X	
Castle Rock (Villages)	X	
Cottonwood	X	
Hughes Property		X
Inverness	X	
Meridian	X	
Parker	X	
Pinery	X	
Rampart Range		X
Stonegate	X	
Stroh Ranch		X

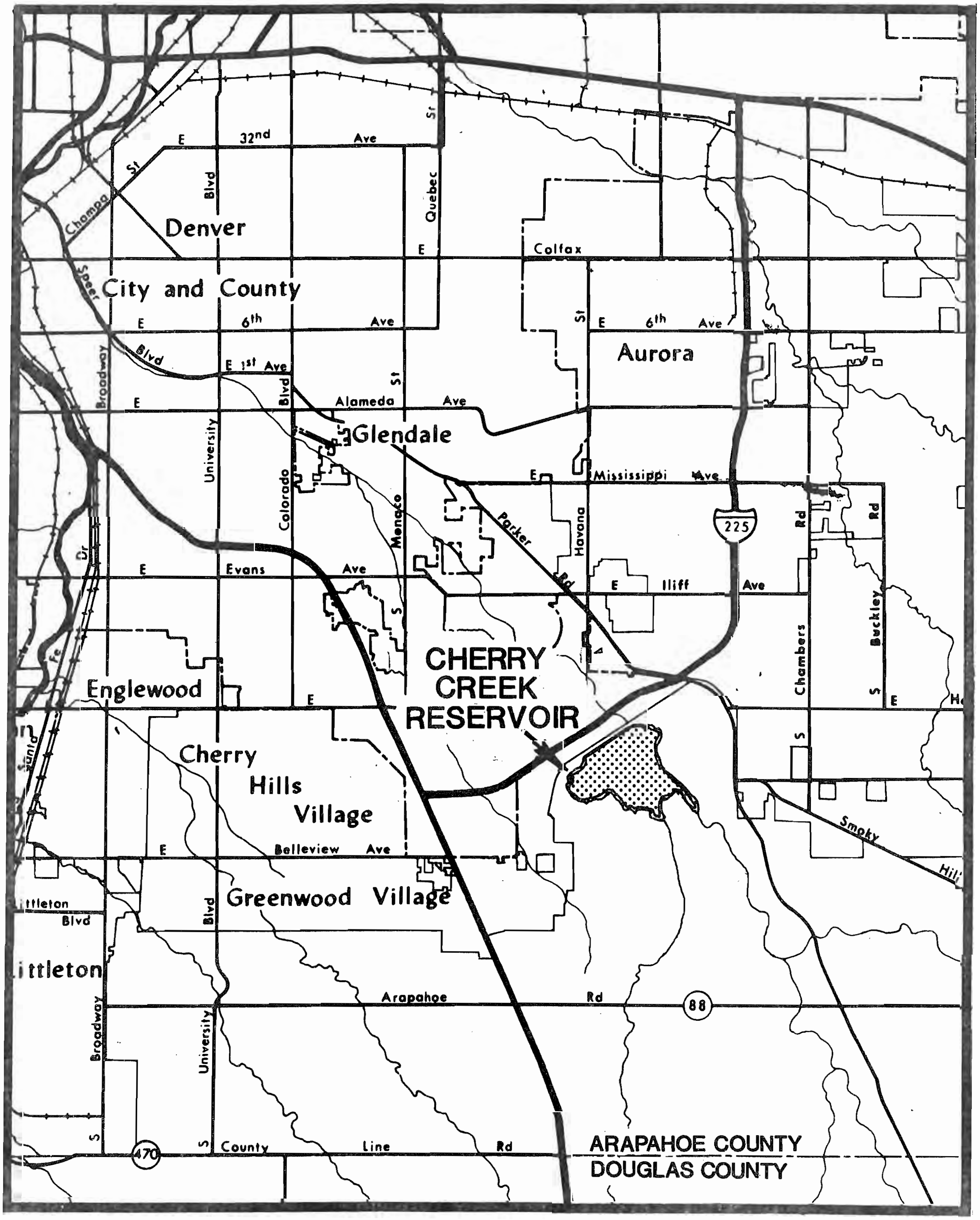
[1]Existing refers to development areas recognized as of May, 1983.

development will come an increase in population, estimated to increase 770 to 1300 percent by the year 2010 over the 1980 population estimate. Figure 2 shows the Cherry Creek basin and the existing and proposed development areas.

Surface water within the basin is very limited. The surface waters originate from two main sources, either groundwater seepage or by rainfall. Accumulation of snow and snowmelt provide only a small portion of the surface water flow. The major hydrologic feature is Cherry Creek which is a typical plains stream characterized by low streamflow, low slope, and sandy channel bottom. In the lower portion of the basin, (from the Arapahoe/Douglas County line) Cherry Creek is an intermittent stream, transmitting water to the reservoir only during periods of heavy rainfall. In the upper reach of the basin and down below Franktown, Cherry Creek flows continuously. It is suspected that groundwater pumping around the Arapahoe/Douglas County line is responsible for de-watering the stream. Numerous small tributaries are connected to the reservoir and these, like Cherry Creek, usually flow during periods of heavy rainfall.

FIGURE 1

CHERRY CREEK RESERVOIR VICINITY MAP



~~FIGURE 2~~

CHERRY CREEK RESERVOIR BASIN AND DEVELOPMENT AREAS

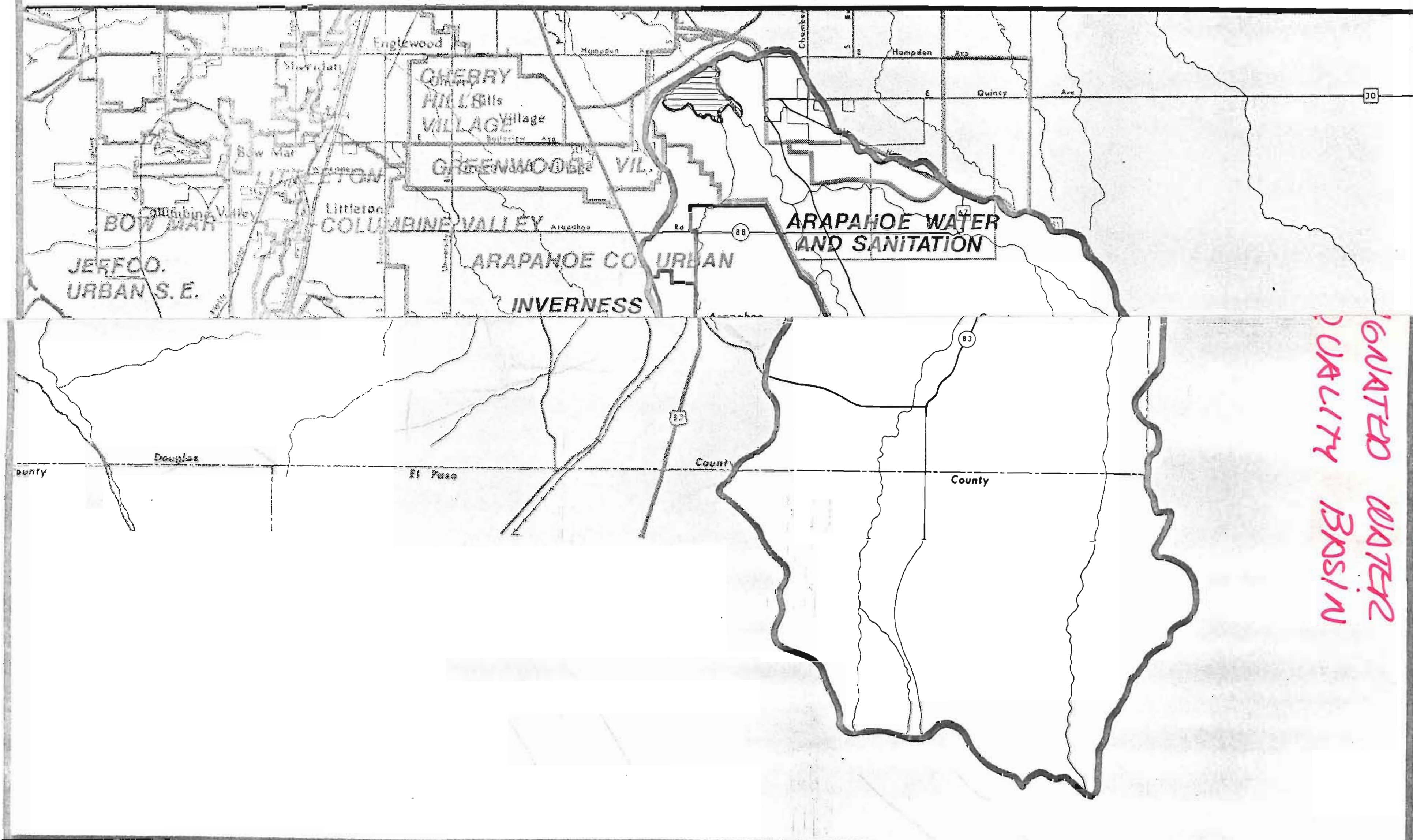


FIGURE 1501

DESIGNATED WATER QUALITY BASIN

The reservoir was built as a flood control facility in 1950 by the U.S. Army Corps of Engineers. Except for flood flows, no water was placed into storage until 1957, when a 10,000 acre-foot minimum pool was established for recreation and aquatic life propagation purposes. These latter two uses are what most residents and visitors to the Denver area view as the role of the reservoir. Consequently, the reservoir is used extensively for swimming, fishing, and boating; while the shoreline accommodates visitors who enjoy the picnic grounds and trails for jogging, bicycling, and horseback riding. All of these activities rely on a reservoir water quality compatible with a healthy aquatic life and primary contact water sports.

The reservoir does not have a regular outflow and has discharged only occasionally during its 24 years of operation. Due to the non-discharging system, nutrients such as nitrogen and phosphorus are not flushed out of the reservoir and this tends to increase the algal productivity of the lake. Since there were no wastewater treatment plants near the reservoir or within the basin until recently, and none of these discharge to any water courses in the basin, the eutrophication problems in the reservoir resulted from nonpoint sources of pollution.

II. WATER QUALITY GOALS

Water quality goals for the reservoir were set early in the project and used to guide the technical portions of the study. With inadequate water quality data prior to this study, only general goals were established initially and as more technical information was generated, these general goals were refined. This chapter describes how the goals were formulated and incorporated into the project.

Normally, Clean Lakes Studies focus on maintaining or improving the existing water quality of the selected lake. The water quality of Cherry Creek Reservoir was not well documented after 1975 until the Colorado Department of Health (CDH) issued its report on the reservoir water quality conditions in October, 1983.[2] Without knowing the present water quality, it was not possible to state at project inception that reservoir water quality should be maintained or improved. The water quality report issued by the CDH provided the basis from which to make decisions and evaluate water quality goals. In establishing goals for this study, three areas were considered important. These areas were: 1) general water quality goals, 2) technical aspects such as defining an acceptable trophic status based on chlorophyll a and total phosphorus, and 3) recreationists' or user perception of water quality.

GENERAL WATER QUALITY GOALS

With only limited data on existing water quality conditions, three general water quality goals were selected for evaluation. These three general water quality goals were:

1. Allow no water quality degradation; maintain chlorophyll a concentration as close to the present chlorophyll a concentration of 10.7 ug/L as possible.

2. Maintain the existing use classifications and identify a trophic status; e.g., a chlorophyll a concentration which would allow the present uses of the reservoir to continue.

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[2] Colorado Department of Health, Water Quality Control Division, "Report on Reservoir Modeling and Sampling for Cherry Creek and Chatfield Reservoir Clean Lakes Study", October, 1983.

3. Change the use classifications if necessary based on other agencies' goals.

With the exception of goal 3, goals 1 and 2 relate to maintaining the beneficial uses of the reservoir. In addition to maintaining the present beneficial uses, the existing numeric standards adopted by the Colorado Water Quality Control Commission were to remain unchanged.

It should be noted that goal statement number 3 relates to changing the reservoir use classification based on other agencies' goals. The intent behind this statement was to acknowledge that other agencies were preparing master plans for the reservoir which may influence the standards setting process. In particular, the Colorado Division of Wildlife and the Colorado Division of Parks and Outdoor Recreation are two agencies which have direct interest in the reservoir. Both agencies are preparing master plans for the reservoir but at the time this report was written, neither agency had completed their master planning effort. Therefore, it was not possible to incorporate any specific goals from these two agencies. However, each agency did submit a letter stating their intended goals for the reservoir. The Colorado Division of Wildlife would like to see the existing water quality conditions maintained or improved. The Colorado Division of Parks and Outdoor Recreation anticipates that this Clean Lakes Study will insure that no recreational activity be precluded at Cherry Creek Reservoir because of real or publicly perceived degradation of water quality.

With these three general water quality goals and the criteria of maintaining the existing beneficial uses and numeric standards, technical aspects relating to trophic conditions of the reservoir were investigated. Following an evaluation of user perception of the water quality, the study goals were refined. From the final set of selected goals, recommendations will be made for specific water quality standards.

Technical Criteria

In addition to the general water quality goals, it was important to define an acceptable trophic status of the reservoir. The trophic status was based on two constituents: total phosphorus concentration and chlorophyll a concentration. The trophic status, based on these two constituents is important, as the trophic status in the reservoir relates to the amount of productivity within the reservoir. If the productivity is too high or too low, it could limit or prohibit beneficial uses of the reservoir.

The task of defining an acceptable trophic conditions related to total phosphorus and chlorophyll *a* proved to be the most difficult task in setting water quality goals. Early in the study, it was realized that the trophic status of the reservoir could be indicated by three variables: total phosphorus, chlorophyll *a* and secchi disk depth. After reviewing the information on reservoir water quality, secchi disk depth was dropped as an indicator of trophic status as inorganic suspended material in the water column interfered with the depth readings. This resulted in emphasis being placed on defining an acceptable concentration of chlorophyll *a* and total phosphorus.

Chlorophyll *a*

Consideration was given to selecting a limit on chlorophyll *a*. This chlorophyll *a* limit would be related to a degree of eutrophication or trophic status and would define a level of chlorophyll *a* which would not prohibit any of the beneficial uses.

Presently, no rigid criteria exist for precisely defining or determining the relationship of chlorophyll *a* to lake water quality or its effect on uses of the lake. There are no regional or national standards which define excessive eutrophication based on chlorophyll *a* where certain beneficial uses of the water body are lost. Therefore, current scientific knowledge makes it difficult to place a fixed boundary on excessive chlorophyll *a*.

As no standards or reference points exist for defining an excessive chlorophyll *a* concentration, the Task Force first established a range of chlorophyll *a* which defined an upper and lower boundary for this constituent. This boundary condition represented a range in chlorophyll *a* where above or below it, a particular beneficial use may be impaired. The range selected was 11 to 40 ug/L of chlorophyll *a*.

The 11-40 ug/L range was determined by comparing it to data from two other lakes in Colorado. First, the lower limit of 11.0 ug/L represents a close approximation of the existing chlorophyll *a* concentration in Cherry Creek Reservoir. Additionally, Dillon reservoir in Dillon, Colorado, reports a mean summer chlorophyll *a* concentration of less than 11.0 ug/L and is classified as a Class 1 Cold Water fishery and Class 1 Recreation (primary contact). In this case, the recreational uses of the reservoir are not being impacted by the chlorophyll a level. However, in Sloans Lake, in Denver, Colorado, the mean chlorophyll a is approximately 40.0 ug/L and has a goal of a Class 1 Warm Water Fishery with Class 2 Recreation (secondary contact). Primary contact recreation (swimming) is not allowed at Sloans Lake and the warm water fishery has to be maintained through artificial methods such as stocking. The result is that the 11-40 ug/L range of chlorophyll a represents extremes in chlorophyll a relating to impairment of uses.

From this range of 11-40 ug/L of chlorophyll a, a specific chlorophyll a limit was established later in the study. Justification for the rationale behind selecting a chlorophyll a limit appears in Chapter X, "Recommendations".

Total Phosphorus

Total phosphorus was the other variable related to eutrophication and a trophic status which was evaluated in this study. As total phosphorus is one of the nutrients which influences algal production and chlorophyll a production, it was necessary to define a limit for this nutrient. Also, a direct relationship exists between chlorophyll a and total phosphorus, so once a specific limit was established on chlorophyll a, it was possible to define a specific limit for total phosphorus. The relationship between total phosphorus and chlorophyll a is described in Chapter VIII, "Water Quality Modeling". The total phosphorus limit became one of the recommended standards for the reservoir.

Once the total phosphorus limit was established as a recommended standard, point and nonpoint control options were evaluated in terms of meeting this limit. The point and nonpoint control options represented the best possible technology available today for treating wastewater and nonpoint source phosphorus contributions. This approach allowed for a determination of appropriate effluent and nonpoint water quality using technology-based control strategies. Specific mass limits in the form of pounds of phosphorus per year were not evaluated as a control strategy as it was not the intention of this study to perform waste load allocations. Rather, concentration limits were considered as the appropriate control mechanism. These concentration limits would be enforced through the state discharge permit system. It clearly was not the intention of this study to determine sizing, staging, location or number of wastewater treatment facilities serving the upper Cherry

Creek Basin, but rather to identify the degree of treatment which is technically and economically feasible and will protect the reservoir. It should be remembered that this study provides an opportunity to protect the beneficial uses of the reservoir before growth and any uncontrolled practices of wastewater treatment and nonpoint source contribution create a water quality problem in the reservoir. Most Clean Lakes studies are faced with trying to correct a water quality condition in a lake once a given basin is already developed. The approach taken in this study is just the opposite: the opportunity exists to establish water quality goals for the basin and reservoir which may prevent a future water quality problem condition.

Users' Perception

In establishing water quality goals for the reservoir, the users' perception of the reservoir water quality should not be ignored, as well over one million people visit the reservoir annually. In an attempt to define users' perceptions, the Colorado Department of Health contracted with Dr. Robert Aukerman, Professor of Recreational Resources, Colorado State University, to conduct a survey of reservoir users to determine their perceptions of the water quality.

A total of 876 users were surveyed during a six-week period in the summer of 1982 at both Cherry Creek and Chatfield Reservoirs as a part of this study. Four hundred thirty-six of these were surveyed at Cherry Creek. Individual users were personally interviewed and asked to respond to a pre-prepared questionnaire relating to user perception of water quality. Users were categorized as either swimmers, boaters, fishermen, or sightseers, based upon the activity they were engaged in at the time of the interview.

Questions were asked in the survey to gather information in the following five areas:

1. Demographic and background information, including frequency of visitation, travel time to reservoir, and activities participating in;

2. Site preferences, including comparison to Chatfield Reservoir;

3. Users' attitudes and beliefs about water and water-related characteristics of the site;

4. Effects of present reservoir water-related characteristics on users' use of site and activities, and the effects of future changes in these characteristics on use; and,

5. The quality and sources of pollutants entering the reservoir.

The answers to these questions were statistically analyzed by computer to determine users' perceptions. Comparisons of responses between users at both reservoirs proved valuable since these two sites have differing water quality characteristics. The results of the survey were grouped into several categories and are summarized below:

Users' Attitudes and Beliefs About Pollutants

1. Few users of Cherry Creek Reservoir found water quality attractive and most people considered it unattractive. Most considered the reservoir to be polluted a little, with a significant number of swimmers considering it polluted a lot.

2. The pollutants that people perceived to be present include oil, gas, litter, scum, algae, muddy water and weeds. These pollutants were the same ones that people found least objectionable. Of these, gas and litter were the least liked.

3. The most disliked pollutants included chemicals, sewage, and manure. None of these were perceived as being present in the reservoir water.

Sources of Pollutants

Half of those interviewed at Cherry Creek Reservoir considered the water entering the reservoir to be clean. Pollutants identified in inflows include soap, detergents, and scum. The exact nature of what was meant by "scum" was not determined.

Water Quality Perceptions vs. Site Characteristics and Use

1. Reservoir users chose either to use or not use Cherry Creek Reservoir based at least somewhat on water quality. This was found because 25 percent of the users interviewed at Chatfield reservoir said that they have never used or have left Cherry Creek due to degraded water quality.

2. Users identified scum, gasoline, litter, muddy water, sewage and weeds as pollutants which caused them to decrease their use of Cherry Creek Reservoir.

3. In general, all users perceived the same pollutants to be present at their site, but the relative importance of each pollutant, whether found or not, varied between recreational group. For example, many swimmers and boaters identified dirty water as the characteristic most disliked. Fishermen and sightseers also identified dirty water as being present but did not cite this factor as one they strongly disliked.

Behavior and Pollutants

1. If those pollutants most disliked - chemicals, sewage, and manure - became present in Cherry Creek Reservoir, or if amounts of less objectionable pollutants already perceived as being present increased slightly, over half of those interviewed would likely stop using the reservoir. Highly treated wastewater in the reservoir would not cause the majority of the users to decrease their use.

2. People would increase their use of Cherry Creek Reservoir if water quality improved. All user groups would be willing to pay an average of $3.00 per visit for water quality improvements.

3. The majority of reservoir users in all recreational groups responded that if water quality became very bad, they would have no other place to go. The main reasons given for this were that the drive would be too long and cost too much to go to another equivalent recreational resource.

Overall Findings and Conclusions

1. Water quality is an important factor to users of Cherry Creek Reservoir, and any water quality standards imposed should consider all types of recreationists.

2. In general, only a few pollutants which are aesthetic and not physically harmful, are affecting recreationists at the reservoir. These pollutants are mainly caused by the recreationists themselves.

3. While an understanding of users' perceptions, values, and behavior is important, other factors such as costs, projected growth, public health and safety, and water

and land availability need to be assessed to develop water quality standards for Cherry Creek Reservoir.

Dr. Aukerman's study points out several interesting conclusions. In general, the users perceive the pollution in Cherry Creek Reservoir from an aesthetic point of view, as evidenced by their dislike for oil, gas, grease, litter, scum, and soaps and detergents. None of these perceived pollutants are constituent of wastewater or storm water runoff and as such, it becomes difficult if not impossible to relate these dislikes to a chlorophyll a or phosphorus limit.

Dr. Aukerman points out that it is more realistic to recognize that the quality of recreationists' experience will often need to be balanced with other goals that some people might consider equally important. Other goals according to Aukerman include economic costs, availability of land and water, projected population growth, and public health and safety.

Dr. Aukerman's report can be used to justify certain standards for the reservoir such as litter control. However, it cannot be used alone to set water quality standards and use classifications for the reservoir. More weight should be given to technical aspects of water quality in setting appropriate standards.

Chapter X, "Recommendations", describes the recommended water quality standards for the reservoir. These recommendations take into account Dr. Aukerman's report along with proposed chlorophyll a and total phosphorus limits. The Task Force considered each of the water quality goals and Dr. Aukerman's study concerning the user perception of the reservoir. The Task Force determined it was inappropriate to change any of the uses of the reservoir and agreed that a maximum trophic status for the reservoir could be 40 ug/L of chlorophyll a but that 40 ug/L would be too high. A lower chlorophyll a limit would be an acceptable goal and it should not impair the existing reservoir uses.

SELECTED WATER QUALITY GOALS

Based on the information stated above, the Task Force refined goals for Cherry Creek Reservoir. These goals, described below, relate to the three general water quality goals mentioned earlier in this chapter and account for technical considerations for defining an acceptable trophic status for the reservoir. Future reservoir water quality conditions and point and nonpoint control options were evaluated to determine if they could meet the following refined study goals:

1. Maintain the present use classifications of the reservoir;

2. Maintain the existing numeric water quality standards for the reservoir;

3. Maintain the chlorophyll a as close as possible to existing conditions considering such factors as feasibility and economics;

4. Maintain the existing use classifications and identify a trophic status; e.g., a chlorophyll a and total phosphorus concentration which would allow the present uses of the reservoir to continue; and,

5. Define appropriate point and nonpoint control measures necessary to meet the recommended chlorophyll a and total phosphorus limit.

With this set of study goals, the remainder of the report describes how these goals could be achieved. Also, details of the technical aspects of the study are described.

III. STUDY DESIGN AND SAMPLING METHODS

A comprehensive water quality investigation was conducted on Cherry Creek Reservoir as well as the Cherry Creek basin. All work related to reservoir sampling and data interpretation was completed by the Colorado Department of Health (CDH), and all basin sampling, data analysis, and basin characteristics were completed by DRCOG in cooperation with the U.S.G.S. It was necessary to conduct an in-depth investigation of both the reservoir and basin because of the complex interaction of the two. Projections of future land use and nutrient loading in the basin were made, and used to determine the impacts of growth on water quality in the basin and reservoir. These future projections were used in the reservoir modeling effort to define future changes in water quality as a result of the growth and development within the basin.

Data collection from the reservoir and basin was conducted from November, 1981 through November, 1982. The monitoring program included collecting samples in-lake as well as collecting ambient and storm event samples from the surface waters in the basin, and collecting groundwater samples from fixed monitoring wells located throughout the basin. Data from the monitoring program were used to: (1) assess the water quality conditions in the reservoir and basin, (2) determine trends in the data, and (3) identify specific sources of nutrient loading. Since the data collected during 1982 is the only set of comprehensive, continuous data, all conclusions drawn on Cherry Creek Reservoir are based on this set of data.

Sampling Methods

Reservoir samples were collected by the CDH from three separate areas within the reservoir. Monthly samples were collected from each area January through May and October through December, and twice monthly from June through September. Samples from each area of the reservoir were collected at two meter intervals over the entire vertical profile of the water column. Specific information regarding sampling methodology, location, frequency and water quality variables analyzed can be found in the Reservoir Sampling and Modeling report prepared by the CDH.

Surface Water Monitoring

Surface water monitoring stations were located on six major tributaries to Cherry Creek. Locations of the surface water monitoring stations are shown on Figure 3 and listed in Table 2.

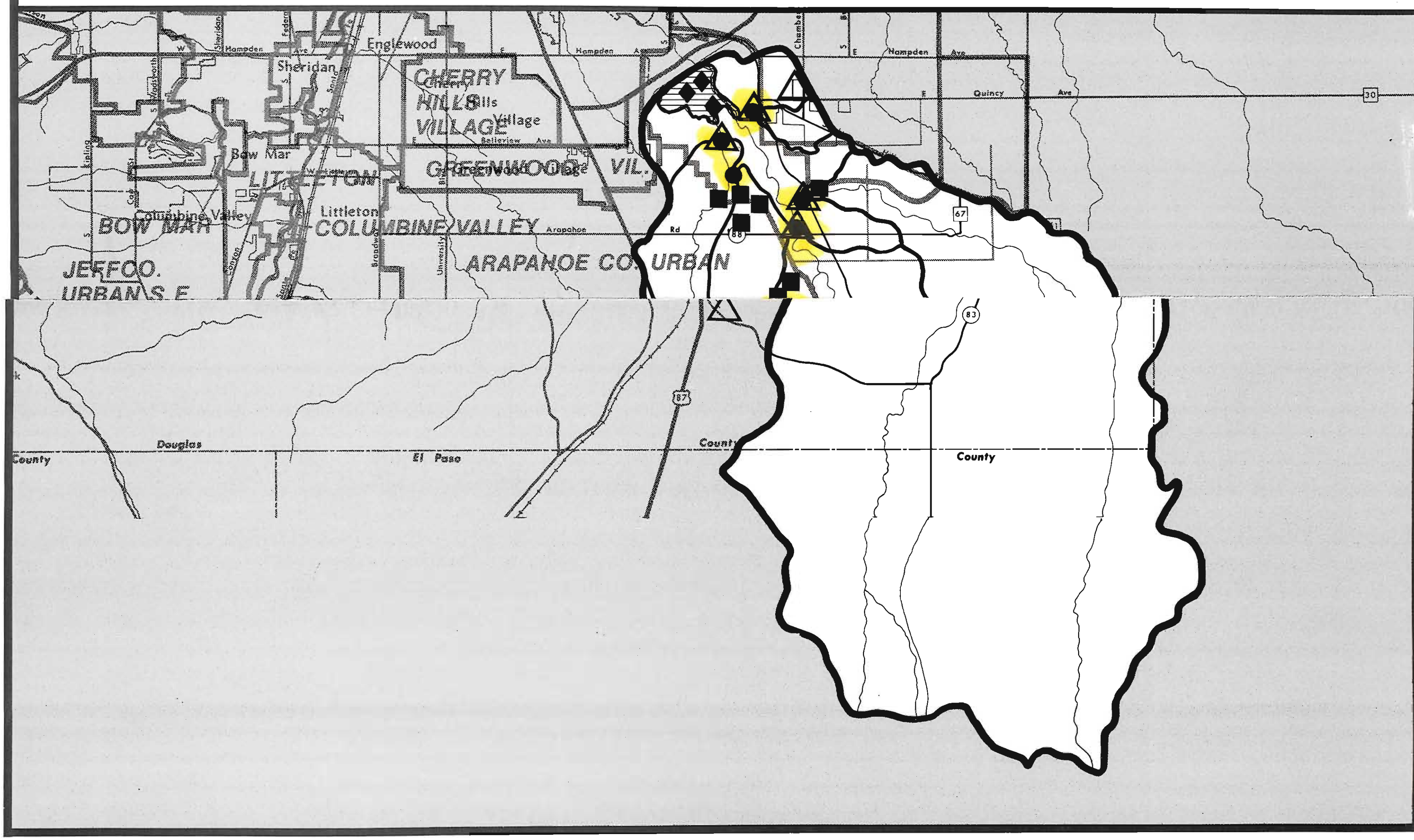
Table 2
Surface Water Monitoring Stations

USGS Identification Number	Location
06712450	Cherry Creek at Arapahoe Road, near Aurora, Colorado
06712495	Piney Creek at Parker Road, near Aurora, Colorado
06712855	Cherry Creek Tributary No. 1 near Aurora, Colorado (Shop Creek)
06712950	Lone Tree Creek at Mouth, near Aurora, Colorado
06712960	Cottonwood Creek above Cherry Creek Lake, Colorado
06712440	Happy Canyon Creek above Jordon Road, near Aurora, Colorado

All stations were equipped with a staff gage and strip chart recorder at a minimum to record stream flow. Three stations, Cherry Creek, Cottonwood Creek, and Piney Creek were equipped with automated sampling and recording equipment in addition to the strip chart recorder. This equipment was used to record stream flow at 5-minute intervals and collect and refrigerate individual samples form storm-induced runoff events. Raingages were installed at nine locations throughout the basin (See Figure 3) to record the amount of precipitation occurring during any storm event and to estimate total basin rainfall.

FIGURE 3

CHERRY CREEK RESERVOIR BASIN, SUB-BASINS AND MONITORING SITES



Over the 12-month sampling period, ambient samples were collected once-a-month from November through March and twice-a-month from April through October. Storm events were monitored from March through September, 1982, with a maximum of nine storms monitored at Cottonwood Creek and a minimum of two storms monitored at Lone Tree and Piney Creeks. The number of storms monitored at the other stations varied but fell within the range of 2 to 9 storms. The reason for the variability in the number of storms sampled was due to the absence or presence of storm water runoff. Not all storm events produced runoff at each station due to either specific basin characteristics or spatial variability in the storm event. Originally, one set of samples was to be taken from a snowfall-induced runoff event during the January through March period. However, no significant snowfalls occurred during this period.

Samples collected from the surface water stations were analyzed for the variables listed in Table 3.

This table lists all variables quantified from storm event samples, ambient samples, and groundwater samples. All laboratory analyses were performed by the Metropolitan Denver Sewage Disposal District #1 (MDSDD #1) laboratory. Trace elements were analyzed for both the total and dissolved fractions. Samples were analyzed for cadmium, copper, iron, lead, manganese, and zinc.

Sample Collection

All surface water samples were collected by USGS personnel with assistance from DRCOG personnel. Ambient samples were collected according to standard procedures recognized by the USGS.

Once samples were collected, they were preserved as follows:

1. Orthophosphate, dissolved phosphorus, soluble metals: filtered, placed in acid-rinsed bottles.

2. Total organic carbon: preserved with hydrochloric acid.

3. Total metals: preserved with nitric acid.

4. Fecal coliform: raw sample, chilled.

Table 3

Water Quality Variables Analyzed for in Surface Streams and Groundwater

	Variable	Surface Streams: Event[1]	Surface Streams: Ambient	Groundwater
1.	Temperature[2]		x	x
2.	pH[2]	x	x	x
3.	Specific Conductance[2]	x	x	x
4.	Total Suspended Solids	x	x	
5.	Total Dissolved Solids	x	x	x
6.	Dissolved Oxygen[2]		x	
7.	Fecal Coliform		x	x
8.	Carbonaceous BOD_5	x	x	
9.	Alkalinity	x	x	x
10.	Total Organic Carbon	x	x	
11.	Dissolved Organic Carbon	x	x	
12.	Nitrogen Species			
	a. Total Kjeldahl	x	x	x
	b. Ammonia	x	x	x
	c. Nitrite	x	x	x
	d. Nitrate	x	x	x
13.	Phosphorus Species			
	a. Total	x	x	x
	b. Ortho[3]	x	x	x
14.	Trace Elements[4]	x	x	x

[1] Discrete storm event samples collected over the storm hydrograph were composited prior to analysis.

[2] Measured on-site.

[3] Orthophosphate was dropped in March, 1982 and replaced with Total Dissolved Phosphorus.

[4] See Test for explanation of selected trace elements.

5. Total phosphorus, total Kjeldahl nitrogen, ammonia, nitrate and nitrite, chemical oxygen demand: preserved with sulfuric acid.

6. Remainder of constituents: raw sample, chilled.

All samples were given to the MDSDD #1 laboratory and analyzed within the prescribed holding time. Instantaneous stream flow discharge measurements were made at the time of sampling for ambient samples.

Storm events were sampled over the duration of the storm. Samples were either collected by automatic sampling equipment or were manually sampled. Once the discrete samples were collected from the storm event, the samples were composited into one flow-weighted sample. This composite sample was taken to the MDSDD #1 laboratory for analysis. Due to the long duration of the storm events, composite samples were not analyzed for dissolved oxygen, temperature, or fecal coliform as the holding time would have been exceeded for the fecal coliform and dissolved oxygen, and temperature was not accurately represented by the composite sample. The storm event discharge was recorded on strip charts and presented as the total volume of water (ft^3) recorded at the station over the duration of the storm.

Groundwater Monitoring

Twelve shallow, alluvial wells were monitored by the USGS. These twelve wells, shown on Figure 3, were sampled on a monthly basis to determine the quality of the alluvial groundwater in the basin. Table 4 lists the wells and provides their identification number.

Table 4

Groundwater Monitoring Stations

Well No.	USGS Identification No.	Elevation of Land Surface (ft)	Depth of Well (ft)
1	393609104501501	5635	50
2	392658104460601	5972	64
3	392842104460501	5897	70
4	393101104455201	5846	72
5	392329104453291	6087	38
6	393416104481701	5705	52
7	393451104480601	5673	57
8	393617104493901	5628	68
9	393634104501301	5611	64
10	393618104505001	5620	42
11	393636104483401	5644	70
12	393234104465601	5764	57

In addition to analyzing for the water quality variables listed in Table 3, monthly depth-to-water measurements were recorded at the time of sampling. All groundwater samples were analyzed by the MDSDD #1 laboratory.

Sample Collection

Prior to collecting groundwater samples, all wells were either bailed or pumped a few hours to 24 hours ahead of sample collection. This action was necessary to evacuate water which had been standing in the well and provided fresh alluvial groundwater for the sample. Sample collection was accomplished by either bailing water from the well or pumping the well. Samples were placed in plastic bottles, filtered, or preserved with acid according to standard procedures.

IV. BASIN CHARACTERISTICS AND WATER QUALITY

This chapter details the physical characteristics of the Cherry Creek Reservoir Basin and the results of the tributary and groundwater quality monitoring programs. Basin characteristics measured include basin and sub-basin areas, population projections and land use. Population and land use projections were developed for the years 1985, 1990, 2000 and 2010. Present wastewater management was analyzed and flows were projected for the same years. Land use and wastewater flow projections were used in Chapter VII to develop nutrient loading to the reservoir for those management scenarios described in Chapter VI. These loadings are used in the reservoir modeling to assess future water quality.

Population, land use and wastewater flow projections were made for those developments and districts identified in this study in May 1983. It is realized that future unknown developments may significantly increase these projections, but it was not possible to continuously update projections in this study. The effect of future unknown developments and accelerated growth would be that projections would actually be realized prior to the projected date. This would hasten reservoir enrichment and eutrophication processes. Conversely, a slump in real growth would slow reservoir enrichment and aging. The consequences of projections used in this study being surpassed or never reached is discussed further in Chapter VII.

The Cherry Creek Reservoir Basin is shown in Figure 2. The basin is long and narrow and of moderate size. It is presently largely undeveloped except in its northern portion, but much growth is anticipated in the future.

BASIN CHARACTERISTICS

Climate

The climate of the Cherry Creek Basin is considered to be semi-arid with moderate temperatures. Temperatures below freezing can be expected from November through May, but sustained freezes lasting longer than a week are infrequent. Likewise, summer maximum daily temperatures above 90 degrees Fahrenheit occur usually during less than twenty days during each summer.

Mean annual precipitation recorded during a 14-year period of record (1969-1982) at the Cherry Creek Reservoir dam raingage is 18.9 inches. Average rainfall reported by the Army Corps of Engineers is 18.5 inches. However, mean annual precipitation recorded at Stapleton International Airport, which is the reference station for the Denver area, is approximately 15 inches. The higher recorded precipitation at the Cherry Creek dam raingage may be due to this gage lying within a preferred thunderstorm track or gage location and exposure. It was concluded in the Denver Regional Urban Runoff Program (DRURP) that north and south thunderstorm tracks do exist in the area and the Cherry Creek dam gage lies beneath the southern track.[3] Large spatial variation in precipitation is characteristic of the Denver region in general and is discussed in the DRURP report.

The Cherry Creek Reservoir Basin receives precipitation from four general types of storms: summer thunderstorms and cloudbursts, upslope rainstorms and snowstorms. Approximately two-thirds of the annual precipitation is received during spring and summer from thunderstorms and upslope events. Severe, localized cloudburst thunderstorms producing an inch of rain per hour may also occur and produce flooding.

Physiography

The Cherry Creek Reservoir Basin is situated in the Piedmont Region of Colorado between the Rocky Mountains to the west and High Plains to the east. The basin is presently largely undeveloped and consists mostly of gently sloping grasslands, oakbrush communities and coniferous forests. Most of the basin is grassland. Elevations range from 7,600 feet (2,316 meters) in the upper basin to 5,500 feet (1,692 meters) at the reservoir (at multi-purpose pool level). The reservoir basin and major tributaries are shown in Figure 3.

Cherry Creek itself largely lies within a broad alluvial floodplain consisting of sand and gravel except for several areas of exposed bedrock such as in Castlewood Canyon and other areas in the upper basin. Alluvial deposits near the reservoir are as much as 50 feet (15.2 meters) deep.

Below the dam, large segments of Cherry Creek are channelized as it flows through Denver County and borders the downtown Denver area. Much of this portion of the creek has been developed into a greenway. Cherry Creek intersects the South Platte River at Confluence Park (river mile 317.7).

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[3]Denver Regional Council of Governments, "Urban Runoff Quality in the Denver Region," September 1983.

Geology

Cherry Creek is located approximately in the center of the Denver Basin, a geological feature of approximately 1,000 square miles which was formed during the late Cretaceous period. The area is underlain by nearly 20,000 feet of primary, secondary and recent sedimentary deposits. The Denver formation, one of the most recent of the deposits, is the only bedrock in most of the Cherry Creek basin. Alluvial deposits of the Pleistocene age cover the valley slopes and the channel bottom to depths as great as 100 feet or more. The Denver formation is made up of clay stones, siltstones and sandstones which are reasonably compact but not granularly cemented.

Soils

Soils information for Cherry Creek basin within Arapahoe and Douglas Counties was limited to general soil descriptions.[4] These soil descriptions or associations are not detailed here but are intended to provide planning level information only.

Within the portion of the basin which lies within Arapahoe County, four major soil associations have been identified. They are:

1.	Nunn-Haplustolls Association	0-8 percent slope
2.	Renohill-Buick-Litle Association	1-20 percent slope
3.	Truckton-Bresser Association	1-20 percent slope
4.	Fondis-Weld Association	0-5 percent slope

All of these soils are well drained, deep, and occur on nearly level to moderate slopes. The Nunn-Haplustolls Association occurs on terraces and floodplains. The other three associations occur on upland areas out of the floodplain.

Five major soil associations have been identified within the Douglas County portion of the basin. They are:

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[4]U.S. Geological Survey, "Water Resources Data, Colorado Water Year 1981. Vol. 1," USGS Water-Data Report CO-81-1, 1982.

1.	Torrifluvents-Table Mountain Association	0-3 percent slope
2.	Fondis-Kutch Association	1-40 percent slope
3.	Bresser-Newlin-Stapleton Assoc.	1-30 percent slope
4.	Brussett-Jarre Association	1-25 percent slope
5.	Weld-Bresser Association	0-25 percent slope

All of these soils are well drained to moderately well drained, deep, and range from level to steeply sloping. The Torrifluvents-Table Mountain Association occurs in the floodplain while the other four associations occur on uplands, terraces and valley sideslopes.

Hydrology

The Cherry Creek Reservoir Basin is relatively dry. Flow in most tributaries is intermittent, and only one tributary exhibited perennial flow to the reservoir during the study period. The only continuous record of streamflow within the basin is from the gage on Cherry Creek at Franktown (Figure 3). Reported average flow for this gage by the United States Geological Survey (USGS) for a 41-year period of record is 8.54 cubic feet per second (cfs). Extremes in flow for the period of record range from 9,170 cfs (in 1945) to 0.20 cfs (in 1946 and 1950). The Castlewood Dam located in Castlewood State Park several miles south of Franktown was destroyed in 1933 in a flood estimated to have been of greater magnitude than all other observed flows.

The only other source of flow data is provided by the Army Corps of Engineers in their monthly reservoir operations reports. In these, the Corps reports the total inflow to the reservoir as a function of the change in storage plus direct precipitation, minus evaporation and outflow. An analysis of a fourteen-year period of record of operations reports showed that surface flows to the reservoir are relatively small. Direct precipitation accounts for as much as an order of magnitude more water to the reservoir, using average conditions.

Pumping of alluvial groundwater in the lower portion of the reservoir basin has diminished flows from Cherry Creek reaching the reservoir. Except during spring runoff after a good snow year or during and shortly following storm events, surface flows in Cherry Creek disappear in the lower basin and water may only reach the reservoir from the alluvium. The effect of pumping on the reservoir itself is not known, however analysis of operations records indicate that the reservoir losses significant amount of water to the groundwater system.

Nonstorm-related flows from other tributaries to the reservoir are minimal. Perennial flows were only recorded in Cherry Creek Tributary Number 1 (Shop Creek) during the study period. Storm-related flows may far exceed ambient ones, but are typically short in duration.

Basin and Sub-basin Areas

The total area of the Cherry Reservoir Basin is 245,537 acres. The breakdown of total basin area to those tributaries which were monitored is shown in Table 5. Details of the measurement of basin and sub-basin areas can be found in Clean Lakes Technical Memorandum No. 1.

Table 5

Cherry Creek Reservoir Basin and Sub-basin Areas[1]

Station/Basin	Area[2] Acres	Area[2] Square Miles	Percent of Total Basin Area[2]
S1 - Cherry Creek	215,168	336.2	86.6
(Gage at Franktown)	(108,160)	(169)	(44.1)
(S6 - Happy Canyon Creek	(9,472)	(14.8)	(3.9)
S2 - Cottonwood Creek	9,101	14.22	3.7
(S4 - Lone Tree Creek)	(3,200)	(5.0)	(1.3)
S3 - Piney Creek	13,754	21.49	5.6
S5 - Shop Creek	614	0.96	0.3
Unmonitored area adjacent to Cherry Creek Reservoir	6,900	10.78	2.8
TOTAL	245,537	383.65	100.0

1Source: Clean Lakes Technical Memorandum No. 1.

[2]Figures in parentheses are a subset of and included in the above figure.

It was assumed that basin and sub-basin areas would not change significantly in the future due to drainage improvements or other development-related activities.

Population

No estimate was made of current basin population. Three scenarios of population projections were developed due to the present, tremendous uncertainty in growth in northern Douglas County and southern Arapahoe County and widely varying population projections. Projections were generated using: 1) DRCOG population allocations,[5] 2) Douglas County Planning Department projections,[6] and 3) developer projections.[7] DRCOG allocations are usually much lower than developer projections which are representative of development under more optimal economic and market conditions. Douglas County projections are moderate and fall between the other two scenarios.

Projections were made for all major development areas shown in Figure 2 and other intervening areas with substantial populations projections are contained in Tables 6, 7 and 8 using DRCOG, Douglas County and developer expectations, respectively. It should be noted that due to a lack of available data, the same set of population projections are used in all three scenarios for the following areas: Greenwood Village, Smoky Hill, and El Paso County. Also, projections for the Hughes Property were adjusted to reflect that portion of this future development area within the basin. Other special situations are footnoted on each table. The development of population projections is detailed in Clean Lakes Technical Memorandum No. 3.

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[5] Denver Regional Council of Government, "1981-82 Report on Regional Growth and Development," DRCOG, October 1982.

[6] Douglas County Planning Department, "Douglas County Population, Employment and Growth, 1982 Update," Douglas County Planning Department, May 1982.

[7] Ibid.

Table 6

Cherry Creek Reservoir Basin Population Projections
Based Upon DRCOG Population Allocation[1]

Development Areas:	1980	1985	1990	2000	2010[8]
Arapahoe[2]	0	0	0	0	0
Aurora[3]	6,900	7,000	7,000	7,000	7,000
Cottonwood	50	1,800	3,400	4,200	(5,430)
Greenwood Village[4] (Denver Basin)	2,700	3,500	4,500	6,400	8,250
Inverness[2]	0	0	0	0	0
Lincoln Park West[5]	0	0	0	0	0
Parker	600	3,400	6,600	9,400	14,330
Pinery	2,700	3,600	6,300	13,000	17,700
Rampart Range[7]	0	0	0	0	0
Smoky Hill[4]	1,487	5,425	9,362	17,237	25,110
Stroh Ranch[7]	0	0	0	0	0
Stonegate	0	1,100	4,000	5,750	(7,500)
Castle Rock (Village Area)	0	7,900	13,850	28,650	42,410
Hughes Property[7]	0	0	0	0	0
Other Areas:					
Arapahoe County[4] (Non-Urban)	2,500	4,900	5,500	7,600	8,900
Douglas County	12,300	14,300	15,500	18,400	21,100
El Paso County[4]	2,144	2,644	3,144	4,144	5,140
Franktown[6]	0	0	0	0	0
Total Population	31,381	55,569	79,156	121,781	162,870

[1] Source: Clean Lakes Technical Memorandum No. 3.
[2] Non-residential population.
[3] Assumed population would stabilize in 1985 and no further growth would occur.
[4] Projections same for all 3 scenarios developed.
[5] Projections of <50 persons given through year 2000.
[6] Projection included in Douglas County non-urban figures.
[7] No DRCOG projections are available for development due to it still being in planning stage and not recognized by DRCOG.
[8] Population projected by lienar extrapolation, value in parenthesis indicates full build-out.

Table 7

Cherry Creek Reservoir Basin Population Projections
Based Upon Douglas County Figures[1]

Development Areas:	1980[6]	1985	1990	2000	2010[7]
Arapahoe[2]		0	0	0	0
Aurora[3]		7,000	8,500	10,000	10,000
Cottonwood		1,950	3,700	4,450	(5,430)
Greenwood Village[4] (Denver Basin)		3,500	4,500	6,400	8,250
Inverness[2]		0	0	0	0
Lincoln Park West[2]		0	0	0	0
Parker		3,600	7,200	9,800	14,040
Pinery		3,900	6,900	13,650	20,130
Rampart Range		3,400	6,100	14,000	21,000
Smoky Hill[4]		5,425	9,362	17,237	25,110
Stroh Ranch		1,500	5,500	10,500	(15,000)
Stonegate		1,100	4,000	5,750	(7,500)
Castle Rock (Village Area)		7,900	13,850	28,650	42,410
Hughes Property[5]		164	410	492	720
<u>Other Areas</u>:					
Arapahoe County[4] (Non-Urban)		4,900	5,500	7,600	8,900
Douglas County		14,300	15,500	18,400	21,120
El Paso County[4]		2,644	3,144	4,144	5,140
Franktown		300	300	400	460
Total Population		61,583	94,466	151,473	205,210

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[1] Source: Clean Lakes Technical Memorandum No. 3.
[2] Non-residential population.
[3] Assumed remaining undeveloped land in basin would develop by 2000 and result in populations shown.
[4] Projections same for all 3 scenarios developed.
[5] Forty-one percent of projection used: this represents portion of area in Cherry Creek Basin.
[6] No data.
[7] Population projected by linear extrapolation, value in parenthesis indicates full build-out.

Table 8

Cherry Creek Reservoir Basin Population Projections
Based Upon Developer Figures[1]

Development Areas:	1980[7]	1985	1990	2000	2010[8]
Arapahoe[2]		0	0	0	0
Aurora[3]		7,000	8,500	10,000	10,000
Cottonwood		2,444	5,431	5,431	(5,430)
Greenwood Village[4] (Denver Basin)		3,500	4,500	6,400	8,250
Inverness[2]		0	0	0	0
Lincoln Park West		0	0	0	0
Parker		6,000	12,000	14,000	19,570
Pinery		3,924	7,841	18,311	(26,155)
Rampart Range		4,453	8,905	20,778	(29,700)
Smoky Hill[4]		5,425	9,362	17,237	25,110
Stroh Ranch		1,648	7,754	14,772	(15,000)
Stonegate		1,200	5,000	7,500	(7,500)
Castle Rock (Village Area)		8,081	18,162	42,337	(52,000)
Hughes Property[6]		225	600	750	(1,060)
<u>Other Areas</u>:					
Arapahoe County[4] (Non-Urban)		4,900	5,500	7,200	8,900
Douglas County		15,976	18,997	24,312	29,627
El Paso County[4]		2,644	3,144	4,144	5,140
Franktown		0	0	0	0
Total Population		68,420	115,696	193,172	243,442

[1] Source: Clean Lakes Technical Memorandum No. 3.
[2] Non-residential population.
[3] Assumed remaining undeveloped land in basin would develop by 2000 and result in populations shown.
[4] Projections same for all 3 scenarios developed.
[5] Projection included in Douglas County non-urban population.
[6] Figures are 41% of projections. This is portion of area within Cherry Creek Basin.
[7] No data available.
[8] Population projected by lienar extrapolation, value in parenthesis indicates full build-out.

It can be seen from Tables 6, 7 and 8 that there is a fairly broad range in population projections, depending upon the source. Total basin projections ranged from 162,870 to 243,442 persons in the year 2010.

Land Use

Present basin land use was measured and future projections were made for those land uses listed and defined in Table 9. Nonpoint loads were estimated in the future based upon the land use projections (Chapter VII) and present land use was used to correlate 1982 measured stormloads to the degree of development within a sub-basin. Details of present land use and projections can be found in Clean Lakes Technical Memorandum No. 2.

Present Land Use

Present basin land use was measured from a series of low-level aerial photographs which covered the basin. Land use was tabulated by sub-basin. Individual acreages were adjusted because of distortion in the photographs to reflect the corrected sub-basin area measured from USGS topographic maps (Table 5). The distribution of present land use by monitored sub-basin is contained in Table 10.

Future Land Use

As was done with population projections, two scenarios of future land use were generated due to the uncertainties in future growth and great disparity in growth projections in the basin. One scenario was developed using primarily DRCOG population and employment allocations;[8] and another scenario was formulated using information and projections from developers. Projections were only made for those developments

Land use projections were first made by development areas for those developments and other contributing areas listed in Table 11.

[8] DRCOG, "1981-82 Report on Regional Growth and Development."

Table 9

Descriptions and Abbreviations of Various Land Uses Defined in the Cherry Creek Reservoir Basin

Land Use	Abbreviation	Description
Commercial	C	1. Commercial Office 2. Commercial retail, includes shopping centers, malls.
Industrial	I	1. Light and heavy industrial, including warehouses, manufacturing and processing plants.
Multi-Family	MF	1. >10 dwelling units/acre, or attached housing of lower density.
Single Family (very large lot)	SF_{vll}	1. <1 dwelling unit/acre, usually >3-acre lots.
Single Family (large lot)	SF_{ll}	1. 1-3 dwelling units/acre.
Single Family (sub-division)	SF_s	1. >3 dwelling units/acre.
Public	PU	1. Public facilities, principally, schools and military bases.
Parks	P	1. Parks, including golf courses.
Agriculture	A	1. Dry land agriculture and irrigated croplands, includes sod farms.
Forest	F	1. Land consisting of deciduous and coniferous trees, includes oak brush and coniferous forests.

Table 9 continued

Land Use	Abbreviation	Description
Vacant	V	1. Idle land juxtaposed between developments, includes some range land and platted land.
Pervious Area	PA	1. This classification is used in future scenarios only, equals difference between the sum of other developed land uses and the total basin area.
Single Family	SF	1. All single family development, refinement not possible.

Projections by development area or other contributing areas were then allocated to sub-basins depending upon the distribution of the areas between sub-basins. If an area was not completely within a sub-basin, land use was distributed based upon the percentage of the area within the sub-basin. Both DRCOG and developer growth scenario land use projections by sub-basin are contained in Tables A-1 through A-7 in Technical Memorandum No. 2. These projections are summarized in Table 12.

Park, forest, vacant, and agricultural land uses could not be projected directly. Instead, these land uses were treated equally and calculated as the pervious sub-basin area by subtracting the total developed area for a given year and scenario from the total sub-basin area. Derivation of future land use projections is discussed in detail in Clean Lakes Technical Memorandum No. 2.

Table 10
Distribution of 1982 Land Use (in acres) Within
Cherry Creek Reservoir Basin

	Tributary or Area[1]						
Land Use[2]	Cherry[3] Creek	Cotton-wood[4] Creek	Piney Creek	Lone Tree Creek	Shop Creek	Happy Canyon Creek	Unmoni-tored Creek
C	86.1	172.9	.0	.0	2.5	.0	.0
I	150.6	72.8	.0	2.9	.0	.0	.0
MF	21.5	3.6	.0	.0	16.6	.0	62.1
SFvll	NM	.0	2,021.0	.0	.0	28.4	.0
SF11	NM	163.8	2,008.0	96.0	19.0	833.5	621.0
SFs	NM	182.0	151.3	.0	238.2	.0	558.9
SF	9,682.6	NM	NM	NM	NM	NM	NM
PU	86.1	618.9	4.1	352.	3.7	.0	276.0
P	15,707.3	764.5	.0	150.1	8.6	303.1	2,863.5
A	52,070.2	3,513.0	1,554.2	1,594.0	191.6	1,790.2	627.9
F	32,705.5	18.2	.0	.0	.0	1,572.4	.0
V	104,658.1	3,591.3	8,014.6	1,005.0	133.8	4,944.4	1,890.6
TOTAL	215,168.0	9,101.0	13,754.0	3,200.0	614.0	9,472.0	6,900.0

[1]NM = Not Measured.

[2]Abbreviations defined in Table 9.

[3]Includes Happy Canyon Creek drainage.

[4]Includes Lone Tree Creek drainage.

BASIN WATER QUALITY

Tributary Water Quality

Base and stormflows were monitored in the six major tributaries to Cherry Creek Reservoir in order to assess tributary water quality and loading to the reservoir. Tributary sub-basins and locations of monitoring stations are shown in Figure 3. Only three of the tributaries monitored flow directly into the reservoir. Happy Canyon Creek and Piney Creek are tributary to Cherry Creek, and Lone Tree Creek is tributary to Cottonwood Creek. Details of the sampling methodology and constituents monitored can be found in Chapter III.

Table 11

Development Areas and Contributing Areas
In The Cherry Creek Reservoir Basin
For Which Land Use Projections Were Made[1]

Development Area	Other Areas
Arapahoe W & S	Douglas County Non-Urban[2]
Villages at Castle Rock	Smoky Hill[2]
Cottonwood	
Hughes Property[2]	
Inverness	
Meridian	
Parker	
Pinery	
Rampart Range[2]	
Stonegate	
Stroh Ranch	

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[1]Locations of areas are shown in Figure 2. Developments are those identified in this study as of May 1983.

[2]Not all of area within Cherry Creek Basin.

Baseflow was only observed in Cherry, Cottonwood and Shop Creeks. All creeks flowed at least during one storm event. Flow was monitored from just one storm in Happy Canyon Creek, but no quality samples were taken.

A total of 24 constituents were analyzed in tributary samples by the Metropolitan Denver Sewage Disposal District No. 1 (MDSDD#1). Average concentrations and total annual tributary loads in baseflow during 1982 were calculated for twelve of these constituents. The other constituents are total and soluble forms of the metals cadmium, copper, iron, lead, manganese and zinc. These metals were never found in very high enough concentrations to be toxic to aquatic life or low enough to limit growth of biota and were not thought to pose a problem in the reservoir. Results of the metals analyses will be available in a report by the USGS. Average concentrations and total 1982 tributary loads for constituents evaluated in baseflow are shown in Table 13.

Table 12

Summary of Land Use Projections For Cherry Creek Reservoir Basin[1]
(Figures Are in Acres)

	1985		1990		2000		2010	
	DRCOG	Developer	DRCOG	Developer	DRCOG	Developer	DRCOG	Developer
Commercial	660	1,040	1,060	2,130	2,280	3,920	3,330	5,220
Industrial	450	620	870	1,530	1,520	2,560	2,040	3,410
Multi-Family	140	170	190	290	260	520	510	780
Single Family								
<1 du/acre	13,360	16,450	15,620	21,110	18,370	26,090	20,670	30,750
1-3 du/acre	14,100	17,120	16,720	22,340	18,920	25,810	20,730	29,150
3+ du/acre	2,500	3,490	3,470	5,300	5,220	8,030	7,450	9,400
Public	830	860	870	940	940	940	940	940
Pervious Area	213,497	205,787	206,737	191,897	198,027	177,667	189,867	165,887
TOTAL	245,537	245,537	245,537	245,537	245,537	245,537	245,537	245,537
% imper.	13%	16%	16%		19%		23	

[1]Source: Clean Lakes Technical Memorandum No. 2. Projections were made for those developments which were identified in this study as of May 1983.

The highest concentrations of ten of the twelve constituents reported occurred in baseflow from Shop Creek. Concentrations of total and dissolved phosphorus and total nitrogen were particularly higher in this sub-basin. Only nitrate-nitrogen and total dissolved solids were found in higher concentrations in other sub-basins.

Sources of pollutants in baseflow are varied but may be related to development, especially in Shop Creek. This is the most intensely developed sub-basin in the reservoir basin. Dry-weather urban runoff resulting from irrigation water draining off lawns and activities such as car washing may contain high levels of nutrients from fertilizers and detergents.

Table 13

Average Flow-Weighted Concentrations (mg/L) and Annual Loads (lbs.) of Constituents in Baseflow[1]

	TRIBUTARY[2]					
	Cherry Creek (06712450)		Cottonwood Creek (06712960)		Shop Creek[3] (06712855)	
Estimated Annual Flow (cu.-ft.)	2.37×10^6		1.56×10^6		1.35×10^7	
Number of Samples	9		2		15	
Constituent	Conc.	Annual Load	Conc.	Annual Load	Conc.	Annual Load
Total Nitrogen	4.5	660	0.4	36	9.4	7,900
Ammonia Nitrogen	0.07	10	0.05	4.9	0.1	120
Total Kjeldahl Nitrogen	0.6	90	0.3	29	0.7	590
Nitrite and Nitrate Nitrogen	3.9	580	0.07	7.2	8.5	7,200
Nitrite Nitrogen	0.05	7	0.01	1.0	0.03	25
Total Phosphorus	0.2	25	0.2	20	0.4	310
Dissolved Phosphorus	0.08	12	0.1	16	0.2	180
Total Dissolved Solids	450	67,000	1,000	100,000	950	800,000
Total Suspended Solids	95	14,000	28	2,700	150	130,000
Total Organic Carbon	4.0	590	4.2	41	8.9	7,500
Biochemical Oxygen Demand (5-day)	3.0	440	1.1	11	6.5	5,500

[1] Concentrations flow-weighted by instantaneous flow at sample site. Annual loads are concentrations multiplied by estimated annual flow and a conversion factor.

[2] Only tributaries with a baseflow reported. Number in parenthesis is USGS station identifier.

[3] Shop Creek is Cherry Creek Tributary No. 1.

As might be expected, Shop Creek contributed the greatest baseload of all constituents reported. This was due both to the higher concentrations of pollutants and large amounts of baseflow measured in this drainage. Shop Creek contributed 77 percent of the estimated annual baseflow to the reservoir. The source of this baseflow may be from groundwater and dry-weather urban runoff, but was not determined in this study.

Average concentrations and monitored loads in stormwater are shown in Table 14. Concentrations of most pollutants were higher in stormwater than baseflow. Only total dissolved solids was found in higher concentrations in baseflow in all tributaries monitored. Nitrite-plus-nitrate nitrogen was highest in baseflow from Cherry and Shop Creeks. This may be due to dilution effects of stormwater which may not be in contact with materials for sufficient time to dissolve or transport them.

Over half of the constituents reported had highest concentrations in stormwater from Cherry Creek. Total phosphorus, total suspended solids and biochemical oxygen demand were highest in Shop Creek.

Stormloads from the three storms monitored in Shop Creek were greatest for all constituents except total organic carbon. The loads of total suspended solids and phosphorus from Shop Creek were particularly high. Likewise, storm runoff volumes from the three storms monitored were high. This is due to the developed nature of this sub-basin and high percent of impervious surfaces (e.g., rooftops, streets, driveways) which don't allow percolation of rainfall. Removal of vegetation during construction activities may have also increased storm runoff and loads from this sub-basin.

It should be remembered that the stormloads contained in Table 14 are not annual loads. These loads are the sum of loads from the storms monitored at each sub-basin. Different numbers of storms were monitored at each sub-basin. For this reason, comparison of the stormloads in Table 14 is limited. Annual stormloads for 1982, 1985, 1990, 2000, and 2010 were calculated using other data and these projections are presented in Chapter VI.

Table 14
Average Flow-Weighted Concentrations (mg/L) and
Loads (lbs.) of Constituents in Tributaries from Monitored Storm Events[1]

	TRIBUTARY[2,3]									
	Cherry Creek (06712450)		Cottonwood Creek (06712960)		Piney Creek (06712495)		Lone Tree Creek (06712950)		Shop Creek[5] (06712855)	
Monitored Storm Flow (cu.-ft.)[4]	0.47×10^6		5.12×10^6		19,000		0.34×10^6		2.25×10^6	
Number of Storms Monitored	5		9		2		2		3	
Constituent	Conc.	Monitored Load	Conc.	Monitored Load	Conc.	Monitored Load	Conc.	Monitored Load	Conc.	Monitored Load
Total Nitrogen	17.0	502	2.6	838	1.5	17.6	1.5	31.3	9.9	1,390
Ammonia Nitrogen	0.6	18.4	0.1	41.7	0.4	0.43	0.06	1.3	0.3	36.3
Total Kjeldahl Nitrogen	16	474	2.2	690	1.4	16.8	0.8	17.0	9.6	1,355
Nitrite and Nitrate Nitrogen	1.1	32	0.5	144	0.2	0.3	0.7	14.0	0.4	50.7
Nitrite Nitrogen	0.1	3.3	0.03	10.8	ND	ND	0.04	0.87	0.1	15.0
Total Phosphorus	5.7	169	1.5	486	4.9	5.8	0.5	11.5	6.0	850
Dissolved Phosphorus	0.5	13.6	0.9	27.6	0.1	0.156	0.3	5.9	0.2	32.4
Ortho-Phosphate	ND[6]	ND	ND	ND	ND	ND	ND	ND	5.4	7,660
Total Dissolved Solids	120	3,640	480	152,500	100	122	810	17,314	84.0	11,740
Total Suspended Solids	880	261,500	880	282,520	460	5,500	270	5,653	970	1,369,200
Total Organic Carbon	120	3,420	23	7,430	9.4	111	7.6	162	9.2	1,300
Biochemical Oxygen Demand (5-day)	7.6	224	3.2	1,040	5.1	6.1	3.9	84.0	9.1	1,290

[1]Loads are total lbs from all storms monitored; concentrations were calculated by dividing total monitored load by total monitored storm runoff and multiplying the result by a conversion factor.
[2]Only one storm monitored at Happy Canyon Creek. No quality data available.
[3]Number in parenthesis is USGS Station Identifier.
[4]Represents sampled storm flow, not an annual estimate.
[5]Shop Creek is Cherry Creek Tributary No. 1.
[6]ND = No Data.

Groundwater Quality

Groundwater samples were collected by the USGS from the twelve wells shown in Figure 3. Monthly samples were taken and analyzed for several forms of nitrogen and phosphorus and other parameters by the MDSDD#1 laboratory. Several other duplicate samples were taken and analyzed by the USGS Central Laboratory in Denver for quality assurance. Details of the groundwater monitoring program are discussed in Chapter III.

Groundwater flow or movement was not directly assessed. Net groundwater movement was determined by analysis of the Army Corps of Engineers' Reservoir Operations Summaries. This analysis indicated that Cherry Creek Reservoir loses significant water to groundwater. Approximately 10 percent of the total inflow in 1982 was found to be lost to groundwater.

The quality of groundwater was evaluated as an input to the model. While the net movement of groundwater may be out of the reservoir, groundwater inflow may contribute nutrients and phosphorus. Loss of water by exfiltration through the reservoir bottom would most probably result in the deposition of phosphorus not assimulated by biota in sediments.

An estimate was made of groundwater flow through Cherry Creek alluvium to the reservoir by the USGS. It was assumed in the estimate that the saturated depth and width of the alluvium at the reservoir were 40 and 500 feet, respectively. Using calculated slopes, literature values of permeability, and Darcy's Law, flow to the reservoir from Cherry Creek alluvium was estimated as 128,290 cubic meters/year (104 acre-feet/year). The average total phosphorus concentration found in groundwater was applied to this flow to estimate phosphorus loading to the reservoir for modeling. This is discussed in Chapter VI on nutrient loading.

Average concentrations of the parameters monitored are shown for each well in Table 15. The results of the groundwater monitoring effort were not easily correlated to known activities or land uses within the basin. For example, the greatest average concentrations of total phosphorus and ammonia nitrogen were found at Well No. 5 which is furthest away from the reservoir and least influenced by development activities. Wells 2, 3, 4, 7, 11 and 12 are all situated below either development areas or irrigated, fertilized land and higher concentrations of nutrients would be expected from them. The highest average concentration of total nitrogen was found at Well No. 8 which lies within the currently undeveloped drainage of Wind Mill Creek.

Table 15

Average Concentrations of Constituents in Groundwater[1]
(Values in Parentheses are Estimates of Standard Deviation)

Well No.[2]	Water[3] Level (Ft.)	Total Phosphorus (mg/L)	Ortho-Phosphorus (mg/L)	Total Nitrogen[4] (mg/L)	Ammonia Nitrogen[5] (mg/L)	Nitrite/ Nitrate Nitrogen (mg/L)	Alkalinity (mg/L CaCO3)	Total Dissolved Solids (mg/L)
1	21.07 (6.15)	0.06 (0.06)	0.02 (0.01)	5.2 ND[6]	0.06 (0.0)	4.7 (2.1)	229 (25)	697 (382)
2	17.40 (0.92)	0.30 (0.12)	0.14 (0.10)	1.6 ND	0.07 (0.04)	0.85 (0.18)	142 (5)	261 (41)
3	5.08 (1.15)	0.21 (0.11)	0.08 (0.04)	0.9 ND	0.09 (0.04)	0.26 (0.33)	202 (25)	522 (56)
4	23.18 (0.46)	0.17 (0.10)	0.11 (0.01)	4.7 ND	0.10 (0.04)	4.1 (1.1)	215 (8)	374 (24)
5	4.21 (0.54)	0.80 (0.70)	0.33 (0.25)	0.9 ND	0.27 (0.08)	0.26 (0.47)	175 (5)	260 (24)
6	16.84 (0.55)	0.19 (0.15)	0.04 (0.03)	5.1 ND	0.08 (0.05)	3.9 (3.7)	183 (24)	316 (52)
7	14.93 (3.26)	0.23 (0.22)	0.08 (0.05)	2.1 ND	0.09 (0.08)	1.5 (0.70)	239 (25)	639 (61)
8	30.48 (0.70)	0.17 (0.10)	0.05 ND	8.0 ND	0.08 (0.05)	7.4 (1.8)	177 (25)	334 (42)
9	30.47 (0.83)	0.14 (0.12)	0.04 (0.03)	3.7 ND	0.09 (0.08)	2.8 (.5)	196 (60)	640 (80)
10	11.04 (0.21)	0.09 (0.07)	0.06 (0.04)	0.6 ND	0.08 (0.03)	0.09 (0.06)	198 (74)	627 (213)
11	42.88 (0.55)	0.17 (0.14)	0.13 (0.10)	3.8 ND	0.07 (0.03)	2.8 (0.6)	209 (14)	569 (75)
12	20.10 (2.90)	0.19 (0.12)	ND	2.9 ND	0.05 (0.1)	1.7 (0.7)	189 (8)	413 (25)

[1]Sample size equals 12 for all constituents except ortho-phosphate which equals 3 at the following wells: 1,2,3,5,6,7,9,10 and 11. Other sample sizes are as indicated: No. 4=10, No. 8=10, No. 12=4. Only samples analyzed by metro were used.
[2]Well locations are shown in Figure 3, and corresponding USGS identifiers are contained in Table 4.
[3]Equals depth below ground surface.
[4]No estimate of standard deviation available. Total nitorgen was not analyzed directly, but calculated as the sum of nitrite/nitrate plus total Kjeldahl nitrogen.
[5]Ammonia equals total dissolved as N.
[6]ND = No Data.

Concentrations of total phosphorus and total nitrogen were highly variable between and within the wells. Since it was determined that Cherry Creek Reservoir is primarily phosphorus limited and this nutrient was selected for control, levels of phosphorus in groundwater were analyzed in detail. The average concentration of total phosphorus for all 12 wells was 0.23 mg/L. This value is fairly high considering the insoluble nature of phosphorus in soils and rocks, and the high affinity of particulate surfaces for phosphorus. Average groundwater concentrations of phosphorus are reported as 0.02 mg/L by Wetzel.[9] Sources of phosphorus in groundwater in this study may be from agricultural and development-related activities and natural sources (e.g., soils, geologic materials), however contributions from these various sources could not be determined in this study.

Wastewater

Present Conditions

Currently, there are six wastewater treatment plants operating within the Cherry Creek Reservoir basin. This basin has three designated management agencies: Douglas County, Arapahoe County, and Castle Rock. The DRCOG Clean Water Plan (CWP) shows a total of ten wastewater treatment plants within the basin, however four facilities have not been constructed at this time.[10] Descriptions of individual plants, stream standards, and water quality planning issues for the Cherry Creek Basin are contained in the Clean Water Plan Technical Report 1981 Update.[11]

All present facilities provide secondary treatment with land application or non-discharging lagoons, as is recommended by current wastewater management policy. Total basin flows are shown as 1.04 mgd and 3.86 mgd in the CWP for the years 1980 and 1985, respectively. Actual present (1982) flows are between these two figures. Effluent is disposed of by slow-rate land application and rapid infiltration. Both of these treatment systems are being evaluated in this report.

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[9] R.G. Wetzel, "Limnology," W.B. Saunders Company, 1975. p. 239.

[10] DRCOG, "Clean Water Plan," DRCOG, 1983.

[11] DRCOG, "Clean Water Plan Technical Report 1981 Update," DRCOG, August 1981.

There is a void of water quality data that can be used to assess base-line conditions in the Cherry Creek Basin. It is assumed that the present reservoir condition is due to nonpoint source nutrient loading and not wastewater. This is due to both the small wastewater flow and methods of disposal.

Future Conditions

The Cherry Creek Reservoir basin is anticipated to experience much growth in the future which will result in increased wastewater flows. In order to evaluate the magnitude of future wastewater flows, two scenarios of wastewater flow projections were developed using DRCOG flows shown in the CWP and those provided by water and sanitation districts within the basin. This approach more realistically addresses the accuracy of the projections by yielding a range of flows for any given year.

Projections using DRCOG and district figures appear in Tables 16 and 17. District projections were lower than DRCOG projections for 1985, but were 9.6 mgd higher in the year 2010 and higher for all other years. These projections were used to estimate phosphorus and hydraulic loading to the reservoir from wastewater. The flow projections are independent of the level of treatment or method of effluent disposal. The quantity of wastewater and phosphorus actually reaching the reservoir will depend upon the level of treatment and method of disposal. For example, only a portion of the wastewater which is land applied will reach the reservoir and at a concentration much less than if it were directly discharged. The various treatment levels and methods of disposal are described in Chapter VI, and wastewater loading to the reservoir from the various management scenarios is shown in Chapter VII.

Table 16
DRCOG Wastewater Flow Projections
(millions of gallons per day)
For Cherry Creek Basin

District	1980	1985	1990	2000	2010
Arapahoe	0.2	1.2	1.9	2.9	3.9
Cottonwood	0	0.23	0.43	0.63	0.81
Inverness	0.56	0.86	1.0	1.30	1.6
Lincoln Park West	0	0.28	0.63	1.2	1.8
Parker	0.055	0.35	0.73	1.1	1.7
Pinery	0.22	0.30	0.55	1.2	1.6
Rampart Range[1]	0	0	0	0	0
Stroh Ranch[1]	0	0	0	0	0
Stonegate	0	0.14	0.52	1.0	1.5
Castle Rock	0	0.5	1.0	1.6	2.6
Hughes Property[1]	0	0	0	0	0
Total	1.04	3.86	6.76	10.93	15.5

[1]DRCOG projections not available. District not shown in Clean Water Plan.

Table 17
District Wastewater Flow Projections
(millions of gallons per day)
For Cherry Creek Basin

District	1980[2]	1985	1990	2000	2010
Arapahoe		0.38	1.67	4.30	7.0
Cottonwood		0.21	0.46	0.75	0.75
Inverness		0.56	0.86	1.0	1.3
Lincoln Park West		0.35	0.75	1.50	1.50
Parker		0.51	1.00	1.19	1.67
Pinery		0.33	0.67	1.56	2.20
Rampart Range[1]		0	0.58	1.8	3.4
Stroh Ranch[1]		0.16	0.68	1.3	1.30
Stonegate		0.14	0.52	1.0	1.50
Castle Rock		0.77	1.5	3.6	4.4
Hughes Property[1]		0.019	0.051	0.063	0.09
Total		3.43	8.74	18.1	25.1

[1] Based on developer population projections and flow rate of 85 gpcd, unless other numbers were provided.

[2] No data for 1980.

[3] No developer projections: DRCOG projections used.

V. RESERVOIR CHARACTERISTICS AND WATER QUALITY

Cherry Creek Reservoir was sampled from November 1981 through November 1982 in order to determine present water quality and trophic status. Physical and chemical parameters and phytoplankton were measured at regular intervals during this time period. Physical parameters measured included water temperature, turbidity, and secchi disc depth. Total ammonia, nitrite and nitrate, and soluble and total phosphorus were forms of nutrients monitored, and measurements of dissolved oxygen were taken throughout the water column.

This portion of the study was conducted by the CDH. The major findings and conclusions of their work are summarized in this chapter. Further details of the sampling methodology and findings of the reservoir sampling effort can be found in Chapter III of this document and in the final report by the CDH.[12]

RESERVOIR HYDROLOGY AND MORPHOMETRY

Cherry Creek Reservoir is operated by the U.S. Army Corps of Engineers (USACOE). It serves as a flood control structure and is a valuable recreational resource for the Denver region.

Releases from the reservoir have been rare in the past, and no releases occurred during the study period. This is because of the relatively dry nature of the reservoir basin. As was discussed in Chapter III, surface flows to the reservoir are small and operations records show a net loss of water from the reservoir to groundwater.

If inflows to the reservoir are sufficient, the USACOE maintains a multi-purpose pool level which results in a mean reservoir depth of 17.06 feet (5.2 m), surface area of 3.71×10^7 square feet (3.45×10^6 m^2), and a reservoir volume of 13,960 acre-feet (1.72×10^7 m^3). The water level has usually not exceeded the multi-purpose pool in the past, and was below it in 1982.

Monthly reservoir operations reports are kept by the USACOE. Physical characteristics at recreational pool level and during 1982 were gathered from these reports and are shown in Table 18.

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[12] Colorado Department of Health, October 1983.

The impact of nutrients on reservoir water quality is magnified by the reservoir hydrology and morphology. This is caused by the combined influence of: 1) relatively small inflows, 2) loss of water to groundwater, 3) a large surface area to volume ratio, and 4) high evaporation. The result of these factors is that Cherry Creek Reservoir acts much like a sink for sediment and nutrients. There is no large flushing of the reservoir by inflows. It can be seen from Table 1 that, based upon 1982 conditions, it would take over 5 years for inflows to replace the entire reservoir volume. Replacement of water "flushes" the reservoir, thereby diminishing the effects of nutrients (especially phosphorus) on eutrophication and water quality.

Table 18
Physical Characteristics of Cherry Creek Reservoir

Characteristic	Average[1]	1982
Rainfall (inches)	18.50	20.47
Mean Depth (ft.)	17.06	16.08
Surface Area ($ft.^2$)	3.71×10^7	3.45×10^7
Volume (acre-feet)	13,960	12,240
Surface Inflow (acre-feet)	No data	1,090
Surface Outflow (acre-feet)	0	0
Evaporation (acre-feet)	2,550	2,310
Hydraulic Retention Time (yrs)[2]	No data	5.00

[1]At multi-purpose pool level.

[2]Based upon gross total inputs (volume divided by rain plus surface inflow).

RESERVOIR WATER QUALITY

Cherry Creek Reservoir has been classified by the Colorado Water Quality Control Commission for the following uses: recreational class 1, warm water aquatic life class 1, water supply, and agriculture. The standards applicable to these classifications are presented in Chapter VI. Present and future reservoir water quality were evaluated towards protection of the reservoir beneficial uses and maintenance of the associated water quality standards. Results of the reservoir sampling conducted by the CDH are discussed below.

Temperature and Dissolved Oxygen

Water temperatures in Cherry Creek Reservoir were found to vary within a range of 20°C and were homogenous throughout the water column for much of the year. The reservoir was isothermal from November 1981 through May of 1982 (Figure 4). A temperature gradient was noted in June and continued through mid-July. This gradient produced a weak stratification on July 13, but it could not be determined to what extent reservoir circulation was prevented or how long it lasted. It was concluded that the reservoir is well mixed for most of the year, but may be subjected to brief periods of stratification during periods of clear, calm weather in summer months. Intense periods of stratification do not occur because of shallow depth and mixing by wind.

Cherry Creek Reservoir usually retains a permanent ice cover from December through March. Ice formed in late December 1981 during the study period, and lasted until late February 1982. The ice cover was relatively free of snow and encompassed the entire reservoir surface.

Dissolved oxygen levels in surface waters were above or close to the standard of 5.0 mg/L throughout the study period (Figure 5). Levels varied from 14 mg/L in January under the ice cover, to roughly the standard in early September. Oxygen levels were high throughout the water column during cooler months but progressively declined, especially at lower depths, as the water warmed in the summer. Levels were below the standard from mid-July through mid-September at depths greater than three meters. Dissolved oxygen levels approached zero at a depth of 8 meters on September 13, 1982. However, levels at this depth had increased to 4.8 mg/L one week later. In general, oxygen levels fluctuated greatly near the reservoir bottom and this is probably due to a high oxygen demand from reservoir sediments.

As would be expected, low levels of dissolved oxygen were recorded at times of high water temperature. The greatest water temperatures were found on July and August 13th (Figure 4). The lowest oxygen levels in surface waters were found during these times. Conversely, the highest oxygen levels were recorded in January when the reservoir was the coolest.

FIGURE 4

TIME-DEPTH TEMPERATURE PROFILES
IN THE MAIN BODY OF CHERRY CREEK RESERVOIR

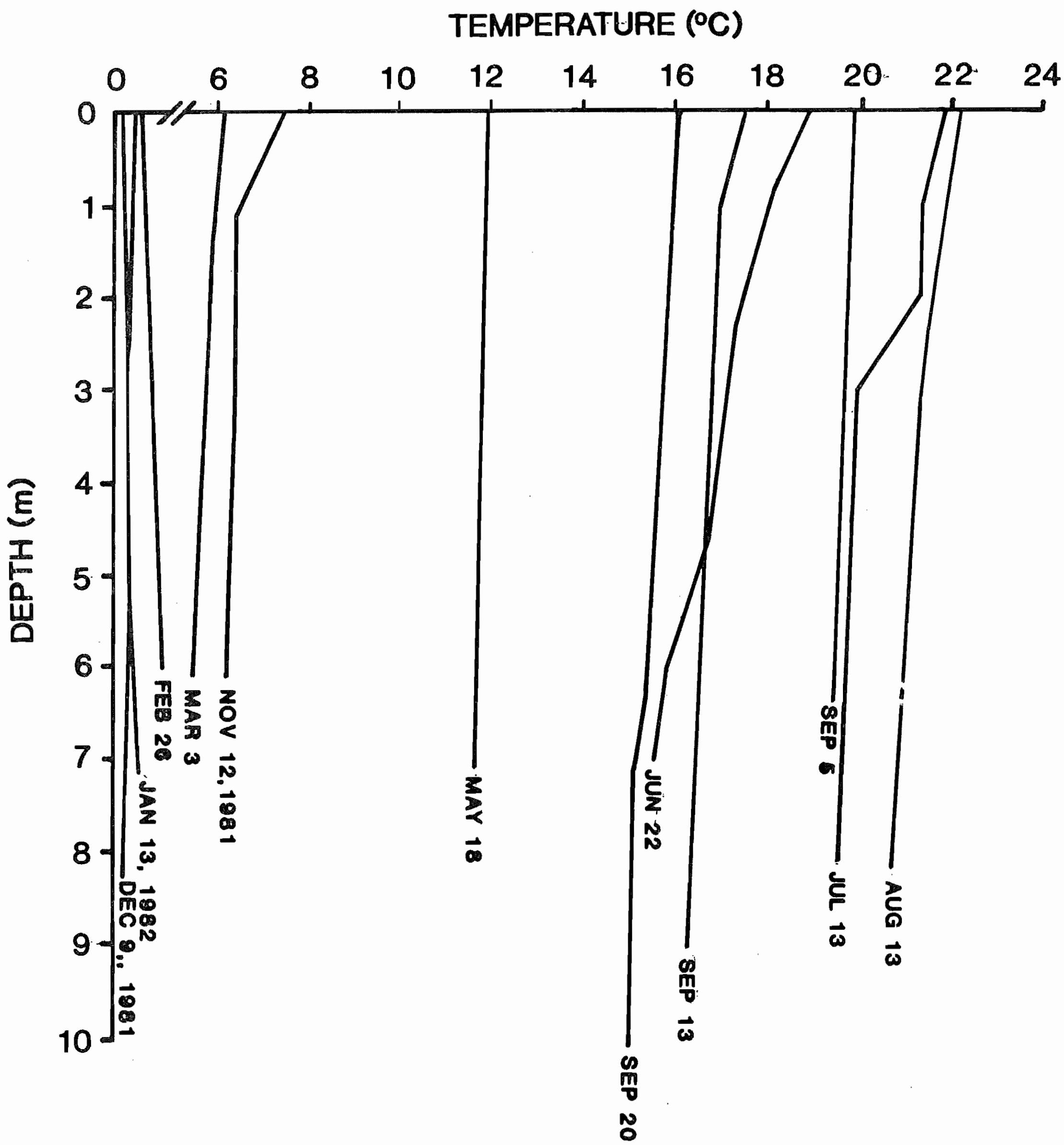
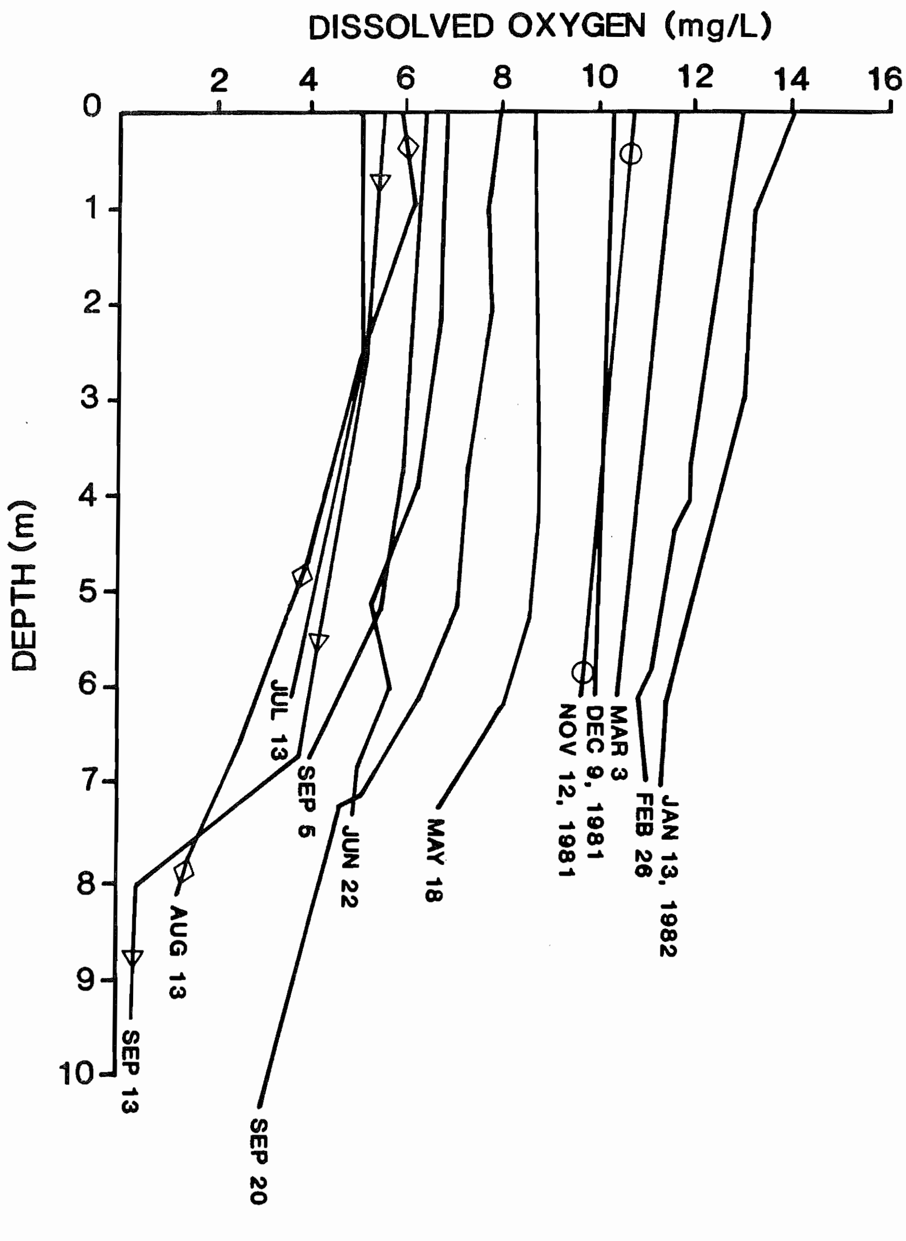


FIGURE 5

DISSOLVED OXYGEN PROFILES IN THE MAIN BODY OF CHERRY CREEK RESERVOIR

○◇▽ SYMBOLS ARE USED TO AID IN DETERMINING THE PATHS OF PROFILE LINES



While these relationships were observed, low oxygen levels were also found at intermediate temperatures. For example, the near depletion of oxygen below depths of 8 meters found on September 13 occurred under isothermal conditions at a temperature approximately 5°C below the maximum recorded. This suggests that reservoir sediments impose a high oxygen demand and can deplete oxygen levels in the water column even when it is well mixed. This may be caused by the die-off of late summer algal growth.

Nutrients

The following forms of nitrogen and phospohrus were monitored: ammonia (NH_3-N), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total phosphorus (T-PO_4 as P), and soluble orthophosphate (O-PO_4 as P). These nutrients and their various forms were selected because of their importance in driving eutrophication processes. Other constituents such as metals were not routinely monitored because at their present levels they do not pose a problem to water quality. Also, fecal coliform bacteria were routinely sampled by the State Parks Department as part of their water quality monitoring program, so were not sampled in this study.

Mean concentrations of the nutrient forms monitored were calculated from each of the three sampling areas in the reservoir and appear in Table 19. Samples below detection limit for a parameter were assumed to equal zero in the calculated of the mean. This is consistent with the methodology used to set state water quality standards. The forms of nitrogen and phosphorus monitored are discussed individually below.

Overall, levels of inorganic nitrogen in the reservoir were low, and were not significantly different between the three sampling areas. Many of the ammonia levels in samples were below the detection limit of 50 ug/L. Using the worst case situation of a water temperature of 25°C and pH of 8.5, it was determined that only 15 percent of the ammonia would be unionized. Applying this percentage to those concentrations found (Table 2), it can be seen that none of the samples came close to violating the standard of 60 ug/L unionized ammonia.

Table 19
Summary of Nutrient Concentrations
Found in Cherry Creek Reservoir

Nutrient	Number of Samples	Mean (ug/L), standard deviation of the mean in parenthesis	Range of measured values, (ug/L)
Total			
Ammonia NH_3-N:			
Main Body	70	61(59)	<50-300
Cherry Creek	31	44(61)	<50-290
Swim Beach	35	56(48)	<50-160
Nitrate NO_3-N:			
Main Body	70	4(6)	<3-19
Cherry Creek	31	2(3)	<3-10
Swim Beach	27	2(3)	<3-11
Nitrite NO_2-N:			
Main Body	45	2(1)	<3-4
Cherry Creek	35	5(2)	<3-6
Swim Beach	24	2(2)	<3-7
Total-Phosphorus:			
(T-PO_4 as P)			
Main Body	68	37(22)	13-157
Cherry Creek	32	39(38)	12-89
Swim Beach	35	32(22)	10-80
Soluble Orthophosphate:			
(O-PO_4 as P)			
Main Body	71	5(6)	<5-24
Cherry Creek	30	5(5)	<5-15
Swim Beach	30	5(5)	<5-10

Likewise, levels of nitrate and nitrite were very low and did not vary appreciably between sampling areas. Both of these constituents were found at levels far below standards. This suggests that there are no present problems to aquatic life or drinking water quality by nitrite or nitrate.

The total inorganic nitrogen levels were far below 200 ug/L which compares to literature values typical of oligotrophic lakes.[13] This may be due to uptake of inorganic nitrogen by aquatic life, especially algae. Detailed monitoring of inorganic and organic forms is needed to verify this hypothesis.

Levels of total phosphorus in the reservoir were moderate and did not vary significantly between sampling sites. Average concentrations for summer months were: June, 31 ug/L; July, 20 ug/L; August, 34 ug/L; and September, 34 ug/L.

Levels of soluble orthophosphate were low on the average and consistent within the reservoir. Many samples were below detection limits. The highest concentrations were found during seasons of low algal growth, and all samples in August, when the highest chlorophyll a was found, were below detection limit. This inverse relationship between orthophosphate and algal productivity can be expected when phosphorus is limiting or co-limiting towards algal growth.

Chlorophyll and Water Clarity

Chlorophyll a is a major pigment found in plant tissue such as algae cells. It is often monitored to determine the productivity of a water body: the higher the chlorophyll a, the more phytoplanktonic algae in the water column and the greater the productivity of the water body.

Productivity is indicative of the aging of the lake and amount of nutrient loading which is usually expressed by lake trophic status: ultra-oligotrophic being young lakes very low in productivity to hypertrophic lakes which are "aged lakes" of very high productivity. Between these two extremes

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[13] R. G. Wetzell, "Limnology", W. B. Saunders Company, Philadelphia, Pennsylvania, 1975, p. 196.

are mesotrophic lakes (moderate in age and productivity) and eutrophic lakes (mature and productive). Excessive nutrient loading can age a lake or cause it to be classified as being eutrophic independent of how old it is.

Oligotrohpic lakes typically have very clear water and low chlorophyll a levels. Such lakes can support cold water fisheries along with warm water ones. The more eutrophic the lake, the less likely it will be capable of supporting a cold water fishery. The more eutrophic the lake, the higher the chlorophyll a and the lower the clarity. This is because water clarity is a function of the suspended material in the water column. More chlorophyll a means more suspended material in the form of phytoplankton in the water, and the lower the clarity. As long as most of the suspended material is phytoplankton, chlorophyll a levels can be directly related to water clarity. High levels of inorganic sediment can interfere with this relationship.

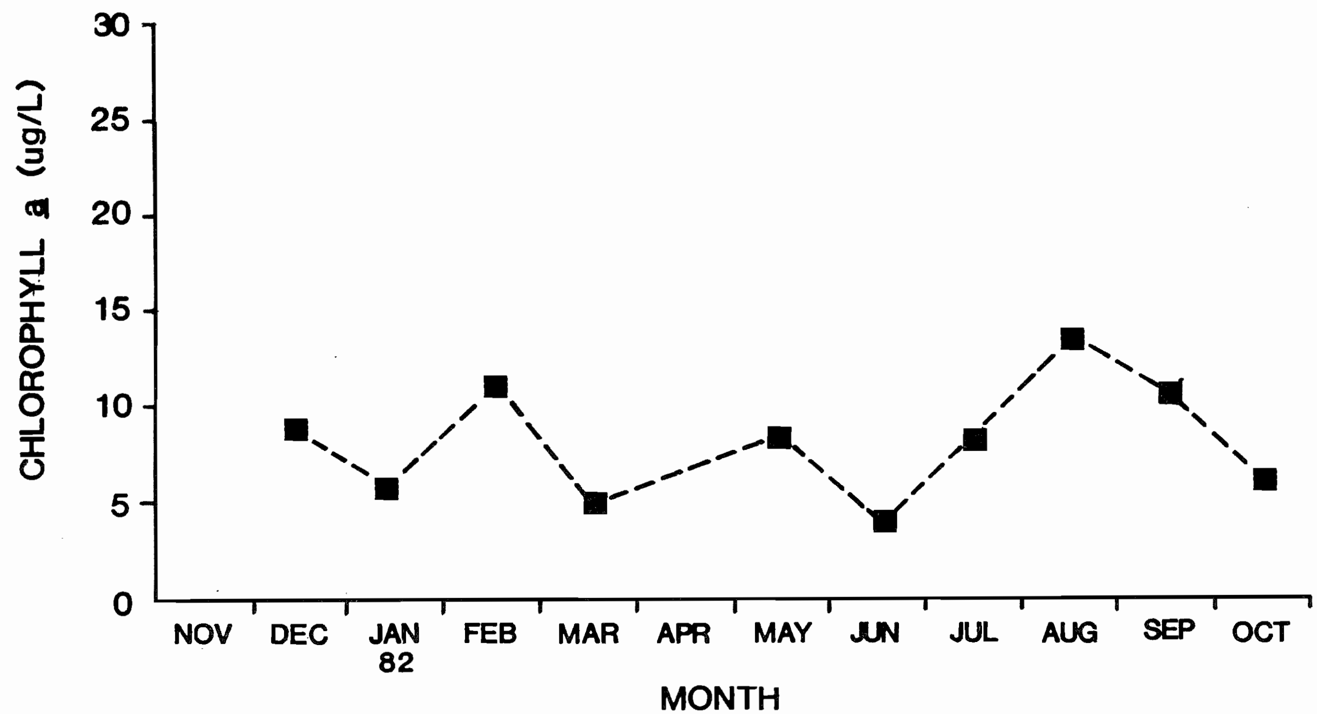
Chlorophyll a levels have been used as a basis for classifying lakes according to trophic status. Chlorophyll a has also been used to assess water quality, beneficial uses, and for developing models to evaluate possible future lake conditions. Models have been developed to predict chlorophyll a concentrations based upon total phosphorous levels. Other models have been derived that predict secchi disc depth based on chlorophyll a. These models are discussed in detail in Chapter VIII. While chlorophyll a is related to specific water quality parameters, it is difficult to precisely relate future changes in these parameters to impacts on beneficial uses such as fishing, swimming, and water supply. This topic is addressed in Chapters IX and X.

Average monthly chlorophyll a levels monitored in Cherry Creek Reservoir are shown in Figure 6. Chlorophyll concentrations were the lowest in June and increased to a maximum in August. A fairly high secondary peak occurred in February and was caused by cold water golden brown algae. The August peak represented the maximum growing season algal growth and was most likely due to blue green algae which were found to be dominant during summer months.

The "average growing season" chlorophyll a concentration is most commonly used to express chlorophyll a concentrations, especially in relation to trophic status. This refers to the period from July through September. For Cherry Creek Reservoir, this value was 10.7 ug/L in 1982. Values greater than 10.0 ug/L are usually considered to refer to eutrophic lakes, however this varies depending upon the classification scheme.

FIGURE 6

AVERAGE CHLOROPHYLL *a* CONCENTRATIONS IN CHERRY CREEK RESERVOIR



Average secchi disc depths and turbidity are shown by month in Figure 7. It can be seen that the reservoir water had the lowest turbidity and highest secchi depth in June when chlorophyll a levels were lowest on the average. This shows the relationship between chlorophyll a and water clarity; but this relationship is not as apparent when chlorophyll levels were high. The smallest secchi depth and highest turbidity were found in February, but chlorophyll a was greatest in August. This suggests that non-chlorophyll related materials such as sediment suspended in the water column are important in determining turbidity.

Phytoplankton

The phytoplankton community composition was analyzed for seven months. Community composition can be used to evaluate water quality and trophic status. Phytoplankton samples were identified down to the lowest taxa possible. The percent composition of the major groups found is shown in Figure 8 for the months sampled.

It can be seen from Figure 8 that the percent compositon changed greatly during the year. This is characteristic of aquatic systems where a myriad of algae alternately appear throughout the year. Golden-brown algae and diatoms were dominant through the winter months. Golden-browns comprised over 80 percent of the community in January and were most likely responsible for the high chlorophyll a levels sampled in February. These algae are typical of cold waters. Cryptomonas were also found in November and December.

Diatoms always constituted at least half of the community composition, but their percent composition varied between months. This group represented 100 percent of the community in April.

Summer months were characterized by blooms of green and blue-green algae. This latter group is indicative of eutrophic waters during summer months and can develop large, sudden blooms in August and September. Many species of this group can fix nitrogen from the atmosphere which may exacerbate the eutrophication process. While phytoplankton were not collected in August, blue-green algae probably also comprised much of the algal growth that month. The near depletion of oxygen noted at lower depths in early Sepetmber (Figure 5) may have been due in part to the "die-off" of this late summer algal growth.

FIGURE 7

AVERAGE SECCHI DEPTH AND TURBIDITY IN CHERRY CREEK RESERVOIR

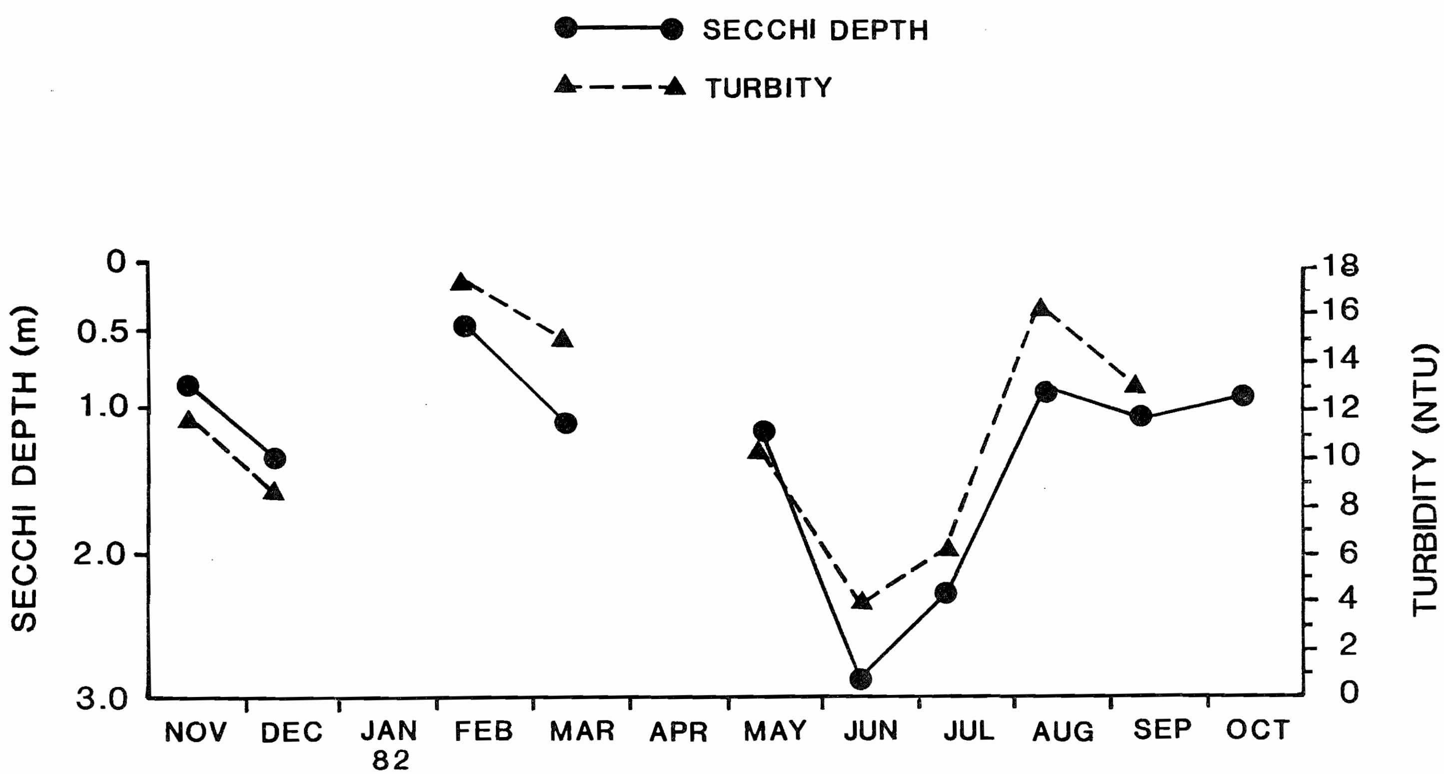
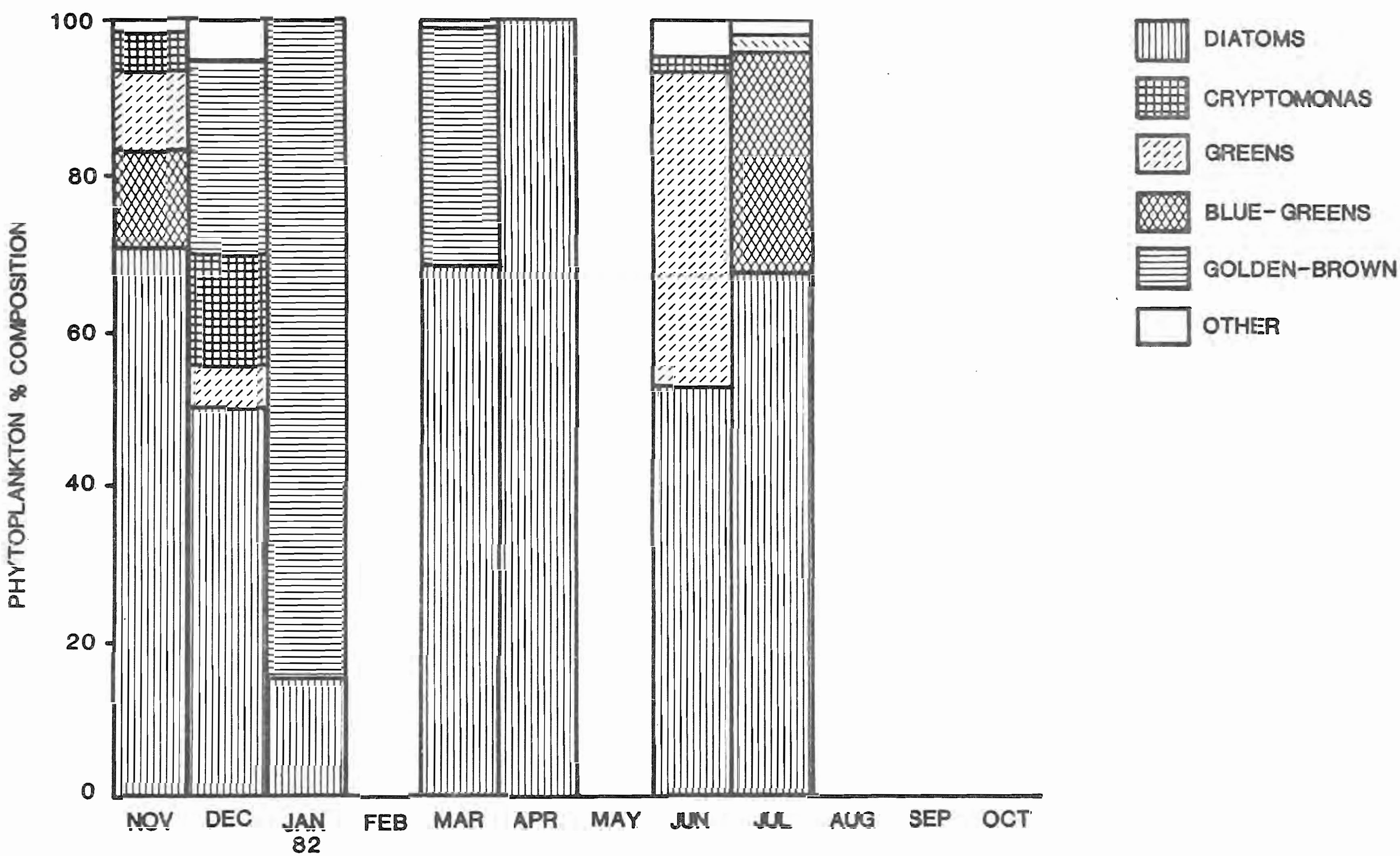


FIGURE 8

SUMMARY OF PHYTOPLANKTON COMPOSITION IN CHERRY CREEK RESERVOIR



LIMITING NUTRIENT DYNAMICS

The CDH performed four limiting nutrient studies on Cherry Creek Reservoir to determine the response of algae to nitrogen and phosphorus, separately, or in combination. Information from these studies was used to select the nutrient for control.

Studies were conducted during February, April, July, and August. All were performed in situ, except for the one in February which was done in the laboratory. Vandalism ruined an additional study performed in June, and resulted in incomplete data for the July study.

The CDH concluded that algal growth in Cherry Creek Reservoir is co-limited by nitrogen and phosphorus. Two of the studies showed a co-limitation with nitrogen imposing a secondary limitation; and the other two studies showed that phosphorus was limiting to algal growth. Phosphorus was targeted for control because this nutrient is economically and technically easier to control.

This conclusion is reinforced by the recent findings of limnologists that: 1) the majority of temperate lakes studied are phosphorus limited, and 2) lakes not phosphorus limited can be induced to be so through phosphorus control.[14]

TROPHIC CLASSIFICATION OF WATER BODIES

The classification of a water body by trophic status is largely a subjective process. Several classification systems exist, each with its own water quality parameters and criteria.[15,16] Most systems define varying degrees of eutrophication (e.g., oligotrophic, mesotrophic) by a range of

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[14]S. R. Hein, et al., "Modifications of Models Predicting Trophic State of Lakes . . .", Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, EPA-600/3-81-001, 1981.

[15]R. E. Carlson, "A Trophic State Index for Lakes", Limnol. and Oceanogr. 22: 361-369, 1977.

[16]D. B. Porcella, et al., "Index to Evaluate Lake Restoration", Journ. Environ. Engr. Div. ASCE, 106: 1151-1169, 1980.

values. A common classification scheme is that lakes under 5 ug/L chlorophyll a are oligotrophic; those between 5 and 10 ug/L are mesotrophic; between 10 and 40 ug/L is considered eutrophic; and greater than 40 ug/L represents hypertrophy. However, a lake classified by this scheme may be reclassified differently by another one.

A statistical approach to the problem was taken by Vollenweider in his classification scheme proposed in 1980.[17] His system was developed as a result of a consensus of opinion among leading limnologists. Vollenweider used average growing season chlorophyll a to determine trophic status, but did not set rigid boundaries between trophic levels. Rather, he proposed a series of probability distributions which can be used to determine the probability of correctly classifying a water body by chlorophyll a concentration. This system is based on the trophic classification of a large number of lakes using chlorophyll a by limnologists, and accounts for differences of opinion. The system is shown in Figure 9.

The use of Figure 9 is shown in Table 20. This table shows the probability of classifying four hypothetical water bodies with chlorophyll a levels of 5, 10, 20, and 40 ug/L.

Table 20
Example of the Use of Vollenweider's Trophic Classification Probability Curves (Figure 9)

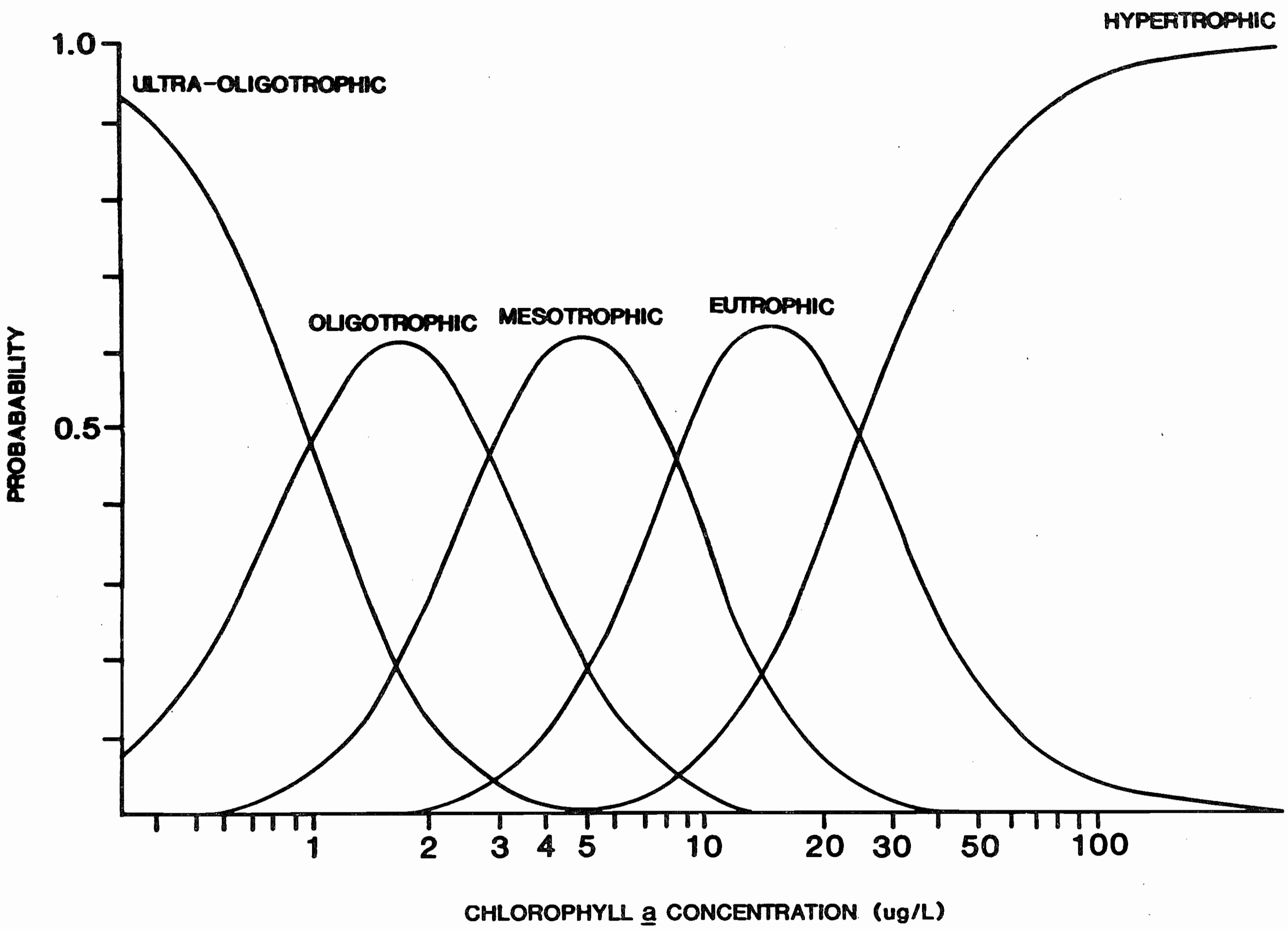
	PROBABILITY* Chlorophyll a (ug/L)			
Trophic Classification	5	10	20	40
ultra-oligotrophic	0%	0%	0%	0%
oligotrophic	20%	5%	0%	0%
mesotrophic	60%	40%	8%	0%
eutrophic	20%	50%	57%	28%
hypertrophic	0%	5%	35%	72%

*Determined from curves in Figure 9.

[17] R. A. Vollenweider and J. J. Kerekes, "Background and Summary Results of the OECD Cooperative Program on Eutrophication", Int'l. Symposium on Inland Waters and Lake Rest., Portland, MA, EPA 44015-81-101, 1980.

FIGURE 9

TROPHIC STATUS CLASSIFICATION PROBABILITIES PROPOSED BY VOLLENWEIDER



From Table 20, it can be seen that a water body with a chlorophyll a of 5 ug/L would most likely be classified as mesotrophic; 10 ug/L as eutrophic; 20 ug/L as eutrophic; and 40 ug/L as hypertrophic. It is important to note that there are certain probabilities that these hypothetical lakes would best be classified differently. For example, there is a 0.05 probability that a lake with a chlorophyll a of 10 ug/L would be classified as being hypertrophic.

Using Figure 9, Cherry Creek Reservoir would best be classified as being eutrophic (P = 0.60) based upon the average growing season chlorophyll a of 10.7 ug/L. However, there is also a 0.10 probability of it being classified as hypertrophic, a 0.28 probability of mesotrophic, and a very small chance that it would be classified as oligotrophic.

While Figure 9 may provide a means of classifying Cherry Creek Reservoir by trophic status, it does not provide information on the effects of varying degrees of eutrophication on water quality and beneficial uses. Trophic status, however arrived at, is an artificial designation or label. Usually, only general statements between the various trophic states (or chlorophyll a) can be made. For example, hypertrophic lakes will most likely not support a trout fishery and will have low transparency. The amount of algae and weeds in such lakes may limit swimming or boating, and associated problems such as odors and high bacteria counts may occur. But oligotrophic lakes most likely will have very clear water conducive to swimming which will support a trout fishery. Obviously, water quality goals and desired beneficial uses must all be assessed to determine acceptable levels of eutrophication.

Figure 9 also does not distinguish between different chlorophyll a levels which lead to the same classification. For example, a lake with a cholorphyll a of 9 ug/L would be best classified as eutrophic, as would a lake with a chlorophyll a of 25 ug/L. Obviously, these lakes will have different water quality. Beneficial uses would more likely be impaired at higher chlorophyll a levels.

Relating changes in future chlorophyll a and eutrophication to beneficial uses is difficult. This involves defining levels at which certain uses would be affected. A chlorophyll a level of 50 ug/L would most probably affect uses such as swimming and fishing. Odor problems and outbreaks of nuisance insects might also occur and even cause non-bathers or non-fishermen to stop using picnic areas around the reservoir. But it would be difficult to determine whether a chlorophyll a level of 25 or 20 mg/L would have the same impact on beneficial uses.

Conversely, if the chlorophyll a was reduced to 5 ug/L, the water would be clear, but it might not be able to sustain angling pressures of an urban warm water fishery. This is because of the lower productivity of oligotrophic lakes in general which results in less food available for fishes.

Because of the uncertainty as to the effects on beneficial uses, the best approach towards providing protection to Cherry Creek Reservoir by setting of an acceptable level of nutrient loading and water quality may be through defining a range of acceptable chlorophyll a levels which can be related to both in-reservoir phosphorus concentrations and phosphorus loading. This range would be re-assessed in the future pending new information on reservoir water quality, impacts on beneficial uses, control technologies, and basin growth patterns. The range chosen should reflect water quality goals and present information on basin growth and reservoir quality.

VI. WATER QUALITY MANAGEMENT OPTIONS

Water quality management options for the basin will depend on the classifications and standards set by the Colorado Water Quality Control Commission (WQCC) for the reservoir and waterways tributary to the reservoir. Classifications and standards already adopted by the WQCC are listed in Table 21.

Table 21
Classifications and Numeric Standards for Cherry Creek Reservoir

Classification

Recreation Class 1 (Primary Contact)
Warm Water Aquatic Life Class 1
Water Supply
Agriculture

Numeric Standards[1]

Dissolved Oxygen	=	5.0 mg/L
pH	=	6.5-9.0
Fecal Coliform	=	200/100 ml
NH_3 unionized	=	0.06 mg/L

[1]Partial list only. For description of all numeric standards, refer to the Reservoir Modeling and Sampling Report prepared by the CDH, p. 9.

While these classifications and standards are designed to protect the beneficial uses of the reservoir, they do not address a standard for total phosphorus or chlorophyll a nor do they relate to eutrophication. Since total phosphorus has been determined to be a limiting nutrient in the reservoir and directly relates to production of chlorophyll a, all water quality management options in the basin have focused on controlling or reducing total phosphorus concentrations. In adopting future water quality standards for the reservoir, the WQCC should consider adopting an in-lake total phosphorus concentration which, in turn, relates directly to total phosphorus limits on wastewater effluent and reducing the total phosphorus in nonpoint runoff, if necessary. The in-lake total phosphorus concentration should be established by relating it to an acceptable concentration of in-lake chlorophyll a. The chlorophyll a concentration in-lake will likely vary throughout the year; therefore, the acceptable chlorophyll a concentration should be based on the average concentration experienced during the summer growing season (July-September) which is the period when beneficial uses would be most impacted.

In determining appropriate water quality management options, consideration was given to controlling the total phosphorus from both point and nonpoint sources of nutrient loading. The objective in controlling the phosphorus loading was to arrive at effluent standards for wastewater treatment and standards for phosphorus removal in nonpoint sources. In order to arrive at recommendations for phosphorus loading from the basin to the reservoir, it was necessary to evaluate several different wastewater systems which were capable of removing various amounts of phosphorus. Also, several systems to remove phosphorus in stormwater runoff were evaluated in order to achieve a phosphorus removal rate from the entire basin.

The conclusions and recommendations resulting from this study are oriented toward water quality goals for the basin and reservoir. Also, this study will provide a framework for wastewater management and setting a phosphorus standard for the reservoir but it is not intended to be used or substituted for a wastewater master plan for the basin. In evaluating the point and nonpoint source control options, it was necessary to specify detailed treatment systems; however, this report will not be recommending specific types of treatment systems but rather recommending wastewater effluent quality. The type of treatment systems evaluated are representative of technology which exists today and these systems were detailed for the purpose of producing cost estimates. It should be recognized that other wastewater treatment technologies may be available or become available which produce the same or better effluent quality. These systems should not be precluded from use within the basin as long as the effluent quality meets the standards set for the basin.

Nutrient conditions in the reservoir and the present trophic status of the reservoir indicate that in-lake control measures may be ineffective in controlling nutrients or decreasing the rate of eutrophication. Since nitrogen and phosphorus levels in the reservoir are low (at or near detection limit), in-lake treatment to remove the nutrients would be of little benefit and the cost would probably out-weigh any gain in nutrient reduction. Dredging, which often is effective in removing nutrient-laden sediments and providing a larger volume of water would probably aggravate the nutrient situation in Cherry Creek as it would stir up sediments and create a longer hydraulic retention time since there is no significant outflow from the reservoir. Also, in-lake treatment methods have uncertain end results and may be ineffective in correcting a problem. Emphasis should be on controlling phosphorus in the basin and preventing an aggravated or accelerated rate of eutrophication in the reservoir. Controlling the phosphorus in the basin now will result in avoiding a serious water quality condition in the reservoir in the future.

POINT SOURCE CONTROLS

Four types of wastewater treatment systems were evaluated to determine the impact on the reservoir from different degrees of phosphorus removal. The four types of wastewater treatment systems are:

1. Secondary treatment and slow-rate land application;
2. Secondary treatment and discharge;
3. Phosphorus removal and discharge; and,
4. Nitrogen removal and discharge.

In addition to these treatment systems, an Effluent Transmission Line (ETL) was also evaluated. Under this scenario, each district would have a secondary wastewater treatment plant and all effluent would be discharged into a pipeline (ETL). This pipeline would collect all the treated wastewater in the basin and discharge it around the reservoir via Goldsmith Gulch. A detailed description of each option appears in Technical Memorandum No. 4.

Effluent Quality

The effluent quality of each point source option described above appears in Table 22. The collective load (pounds) of total phosphorus from each wastewater option was then used as one of the phosphorus sources in the reservoir model.

Table 22

Effluent Quality of the Five Wastewater Treatment Options

1. Secondary Treatment and Slow-Rate Land Application
   - BOD_5 = less than 5.0 mg/L
   - Total Phosphorus = 0.1 mg/L
   - Total Nitrogen = agronomic rates for crop uptake, but not to exceed 10.0 mg/L
   - Suspended Solids = less than 1.0 mg/L
   - Fecal Coliform = drinking water standards
   - Note: 50 percent of the wastewater flow was assumed to migrate to the reservoir via the Cherry Creek alluvium; 50 percent was assumed to be consumed by crop uptake and evaporation.

2. Secondary Treatment and Discharge
   - BOD_5 = 30 mg/L
   - Total Phosphorus = 4.0 mg/L
   - Total Nitrogen = 20.0 mg/L
   - Suspended Solids = 30.0 mg/L
   - Fecal Coliform = 2000/100 ml

3. Phosphorus Removal and Discharge

	Without Filtration	With Filtration
BOD_5	15.0 mg/L	5.0 mg/L
Total Phosphorus	1.0 mg/L	0.2 mg/L
Total Nitrogen	20.0 mg/L	20.0 mg/L
Suspended Solids	15.0 mg/L	5 mg/L
Fecal Coliform	2000/100 ml	2000/100 ml

NOTE: High rate or rapid infiltration land application was assumed to have a performance equivalent to advanced treatment (phosphorus removal) with filtration.

4. Nitrogen Removal and Discharge
   - BOD_5 = 10.0 mg/L
   - Total Phosphorus = 4.0 mg/L
   - Total Nitrogen = 1.0 mg/L
   - Suspended Solids = 10.0 mg/L
   - Fecal Coliform = 2000/100 ml

5. Effluent Transmission Line (ETL)
   - BOD_5 = 30 mg/L
   - Total Phosphorus = 4.0 mg/l
   - Total Nitrogen = 20.0 mg/L
   - Suspended Solids = 30.0 mg/L
   - Fecal Coliform = 2000/100 ml

NOTE: All treated effluent in the basin is collected in the ETL and discharged around the reservoir via Goldsmith Gulch.

Option number 4, nitrogen removal and discharge was dropped from consideration as a water quality management option as phosphorus was identified as being the nutrient to control. Even though the 1982 limiting nutrient studies conducted by the Colorado Department of Health indicated a co-limitation of nitrogen and phosphorus existing in the reservoir, the report suggests that emphasis be placed on controlling phosphorus.[18]

Option number 5, the effluent transmission line, will result in numerous problems which are not addressed in this report. In evaluating this option, no consideration was given to several technical aspects which may prohibit or severely affect the cost of the ETL. As effluent from the ETL would be discharged to Cherry Creek below the reservoir via Goldsmith Gulch, no assessment was made of the water quality impacts this would have on Cherry Creek and eventually on the South Platte River. Other technical considerations include an evaluation of Goldsmith Gulch to determine if it has the capability to convey the total volume of wastewater and whether nitrogen removal would be necessary to meet water quality standards in Cherry Creek. The biggest problem with the ETL is the impact the system would have on the water rights issues in the basin. As the ETL would collect all the wastewater in the basin and transmit it out of the Upper Cherry Creek basin, a system would need to be devised for replacing the water in the basin, as a portion of the wastewater is used to augment water taken from tributary wells and returned to the Cherry Creek alluvium. Aside from the technical constraints, certain political constraints are also associated with this option such as ownership, responsibilities, operation and maintenance, and the issue of who pays for each portion of the ETL.

Numerous types of land application systems exist and may be applicable to the Cherry Creek basin. However, for the purpose of evaluating a land application system, slow-rate application was chosen. The slow-rate application system would result in a 50 percent wastewater return (to groundwater) with an effluent quality of 0.1 mg/L of total phosphorus. The remaining 50 percent wastewater would be consumed by crop uptake and evaporation. Rapid infiltration

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[18]Colorado Department of Health, Water Quality Control Division, "Report on Reservoir Modeling and Sampling for Cherry Creek and Chatfield Reservoir Clean Lakes Study", October, 1983. p. 31.

for wastewater treatment was not evaluated, but was considered to be equivalent in performance to phosphorus removal with filtration and direct discharge.

NONPOINT SOURCE CONTROLS

The control of phosphorus in nonpoint, urban runoff may be necessary to achieve acceptable levels of chlorophyll a and total phosphorus in the reservoir. These nonpoint controls may be needed in addition to any recommended point source control option, as it may require control of phosphorus in both point and nonpoint sources to achieve the desired in-lake chlorophyll a level.

Three types of nonpoint control options were evaluated in this study. Detention ponds, rapid infiltration basins, and wetlands were determined to be suitable control structures which could be feasibly implemented in the basin. Other options were considered such as treatment of stormwater through mechanical facilities, diversion of stormwater around the reservoir, and removal of sod farms from the basin. However, these other options were dropped from further consideration due to costs, land requirements, or a lack of effective phosphorus removal. The elimination of sod farming practices in the basin was not considered an effective phosphorus control strategy because surface water and groundwater data did not conclusively indicate that sod farming was adding significant amounts of phosphorus to the Cherry Creek hydrologic system.

Specific total phosphorus removal efficiencies through nonpoint control alternatives are variable and not well defined. Removing phosphorus in stormwater runoff is state-of-the-art technology and therefore, overall high removal efficiencies cannot be expected. For the purpose of this study, it should be realized that the nonpoint control measures will require site specific design and modification to achieve optional removal rates.

The strategy established for eliminating phosphorus in stormwater runoff was to remove 25 percent or 50 percent of the phosphorus basin wide. While these two removal rates appear to be low, much higher removal rates would be achieved in specific areas where storm runoff could be controlled. These areas would balance undeveloped areas where no nonpoint was to be controlled and would result in the basin wise removal rate of 25-50 percent.

In order to achieve an overall 25 percent phosphorus removal from the entire basin, it was necessary to utilize a combination of detention ponds followed by a wetlands system. The detention ponds were considered to be capable of removing 25 percent of the total phosphorus in the stormwater and the wetlands were considered to be capable of removing 50 percent of the total phosphorus in the stormwater. This combination of detention ponds followed by diversion of stormwater into a wetlands system resulted in an overall phosphorus removal of 25 percent basin wide, based on the total annual phosphorus load generated in the basin.

Tables 23 and 24 indicate the amount of phosphorus which must be removed via detention and wetlands to achieve an overall phosphorus reduction of 25 percent for DRCOG and developer projections. These tables also indicate the volume of streamflow that must be diverted into the wetlands and the estimated wetlands acreage. The estimated volumes are based on 50 percent removal of the phosphorus contained in the streams tributary to the reservoir. Detention ponds were assumed to be located on developed land; wetlands were assumed to be located on land owned by the U.S. Army Corps of Engineers near the reservoir. Details of the detention system and wetland system appear in Technical Memorandum No. 5.

To achieve an overall 50 percent phosphorus removal from the entire basin, a combination of detention ponds followed by a rapid infiltration system was selected. Again, the detention ponds were considered to be capable of removing 25 percent of the total phosphorus in the stormwater but the rapid infiltration system was considered to be capable of removing 95 percent of the total phosphorus. This combination, designed to accomodate stormwater runoff from developed acreage, resulted in an overall phosphorus removal of 50 percent basin-wide, based on the total annual phosphorus load generated in the basin.

Table 25 and 26 indicate the amount of phosphorus which must be removed to achieve an overall phosphorus reduction of 50 percent for DRCOG and developer projections. These tables also indicate the volume of streamflow that must be diverted into the basins and the estimated basin acreage. The estimated volumes are based on 95 percent removal of phosphorus content of the streams tributary to the reservoir. The detention ponds and rapid infiltration basins would be located on private, developed land. Streamflows would be diverted into the rapid infiltration basins but no attempt would be made to divert all flows into the basins; only that amount required to meet a phosphorus removal goal. Details of the detention system and the rapid infiltration basin appear in Technical Memorandum No. 5.

Table 23
Summary of Nonpoint Control Requirements to Achieve an Overall 25 Percent Phosphorus Removal Basin Wide

DRCOG Projections

25% Detention Pond Removal Efficiency plus
50% Wetland Phosphorus Removal Efficiency

Year	(A) Total Annual Phosphorus Load	(B) Phosphorus Annually Removed in Detention Ponds	(C) Required Annual Phosphorus Removal via Wetlands for 25% Removal	(D) Annual Phosphorus Load Into Reservoir	(E) Annual Volume of Streamflow Diverted Into Wetlands	(F) Required Wetland Area
	(lbs)	(lbs)	(lbs)	(lbs)	(acre-ft)	(acres)
1985	4750	943	245	3563	143	14.3
1990	6180	1238	307	4635	179	17.9
2000	10560	2231	409	7920	239	23.9
2010	16730	3700	483	12548	282	28.2

(A) Annual phosphorus load from Chapter VI, Nutrient Loading

(B) From Tables 1-2, 1-6 in Technical Memorandum No. 5. The 25% removal is from developed areas only, not the total annual load identified in column (A)

(C) (0.25) (column A) - (column B)

(D) (0.75) (column A)

(E) [(column C) (3.07)/(8.34 X 1.26)] X 100/50

(F) Based on an annual loading of 10 acre-ft/acre/year (20 acre-ft/acre/year for six months)

Table 24
Summary of Nonpoint Control Requirements to Achieve an Overall 25 Percent Phosphorus Removal Basin Wide

Developer Projections

25% Detention Pond Removal Efficiency plus
50% Wetland Phosphorus Removal Efficiency

Year	(A) Total Annual Phosphorus Load	(B) Phosphorus Annually Removed in Detention Ponds	(C) Required Annual Phosphorus Removal via Wetlands for Overall 25% Removal	(D) Annual Phosphorus Load Into Reservoir	(E) Annual Volume of Streamflow Diverted Into Wetlands	(F) Required Wetland Area
	(lbs)	(lbs)	(lbs)	(lbs)	(acre-ft)	(acres)
1985	6820	1404	301	5115	176	17.6
1990	12110	2629	398	9083	233	23.3
2000	23680	5399	521	17760	304	30.4
2010	36530	8582	551	27398	322	32.2

(A) Annual phosphorus load from Chapter VI, Nutrient Loading

(B) From Tables 1-3, 1-7 in Technical Memorandum No. 5. The 25% removal is from developed areas only, not the total annual load identified in column (A)

(C) (0.25) (column A) - (column B)

(D) (0.75) (column A)

(E) [(column C) (3.07)/(8.34 X 1.26)] X 100/50

(F) Based on an annual loading of 10 acre-ft/acre/year (20 acre-ft/acre/year for six months)

Table 25
Summary of Nonpoint Control Requirements to Achieve an Overall 50 Percent Phosphorus Removal Basin Wide

DRCOG Projections

25% Detention Pond Removal Efficiency plus
95% Rapid Infiltration Phosphorus Removal Efficiency

Year	(A) Total Annual Phosphorus Load	(B) Phosphorus Annually Removed in Detention Ponds	(C) Required Annual Phosphorus Removal via Rapid Infiltration for Overall 50% Removal	(D) Annual Phosphorus Load Into Reservoir	(E) Annual Volume of Streamflow Diverted Into Rapid Infiltration Basin	(F) Required Rapid Infiltration Basin Area
	(lbs)	(lbs)	(lbs)	(lbs)	(acre-ft)	(acres)
1985	4750	943	1433	2375	441	4.4
1990	6180	1238	1852	3090	569	5.7
2000	10560	2231	3049	5280	938	9.4
2010	16730	3700	4665	8365	1435	14.3

(A) Annual phosphorus load from Chapter VI, Nutrient Loading

(B) From Tables 1-2, 1-6 in Technical Memorandum No. 5. The 25% removal is from developed areas only, not the total annual load identified in column (A)

(C) (0.50) (column A) - (column B)

(D) (0.50) (column A)

(E) [(column C) (3.07)/(8.34 X 1.26)] X 100/95

(F) Based on an annual loading of 100 acre-ft/acre/year (operate 12 months a year if there is sufficient flow).

Table 26
Summary of Nonpoint Control Requirements to Achieve an Overall 50 Percent Phosphorus Removal Basin Wide

Developer Projections

25% Detention Pond Removal Efficiency plus
95% Rapid Infiltration Phosphorus Removal Efficiency

Year	(A) Total Annual Phosphorus Load	(B) Phosphorus Annually Removed in Detention Ponds	(C) Required Annual Phosphorus Removal via Rapid Infiltration for Overall 50% Removal	(D) Annual Phosphorus Load Into Reservoir	(E) Annual Volume of Streamflow Diverted Into Rapid Infiltration Basin	(F) Required Rapid Infiltration Basin Area
	(lbs)	(lbs)	(lbs)	(lbs)	(acre-ft)	(acres)
1985	6820	1404	2006	3410	617	6.2
1990	12110	2629	3426	6055	1053	10.5
2000	23680	5399	6441	11840	1981	19.8
2010	36530	8582	9683	18265	2978	29.8

(A) Annual phosphorus load from Chapter VI, Nutrient Loading

(B) From Tables 1-3, 1-7 in Technical Memorandum No. 5. The 25% removal is from developed areas only, not the total annual load identified in column (A)

(C) (0.50) (column A) - (column B)

(D) (0.50) (column A)

(E) [(column C) (3.07)/(8.34 X 1.26)] X 100/95

(F) Based on an annual loading of 100 acre-ft/acre/year (operate 12 months a year if there is sufficient flow).

SYSTEM COSTS

Costs for point source controls and nonpoint source controls were developed and include capital costs plus operation and maintenance (O&M) costs. Using a planning period of 20 years, an inflation rate of 10 percent, and a discount rate of 10 percent, equivalent annual costs were derived for each point and nonpoint control option. These equivalent annual costs were then used in evaluating each option.

Cost curves were developed for each individual point source control. The curves were developed using standard engineering planning cost estimating procedures and three treatment plant sizes, 0.1, 1.0, and 10.0 mgd. This resulted in an estimated cost for each treatment system as identified in Table 27. From the information in Table 27 equivalent annual costs were developed for the Cherry Creek basin for each of the existing and proposed developments in the basin. Summing the equivalent annual costs by existing and proposed developments resulted in a total basin equivalent annual cost for point source treatment for the years 1985, 1990, 2000 and 2010. The basin wide equivalent annual costs for each point source treatment option appear in Table 28 for DRCOG projections and Table 29 for developer projections.

The cost information presented in Tables 28 and 29 is based on wastewater flow projection only for those districts identified by this study as of May, 1983. The study anticipated that there would be development between existing plan developments, however that these developments would be at a very low density. If these developments were higher density, they may result in increased wastewater flows, even higher than the developers projections used in this report. A periodic revision of wastewater flows to reflect actual growth conditions may be a viable solution to this problem.

Cost estimates for nonpoint control options were calculated by a slightly different procedure. The costs were developed using standard engineering planning estimates but for the purpose of controlling stormwater runoff for phosphorus removal, the estimates were based on a per-developed acreage. This estimate was based on treating runoff from all 1.5 inch and smaller storms, as this storm size is of a magnitude that 95 percent of all precipitation events in the basin would be equal to or less than this amount. Cost curves were then developed which reflected the size of structure (detention, wetlands, or rapid infiltration basin) needed based on the 1.5 inch storm and the number of developed acres in the basin.

Table 27

Wastewater Treatment System Estimated Capital Costs[1]

Wastewater System	Cost[2] 0.1 mgd	1.0 mgd	10.0 mgd
Secondary Treatment and Slow Rate Land Application	$810,900	$7,751,200	$38,507,300
Secondary Treatment and Discharge	394,000	5,506,000	21,708,000
Phosphorus Removal and Discharge			
Without Filtration	481,000	6,023,000	23,771,000
With Filtration	634,000	6,642,000	27,209,000
Effluent Transmission Line (ETL)[3]	66,250,000	71,362,000	87,564,000

[1] Cost information from Technical Memorandum No. 4

[2] January, 1983 dollars

[3] Total capital costs of the ETL are $65,856,600. The cost for secondary treatment and discharge is added to this figure to arrive at the total cost. Construction of the ETL could not be phased or staged, as it would need to be constructed and operational regardless of the initial sizing or staging of wastewater treatment facilities.

Table 28

Equivalent Annual Costs for Point Source Controls in the Cherry Creek Basin[1]
DRCOG Projections

Wastewater System	Equivalent Annual Costs[2] 1985	1990	2000	2010
Secondary Treatment and Slow Rate Land Application	7.18	10.39	14.8	17.8
Secondary Treatment and Discharge	5.68	8.16	10.79	13.0
Phosphorus Removal and Discharge				
Without Filtration	6.02	8.69	11.45	14.45
With Filtration	6.72	9.46	12.3	14.5
Effluent Transmission Line (ETL)[3]	8.92	17.1	19.7	21.9

[1]Costs are in millions of dollars based on January 1983 dollars

[2]Equivalent annual costs for the basin were developed from projected wastewater flows as described in Chapter III, Basin Characteristics and Water Quality.

[3]Equivalent annual cost of the ETL is $8,921,500. This amount is added to the equivalent annual cost of the secondary treatment and discharge system

Table 29

Equivalent Annual Costs for Point Source Controls in the Cherry Creek Basin[1]
Developer Projections

Wastewater System	Equivalent Annual Costs[2] 1985	1990	2000	2010
Secondary Treatment and Slow Rate Land Application	6.64	14.39	21.61	26.39
Secondary Treatment and Discharge	5.79	10.61	15.94	18.89
Phosphorus Removal and Discharge				
Without Filtration	6.33	11.55	16.98	20.22
With Filtration	6.75	12.00	17.64	21.31
Effluent Transmission Line (ETL)[3]	19.7	24.5	29.8	32.76

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[1]Costs are in millions of dollars based on January 1983 dollars

[2]Equivalent annual costs for the basin were developed from projected wastewater flows as described in Chapter III, Basin Characteristics and Water Quality.

[3]Equivalent annual cost of the ETL is $13,873,300. This amount is added to the equivalent annual cost of the secondary treatment and discharge system

Using this cost estimating procedure, Table 30 presents the equivalent annual cost basin wide for nonpoint control by each option. This table also shows the cost per year per developed acre. Using this information, Table 31 presents the cost information basin wide for the years 1985, 1990, 2000, 2010. Details of the cost methodology appear in Technical Memorandum No. 5.

Cost information presented in Tables 30 and 31 are based not only on the cost estimates and land area requirements but also on the amount of runoff generated in the basin. The information on the quantity of runoff generated basin wide appears in Technical Memorandum No. 6. It should be noted that the cost information in Table 30 is for the DRCOG growth projections. Developer growth projections are not presented here; however, there was no appreciable difference in the unit costs for the DRCOG and developer projections.

Table 30
Summary of Nonpoint Control Costs

Cost Item	Detention Ponds[1]	Wetlands[2]	Rapid Infiltration[3]	25% Basin Wide Removal Detention plus Wetlands	50% Basin Wide Removal Detention plus Rapid Infiltration
Equivalent Annual Cost Basin Wide	$960,000	$160,000	$193,000	$1,120,000	$1,153,000
Cost per Developed Acre per Year	14	2	3	16	17

[1]Based on year 2010 developed acreage of 68,526 acres. This will require 562 acres of detention ponds constructed within the development areas.

[2]Based on year 2010 developed acreage of 68,526 acres, 28.2 acres of wetlands would be required. Cost per year of $2 per developed acre is partially due to no cost allotment for land.

[3]Based on year 2010 developed acreage of 68,526 acres, 14.3 acres of rapid infiltration would be required. Cost per developed acre per year of $3 is low due to the small amount of land required.

Table 31

Equivalent Annual Cost For Nonpoint Control
Cherry Creek Basin[1]

DRCOG Projections	1985 Dev. Acres	1985 Cost	1990 Dev. Acres	1990 Cost	2000 Dev. Acres	2000 Cost	2010 Dev. Acres	2010 Cost[4]
25% removal[2]	39977	0.64	48157	0.77	58554	0.94	68526	1.10
50% removal[3]	39977	0.68	48157	0.82	58554	1.00	68526	1.16
Developer Projections								
25% removal	49774	0.80	66570	1.06	83666	1.34	98099	1.57
50% removal	49774	0.85	66570	1.13	83666	1.42	98099	1.67

[1]All costs in millions of dollars per year.

[2]Detention ponds followed by wetlands ($16.00/year/developed acre).

[3]Detention ponds followed by rapid infiltration basins ($17.00/year/developed acre).

[4]Costs vary from Table 30 due to rounding of numbers.

WATER QUALITY MANAGEMENT SCENARIOS

With the point and nonpoint control options identified, it was then possible to develop any combination of point and nonpoint control systems. Using DRCOG projections and developer projections resulted in 30 possible combinations of point and nonpoint systems to control phosphorus in the basin. Evaluating 30 options for the four dates (1985, 1990, 2000, and 2010) resulted in a total of 120 scenarios which were then modeled to determine their effect on the reservoir. Table 32 is a matrix showing every possible combination of control systems to remove total phosphorus from the basin based on the technologies evaluated in this study.

Using the matrix in Table 32, each possible scenario was then numbered to identify it from any other scenario. The resulting 30 scenarios were separated into two categories: 1 through 15 represent DRCOG growth projections, and 16 through 30 represent developer growth projections. The difference between the two sets of projections (DRCOG vs. developer) is the volume of wastewater and stormwater runoff generated by each set of projections. Table 33 numerically identifies each water quality management scenario.

Changes in reservoir water quality, as a result of each scenario identified in Table 32 and 33, were determined by the Colorado Department of Health using their reservoir model. As each scenario was modeled for the years 1985, 1990, 2000, and 2010, changes in reservoir quality (total phosphorus and chlorophyll a and secchi depth) were determined. The next chapter, "Reservoir Loading" discusses the amount of phosphorus and volumn of water generated by each of the point and nonpoint scenarios as well as baseflow, groundwater and stormflows, and direct precipitation.

Table 32

Point and Nonpoint Control Matrix
for Total Phosphorus Removal

Nonpoint Phosphorus Removal	Total Phosphorus in Wastewater Effluent (mg/L)				
DRCOG Projections	0.2[1]	1.0[2]	4.0[3]	Land Application[4]	ETL[5]
No nonpoint phosphorus removal	X	X	X	X	X
25% phosphorus removal[6]	X	X	X	X	X
50% phosphorus removal[7]	X	X	X	X	X
Developer Projections					
No nonpoint phosphorus removal	X	X	X	X	X
25% phosphorus removal	X	X	X	X	X
50% phosphorus removal	X	X	X	X	X

[1]Advanced wastewater treatment, phosphorus removal with filtration and discharge.

[2]Advanced wastewater treatment, phosphorus removal without filtration and discharge.

[3]Secondary wastewater treatment and discharge.

[4]Secondary treated wastewater applied to the land; assumed 50% of the effluent would be consumed by crops or evaporated and 50% would migrate through the groundwater and reach the reservoir at a total phosphorus concentration of 0.1 mg/L.

[5]Piping treated secondary effluent around the reservoir.

[6]Detention ponds followed by wetlands.

[7]Detention ponds followed by rapid infiltration.

Table 33
Water Quality Management Scenarios

Scenario Number[1]	Scenario Description[2]
1	No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
2	No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
3	No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
4	No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
5	No nonpoint phosphorus removal, effluent transmission line
6	25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
7	25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
8	25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
9	25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
10	25% nonpoint phosphorus removal, effluent transmission line
11	50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
12	50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
13	50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
14	50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
15	50% nonpoint phosphorus removal, effluent transmission line
16	No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
17	No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
18	No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
19	No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
20	No nonpoint phosphorus removal, effluent transmission line
21	25% nonpoint phorphorus removal, 0.2 mg/L phosphorus in effluent
22	25% nonpoint phorphorus removal, 1.0 mg/L phosphorus in effluent
23	25% nonpoint phorphorus removal, 4.0 mg/L phosphorus in effluent
24	25% nonpoint phorphorus removal, land application, 0.1 mg/L phosphorus in effluent
25	25% nonpoint phorphorus removal, effluent transmission line
26	50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
27	50% nonpoint phorphorus removal, 1.0 mg/L phosphorus in effluent
28	50% nonpoint phorphorus removal, 4.0 mg/L phosphorus in effluent
29	50% nonpoint phorphorus removal, land application, 0.1 mg/L phosphorus in effluent
30	50% nonpoint phorphorus removal, effluent transmission line

[1]Scenarios 1-15 refer to DRCOG growth projections; 16-30 refer to developer growth projections.

[2]For description of point source control options, refer to Table 22; for description of nonpoint control options, refer to Tables 23, 24, 25, and 26.

VII. RESERVOIR LOADING

Nutrient and hydraulic loadings to Cherry Creek Reservoir are from several sources. Loading is currently mainly from stormflow, tributary baseflow, and direct precipitation onto the reservoir water surface. Loading from activities related to development such as wastewater flow and urban runoff are presently small, but are expected to increase greatly in the future with development. Other sources of nutrients include windblown dust and the slow release of nutrients from sediments. These sources are thought to be small and were not directly evaluated in this study.

This chapter discusses present (1982) loading of total phosphorus and water to Cherry Creek Reservoir and presents projections of reservoir loading resulting from the management scenarios and growth projections used in this study. Total phosphorus was analyzed because this nutrient was determined as being the most limiting for reservoir eutrophication processes and was the one selected for control (Chapter V).

Projections of future stormflow and wastewater loadings are presented and developed into total annual phosphorus and hydraulic loads. These loadings were used in Chapter VIII to assess the impact of growth and selected control measures on future reservoir water quality.

PRESENT LOADING

Surface water, groundwater and precipitation loading to the reservoir were estimated for 1982. Surface water loading included baseflows and stormflows. With the present no direct discharge limitation on wastewater systems in the basin there are presently no contributions to surface flow from wastewater.[19]

Loading for 1982 was calculated using data collected from the monitoring program. This program and sampling methodologies are discussed in Chapter II of this report and loading calculations are detailed in the report entitled "Reservoir Modeling and Sampling" by the Colorado Department of Health.[20]

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[19] DRCOG, "Clean Water Plan," 1983.

[20] Colorado Department of Health, "Report on Reservoir Modeling and Sampling," prepared by the Water Quality Control Division for Clean Lakes Study, October 1983.

Baseflow loads were calculated by applying average baseflow concentrations (Table 13) to the total estimated baseflow volume for 1982. The same methodology was used to estimate groundwater loading by Cherry Creek alluvium. As will be discussed later in this chapter, it was determined that net groundwater movement was out of the reservoir. This results in a gain of phosphorus from groundwater because of phosphorus retention in the reservoir sediments and absorption of phosphorus by particulate surfaces, but a net loss of water through the reservoir bottom.

Precipitation loading was estimated using average monthly concentrations and recorded monthly rainfall amounts. Calculation of annual stormloads is complex and is discussed under "Future Loading" in this chapter. Reservoir loading in 1982 is summarized in Table 34.

Table 34

1982 Reservoir Loading by Source for
Cherry Creek Reservoir

Source	Total Phosphorus Load (lbs)	Percent	Total Flow (ac-ft)	Percent
Baseflow	350	6.8%	400	18.0%
Stormflow	4,010	77.4%	690	31.3%
Groundwater[1]	130	2.5%	-220	-9.9%
Precipitation	690	13.3%	1,360	60.8%
TOTALS	5,180	100.0%	2,230	100.0%

[1]Equals Net Groundwater

The majority of the estimated 1982 phosphorus loading was from stormflow. This source contributed 77.4 percent of the annual phosphorus load this year, but only 31.7 percent of the total inflow. This finding suggests that average phosphorus concentrations in stormflow were high (2.1 mg/L) compared to the average concentration from all sources (0.85 mg/L), which is verified by the high monitored concentrations reported in Table 14. Table 35 presented later in this chapter shows that most of the phosphorus stormload was estimated from Shop Creek. As this is the most developed sub-basin in the reservoir basin, this finding demonstrates the effect of urban runoff on water quality and nutrient loading.

Baseflow concentrations were particularly small during 1982 and this is indicative of the generally dry nature of the basin itself. Baseloads and flows are shown by tributary in Table 13. Perennial tributary flows are small and surface flows from Cherry Creek usually don't reach the reservoir due to alluvial groundwater pumping. However, baseflows may increase significantly in the future if wastewater is discharged instead of land applied. This management option is being evaluated in this study and is discussed in Chapter VI. Baseflows are also likely to increase due to dry-weather urban runoff resulting from lawn irrigation, car washing, and other activities.

Total inflow to the reservoir was small and only represented 18.2 percent of the reservoir volume in 1982. This would correspond to a complete replacement of the reservoir water once every 5.5 years. Such a low flushing rate enhances the impact of phosphorus loading on eutrophication processes.

FUTURE LOADING

Future total phosphorus and hydraulic loading to the reservoir were estimated and used in the modeling to assess reservoir water quality under the various management scenarios described in Chapter VI. This was done by projecting stormflow and wastewater loads and adding them to the groundwater and baseflow loads monitored in 1982, and a direct precipitation load calculated using average rainfall conditions. It was assumed that groundwater, baseflow, and direct precipitation inputs would remain relatively constant.

Stormflow Loading

It was necessary to derive projections of stormflow loading to the reservoir due to the anticipated growth in the basin. This source of loading will increase as development proceeds. This occurs as previous areas are replaced by impervious ones such as streets, rooftops, and parking lots. Rainfall is no longer able to soak into soil or be intercepted by vegetation, and instead "runs off" into a drainage and eventually to the reservoir. Pollutants which accumulate on urban surfaces are remobilized by the runoff and carried with it. This process is aided by the impact of raindrops striking surfaces such as streets and roofs which loosen deposited sediment and pollutants.

One of the potential pollutants in stormflow is phosphorus. A main source of this and other nutrients is from lawn fertilizers. Rain dissolves and washes excessive fertilizer onto sidewalks and streets where it ultimately will be transported to the reservoir. Another large source of phosphorus is from sediment eroded from improper topsoil handling during construction activities. Phosphorus has a high affinity for particularate surfaces so will be carried by sediment.

Two sets of stormflow projections of total phosphorus and runoff volume were made based upon DRCOG and developer land use projections. Loads and flows were first made for each land use by sub-basin using the projections summarized in Chapter IV and presented in Technical Memorandum No. 2 (Tables A-1 through A-7). Sub-basin loads were then summed to obtain total basin loads.

Loading projections were made using models and information from the Denver Regional Urban Runoff Program (DRURP).[21] A methodology was developed employing DRURP models, land use projections, a rainfall distribution and 1982 monitoring data. This methodology is outlined in Figure 10.

It can be seen from Figure 10 that the basis for stormflow projections is land use projections. The DRURP concluded that stormflow loading varies according to land use. The more intense the development and higher the percent impervious surface of the land use type, the greater the stormflow from it. A large-lot single family development would contribute substantially less stormflow and load than a commercial development consisting largely of parking lots or a high density single family development.

DRURP models were adjusted to the sub-basins. This was done by comparing 1982 monitored results with those predicted using the models and deriving scaling factors. A rainfall distribution was used to define the number of storms of certain size categories that could be expected during any given year. Both total phosphorus loads and runoff volumes were predicted, and as Figure 10 shows, these projections were used to estimate total reservoir loading for input to the model. This methodology is further explained in Clean Lakes Technical Memorandum No. 6.

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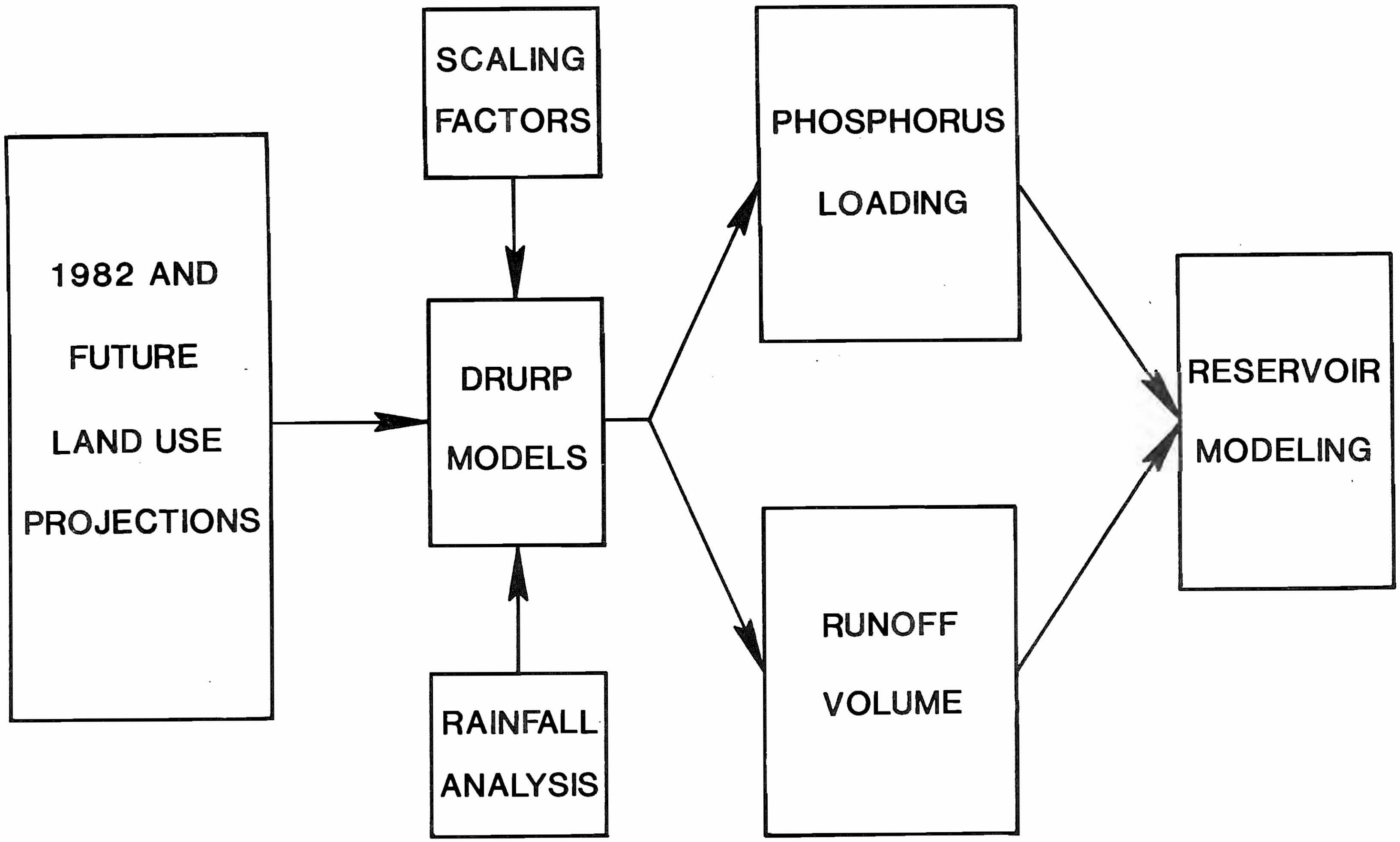
[21] DRCOG, "Urban Runoff Quality in the Denver Region," DRCOG, October 1983.

FIGURE 10

RELATIONSHIPS BETWEEN INFORMATION AND COMPONENTS USED IN METHODOLOGY TO PREDICT PHOSPHORUS LOADING AND RUNOFF



The methodology shown in Figure 10 was also used to estimate annual stormloading to the reservoir in 1982. This was accomplished by using land use measured from aerial photos and shown in Table 10. It was felt that this procedure would ensure consistent results with projections and eliminate the subjectivity involved in the extrapolation of monitored storms to an annual estimate. Estimates of 1982 storm loading by tributary are contained in Table 35.

Table 35

Cherry Creek Reservoir
1982 Predicted Stormflow Total Phosphorus Load (lbs)
and Runoff Volume (ac-ft)

	1982 Load	Percent	1982 Runoff Volume	Percent
Unmonitored Area	378	9.4	174	25.4%
Cherry Creek (includes Happy Canyon)	596	14.9	74	10.8%
Lone Tree Creek	36	0.9	6	0.9%
Cottonwood Creek	343	8.6	181	26.4%
Piney Creek	223	5.6	91	13.3%
Shop Creek	2,429	60.6	159	23.2%
TOTALS	4,010	100.0%	685	100.0%

The majority of the phosphorus load from stormflow in 1982 was from Shop Creek. The load contributed by this tributary was high compared to the annual estimate of runoff volume from it. Shop Creek loading amounted to 60.6 percent of the annual stormload, but only 23.2 percent of the stormflow volume. The high loading from this sub-basin can be attributed to its developed nature. Shop Creek is presently the most developed sub-basin in the reservoir basin. Approximately 46 percent of the total area of Shop Creek was developed in 1982, excluding parks and greenbelts. This sub-basin also has a generally greater overall slope than any other sub-basin. These two factors are most likely responsible for the high loading observed in 1982.

Future stormflows and phosphorus loading by sub-basin up to the year 2010 are presented in Table 36. The DRCOG and developer projections resulted in a range of loading to the reservoir depending upon growth. If growth expectations fall short of developer projections, then future stormwater loading would fall within the range and loads would be realized by the projected dates. However, if accelerated growth occurs, projections for either DRCOG or developer scenarios would be realized prior to the projected date. That is, loading projected to occur in 2010 would occur by 1990, 2000, or some earlier date. In terms of lake water quality, this would mean possible increases in chlorophyll a sooner than predicted.

It can be seen from Table 36 that both the amount of total phosphorus and runoff volume from stormflow reaching the reservoir are predicted to greatly increase in the future. Total phosphorus loading from this source is projected to increase 317 and 811 percent over 1982 conditions for DRCOG and developer scenarios, respectively. Stormflow volume is projected to increase 1,176 and 3,100 percent over 1982 conditions for both scenarios. The cause for the large relative increase in stormflow volume compared to phosphorus loading is not easily explainable, but may be due to changes in land use composition to land uses producing less load per runoff volume.

The magnitude of stormflow generated is a function of the degree of development occurring within a sub-basin. The greater the percentage of developed acres, the larger the stormflow and load of phosphorus. Both the greatest load and flow in 2010 are projected to come from Lone Tree Creek. This sub-basin is also projected to have the greatest percentage of land developed for all the sub-basins (Table A-4, Technical Memorandum No. 2). It should be apparent in Table 3 that relative contributions from Shop Creek decrease in the future as this sub-basin approaches full build-out. This is due to other sub-basins developing to more dense levels, and also because of the small size of the Shop Creek sub-basin.

Wastewater Loading

Present wastewater loading to the reservoir is insignificant due to small flows and wastewater management policy calling for land application of treated effluent. However, loading from this source will increase in the future with the anticipated growth in the basin and any changes in policy allowing direct discharge of effluent. Wastewater loading to the reservoir from the various management options evaluated is projected through 2010 to account for this source and its effects on water quality.

Table 36
Cherry Creek Reservoir
Stormflow Loading Projections

	1985		1990		2000		2010	
	DRCOG	Developer	DRCOG	Developer	DRCOG	Developer	DRCOG	Developer
TOTAL PHOSPHORUS LOADING (Pounds/Year)								
Unmonitored Area	417	580	462	742	615	1,164	792	1,671
Cherry Creek	1,209	1,778	1,807	3,165	3,184	6,109	4,950	8,563
Happy Canyon Creek	143	347	318	1,057	831	2,030	1,406	2,588
Lone Tree Creek	169	502	436	1,491	1,786	5,514	3,957	12,465
Cottonwood Creek	144	299	388	1,640	1,196	3,367	3,547	5,421
Piney Creek	245	341	338	529	509	776	644	1,098
Shop Creek	2,429	2,975	2,429	3,488	2,429	4,719	2,429	4,719
TOTAL	4,750	6,820	6,180	12,110	10,560	23,680	16,730	36,530
RUNOFF VOLUME (Acre-Feet/Year)								
Unmonitored Area	83	285	166	399	199	679	561	1,033
Cherry Creek	315	524	538	1,196	1,200	2,898	2,152	4,402
Happy Canyon Creek	53	172	151	631	461	1,255	812	1,612
Lone Tree Creek	90	331	282	1,082	1,306	4,242	3,007	9,792
Cottonwood Creek	61	156	205	1,091	747	2,327	1,704	3,855
Piney Creek	104	153	152	263	256	427	343	658
Shop Creek	164	240	164	329	164	563	164	563
TOTAL	870	1,860	1,660	5,000	4,330	12,400	8,740	21,920

Wastewater flow projections were discussed and presented in Tables 16 and 17 in Chapter IV. These projections were used to calculate total phosphorus loads in wastewater. It was assumed that 100 percent of the flow would reach the reservoir from direct discharge regardless of the level of treatment. It was also assumed that one-half of the projected flow would enter the reservoir from land application. The possibly lengthy delay between time of land application and conveyance of effluent to the reservoir by groundwater was not considered. No wastewater would remain in the basin or enter the reservoir with the Effluent Transmission Line (ETL).

The load of total phosphorus reaching the reservoir from wastewater is dependent upon the level of treatment and phosphorus concentration in effluent. Three treatment levels were evaluated which produced the following effluent concentrations: 4.0 mg/L for secondary treatment only, and 0.2 mg/L and 1.0 mg/L for advanced treatment with phosphorus removal with and without filtration, respectively. A concentration of 0.1 mg/L was assumed in land application effluent. Wastewater loads were projected for the three direct discharge scenarios and land application with the above-described characteristics.

It was assumed that rapid infiltration land disposal would result in all wastewater entering the reservoir at a concentration of 0.2 mg/L which is the equivalent of advanced treatment with filtration and discharge. Decreases in land application system removal rates due to saturation of soil absorptive capacity would result in the need to construct additional basins or modify the existing basins to sustain their phosphorus removal capacity.

Projections of phosphorus loading from wastewater for each of the management options evaluated are presented in Table 37 using DRCOG and developer growth wastewater projections in Chapter IV. Projections were only made for those wastewater districts identified as of May 1983. It was assumed that all areas outside of the districts would be served by individual sewage disposal systems which would not contribute phosphorus to the reservoir. It was also assumed that all districts would utilize the same level of treatment and effluent disposal for any year. For example, all districts would practice land application at the same time. Some wouldn't use land application and others advanced treatment with discharge.

Table 37 shows that phosphorus loading from wastewater can be significant in the future, depending upon the level of treatment and method of effluent disposal. The greatest loading is produced by direct discharge of secondary effluent wastewater. The greatest loading projected from this management option in the year 2010 (high growth scenario) is 305,980 lbs. which is 5,800 percent of the total basin load from all sources estimated in 1982. Use of the ETL, advanced treatment or land application drastically diminish this amount. Projections of loading from land application are the smallest and are 2,350 lbs. and 3,820 lbs. in 2010 for DRCOG and developer scenarios, respectively. These are the smallest loadings from any system evaluated except for the ETL which would route all wastewater around the reservoir.

Total Basin Loading

Basin loading from all sources was projected to the year 2010. Total basin loads were calculated as the sum of stormflow, baseflow, wastewater and direct precipitation loadings, plus or minus net groundwater flow. This relationship is shown below:

$$\text{Total Basin Load} = \text{stormflow} + \text{baseflow} + \text{wastewater} + \text{precipitation} \pm \text{groundwater}.$$

Stormflow and wastewater loads were presented previously in this chapter. It is assumed that baseflow, precipitation and groundwater inputs would not change appreciably in the future and were held constant.

Net groundwater movement was determined as being out of the reservoir for 1982. A net loss of 220 acre-feet was calculated for this year and used for future years.[22] While a net loss of water was found from this source, a net gain of phosphorus resulted from it. This is because phosphorus entering the reservoir from groundwater will be retained by processes including biological assimilation and sedimentation. Groundwater lost through the reservoir bottom will have very low phosphorus concentrations.

With groundwater, baseflow, and precipitation contributions assumed to be constant in the future, total basin loading becomes a function of stormflow and wastewater loading. Projections of total phosphorus and hydraulic

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[22]Colorado Department of Health, October 1983.

Table 37

Projections of Total Phosphorus Loading to Reservoir From Wastewater[1] (Figures are Pounds/Year)

Management Option[2]	1980[3]	1985	1990	2000	2010
	DRCOG Projections				
Direct Discharge:[4]					
Secondary Treatment (4.0 mg/L)[5]	12,680	47,060	82,410	133,240	188,950
Advanced Treatment (1.0 mg/L)	3,170	11,760	20,600	33,310	47,240
Advanced Treatment (0.2 mg/L)	630	2,350	4,120	6,660	9,450
Land Application[6] (0.1 mg/L)	160	590	1,030	1,670	2,360
	Developer Projections				
Direct Discharge:[4]					
Secondary Treatment (4.0 mg/L)[5]		41,810	106,540	220,650	305,980
Advanced Treatment (1.0 mg/L)		10,450	26,640	55,160	76,490
Advanced Treatment (0.2 mg/L)		2,090	5,330	11,030	15,300
Land Application[6] (0.1 mg/L)		520	1,330	2,760	3,820

[1] Based upon wastewater flow projections in Tables 16 and 17.

[2] Management Options are described fully in Chapter VI. No wastewater would reach the reservoir from the ETL.

[3] No developer data were available for 1980.

[4] Assumed 100 percent of total wastewater flow reached reservoir.

[5] Values in parenthesis are concentrations of total phosphorus in effluent.

[6] Assumed 50 percent of total wastewater flow reached reservoir.

loading from all sources were made using DRCOG and developer projections. These are shown in Tables 38 through 40. The four levels of treatment evaluated resulted in four projections of phosphorus loading each year, for each scenario. Likewise, direct discharge and land application of effluent resulted in two projections of hydraulic loading for each year and scenario.

Several important trends can be gathered from Tables 38 through 40. The most obvious of these is that total phosphorus loadings are projected as increasing 250 through 6,500 percent over 1982 conditions in the year 2010 for minimum loading (DRCOG projections, and the ETL) and maximum loading (developer projections, discharge of 4.0 mg/L phosphorus in effluent), respectively. Hydraulic loading is projected to increase 360 through 2,210 percent over the total inflow monitored in 1982 in the year 2010 depending upon whether effluent is diverted with the ETL or discharged. These hydraulic loadings would result in complete replacement of the entire reservoir volume 0.7 through 3.7 times a year, based on multi-purpose pool capacity.

The increase in reservoir loading is due to development-related activities. The amount and percentage of phosphorus from wastewater and stormflow increase each year and these two sources combined may contribute up to 99.6 percent of the phosphorus load from all sources in 2010. The magnitude of these sources is greatly dependent upon the level of wastewater treatment and effluent disposal. Wastewater receiving secondary treatment which is discharged directly is projected as contributing up to 91.3 percent of the total annual phosphorus load in the year 2010. For the same year, this source is projected as contributing only 11.6 percent as the total load if effluent is land applied, or zero if an ETL is used. Hydraulic loading is not reduced as much by land application, as this management option would still amount to 37.5 percent of the total hydraulic loading in 2010. However, greater hydraulic loading mutes the effect of phosphorus in the reservoir.

It is also apparent in Tables 38 and 39 that as the level of treatment of wastewater increases (phosphorus concentration in effluent decreases) the percentage of the total phosphorus from stormflow increases. Stormflow is projected to contribute as much as 88 percent of the phosphorus load in 2010, with wastewater land applied. This shows that control of this source may be required to achieve water quality goals. This is evaluated in Chapter VI.

Table 38

Projections of Total Phosphorus Loading to Reservoir From All Sources Using DRCOG Projections[1]

	Wastewater Flow[2]													
	4.0 mg/L		1.0 mg/L		0.2 mg/L		0.1 mg/L[3]		Stormflow[4]		Other[5]		Total	
Year	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs	%	lbs.	%	lbs.	%
1985	47,060	88.8							4,750	9.0	1,170	2.2	52,980	100.0
			11,760	66.5					4,750	26.9	1,170	6.6	17,680	100.0
					2,350	28.4			4,750	57.4	1,170	14.2	8,270	100.0
							590	9.0	4,750	73.0	1,170	18.0	6,510	100.0
									(4,750)	(80.2)	(1,170)	(19.8)	(5,920)	(100.0)
1990	82,410	91.8							6,180	6.9	1,170	1.3	89,760	100.0
			20,600	73.7					6,180	22.1	1,170	4.2	27,950	100.0
					4,120	35.9			6,180	53.9	1,170	10.2	11,470	100.0
							1,030	12.3	6,180	73.7	1,170	14.0	8,380	100.0
									(6,180)	(84.1)	(1,170)	(15.9)	(7,350)	(100.0)
2000	133,240	91.9							10,560	7.3	1,170	0.8	144,970	100.0
			33,310	74.0					10,560	23.4	1,170	2.6	45,040	100.0
					6,660	36.2			10,560	57.4	1,170	6.4	18,390	100.0
							1,670	12.5	10,560	78.8	1,170	8.7	13,400	100.0
									(10,560)	(90.0)	(1,170)	(10.0)	(11,730)	(100.0)
2010	188,950	91.3							16,730	8.1	1,170	0.6	260,850	100.0
			47,247	72.5					16,730	25.7	1,170	1.8	65,140	100.0
					9,450	34.6			16,730	61.2	1,170	4.2	27,350	100.0
							2,360	11.6	16,730	82.6	1,170	5.8	20,260	100.0
									(16,730)	(93.5)	(1,170)	(6.5)	(17,900)	(100.0)

[1] See text for discussion of methodology. Numbers in parenthesis are for ETL.

[2] Concentrations represent total phosphorus levels in effluent. Descriptions of treatment levels appear in Chapter V.

[3] Concentrations correspond to slow-rate land application of effluent.

[4] Stormflow phosphorus loads were reduced by 25 or 50 percent in the modeling for those scenarios including nonpoint control.

[5] Includes groundwater, baseflow and direct precipitation inputs. 1982 monitored groundwater and baseflow and direct precipitation conditions were used and assumed to be constant in the future.

Table 39
Projections of Total Phosphorus Loading to Reservoir From All Sources Using Develop Projections[1]

	Wastewater Flow[2]													
	4.0 mg/L		1.0 mg/L		0.2 mg/L		0.1 mg/L[3]		Stormflow[4]		Other[5]		Total	
Year	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs	%	lbs.	%	lbs.	%
1985	41,810	84.0							6,820	13.7	1,170	2.3	49,800	100.0
			10,450	56.7					6,820	37.0	1,170	6.3	18,440	100.0
					2,090	20.7			6,820	67.7	1,170	11.6	10,080	100.0
							520	6.1	6,820	80.1	1,170	13.8	8,510	100.0
									(6,820)	(85.2)	(1,170)	(14.8)	(7,990)	(100.0)
1990	106,540	88.9							12,110	10.1	1,170	1.0	119,820	100.0
			26,640	66.7					12,110	30.3	1,170	3.0	39,920	100.0
					5,330	28.6			12,110	65.1	1,170	6.3	18,610	100.0
							1,330	9.1	12,110	82.9	1,170	8.0	14,610	100.0
									(12,110)	(91.2)	(1,170)	(8.8)	(13,280)	(100.0)
2000	220,650	89.9							23,680	9.6	1,170	0.5	245,500	100.0
			55,160	68.9					23,680	29.6	1,170	1.5	80,010	100.0
					11,030	30.7			23,680	66.0	1,170	3.3	35,882	100.0
							2,760	10.0	23,680	85.8	1,170	4.2	27,610	100.0
									(23,680)	(95.3)	(1,170)	(4.7)	(24,850)	(100.0)
2010	305,980	89.0							36,530	10.6	1,170	0.4	343,680	100.0
			76,490	67.0					36,530	32.0	1,170	1.0	114,190	100.0
					15,300	28.9			36,530	68.9	1,170	2.2	53,000	100.0
							3,820	9.2	36,530	88.0	1,170	2.8	41,520	100.0
									(36,530)	(96.9)	(1,170)	(3.1)	(37,700)	(100.0)

[1] See text for discussion of methodology. Numbers in parenthesis are for ETL.
[2] Concentrations represent total phosphorus levels in effluent. Descriptions of treatment levels appear in Chapter V.
[3] Concentrations correspond to slow-rate land application of effluent.
[4] Stormflow phosphorus loads were reduced by 25 or 50 percent in the modeling for those scenarios including nonpoint control.
[5] Includes groundwater, baseflow and direct precipitation inputs. 1982 monitored groundwater and baseflow and direct precipitation conditions were used and assumed to be constant in the future.

Table 40
Projections of Hydraulic Loading to Reservoir From all Sources[1]

Year	Wastewater Flow[2] Direct Discharge[3] ac-ft	%	Land Application[4] ac-ft	%	Stormflow ac-ft	%	Other[5] ac-ft	%	Total ac-ft	%
					DRCOG PROJECTIONS					
1985	4,320	64.7			870	13.0	1,490	22.3	6,680	100.0
			2,160	47.8	870	19.2	1,490	33.0	4,520	100.0
					(870)	(36.9)	(1,490)	(63.1)	(2,360)	(100.0)
1990	7,570	70.6			1,660	15.5	1,490	13.9	10,720	100.0
			3,790	54.6	1,660	23.9	1,490	21.5	6,940	100.0
					(1,660)	(52.7)	(1,490)	(47.3)	(3,150)	(100.0)
2000	12,240	67.8			4,330	24.0	1,490	8.2	18,060	100.0
			6,120	51.3	4,330	36.3	1,490	12.4	11,940	100.0
					(4,330)	(74.4)	(1,490)	(25.6)	(5,820)	(100.0)
2010	17,360	62.9			8,740	31.7	1,490	5.4	27,590	100.0
			8,680	45.9	8,740	46.2	1,490	7.9	18,910	100.0
					(8,740)	(85.4)	(1,490)	(14.6)	(10,230)	(100.0)
					DEVELOPER PROJECTIONS					
1985	3,840	53.4			1,860	25.9	1,490	20.7	7,190	100.0
			1,920	36.4	1,860	35.3	1,490	28.3	5,270	100.0
					(1,860)	(55.5)	(1,490)	(44.5)	(3,350)	(100.0)
1990	9,790	60.1			5,000	30.7	1,490	9.2	16,280	100.0
			4,900	43.0	5,000	43.9	1,490	13.1	11,390	100.0
					(5,000)	(77.0)	(1,490)	(13.0)	(6,490)	(100.0)
2000	20,280	59.4			12,400	36.3	1,490	4.3	34,170	100.0
			10,140	42.2	12,400	51.6	1,490	6.2	24,030	100.0
					(12,400)	(89.3)	(1,490)	(10.7)	(13,890)	(100.0)
2010	28,120	54.6			21,920	42.5	1,490	2.9	51,530	100.0
			14,060	37.5	21,920	58.5	1,490	4.0	37,470	100.0
					(21,920)	(93.6)	(1,490)	(6.4)	(23,410)	(100.0)

[1] Evaporative losses included. See text for explanation of methodology. Numbers in parenthesis are for ETL.
[2] Includes three discharge and one land application scenario. Description of treatment levels appear in Chapter VI.
[3] Assumed 100 percent of effluent reach reservoir regardless of level of treatment.
[4] Assumed 50 percent of effluent would reach reservoir.
[5] Includes groundwater, baseflow and direct precipitation inputs, 1982 monitored groundwater and baseflow and average precipitation conditions were used and assumed constant. Average rainfall resulted in 1,310 ac-ft. of precipitation input directly to reservoir.

The total basin loads shown in Tables 38 through 39 were used in the modeling to evaluate future reservoir water quality under various management options (Chapter VIII). Stormflow loads of phosphorus were reduced by 25 or 50 percent for those scenarios including nonpoint controls. The effect that management options have on water quality depend upon both phosphorus and hydraulic loading which were presented in this chapter.

VIII. WATER QUALITY MODELING

The present water quality of Cherry Creek Reservoir is a result of nutrient and hydraulic loading influenced by reservoir characteristics such as depth, surface area, volume, and hydraulic retention time. Loading to the reservoir is currently due mainly to natural sources. However, as projected growth occurs within the basin, loading from development-related activities will increase. This increased loading may adversely affect water quality by accelerating reservoir eutrophication. The reservoir would most correctly be classified as being in a eutrophic state in 1982 (Chapter V), but future loading may further degrade water quality and move the trophic status towards hypertrophy.

The effects of the various management options evaluated in this study on future water quality were evaluated using loading projections presented in Chapter VII, Tables 38 through 40. These loading projections were used as inputs in several simple empirical models to predict future in-lake phosphorus and chlorophyll a concentrations and secchi disc depth. Prediction of these parameters which are directly related to eutrophication allows for evaluation of management options and water quality. The models selected for use could not address variables such as dissolved oxygen, fecal coliform bacteria, metals, or other variables.

Reservoir water quality modeling was the responsibility of the Colorado Department of Health (CDH). The modeling completed by them is summarized in this Chapter. Comparison of the results with water quality goals and systems' costs is undertaken in Chapter IX.

OVERVIEW

The importance of phosphorus in determining lake eutrophication has been well documented in the literature.[23,24] This nutrient is most commonly found in concentrations that

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[23] R. G. Wetzel, "Limnology", W. B. Saunders Company, Philadelphia, Pennsylvania, 1975.

[24] R. W. Bachmann and J. R. Jones, "Phosphorus Inputs and Algal Blooms in Lakes", Iowa State J. Res., 49(2):155-160, 1974.

are limiting to algal growth, and is most often selected for control over nitrogen for two reasons: 1) it is easier and cheaper to control, and 2) if not already limiting, it can be induced to be the limiting nutrient by control.[25] The relationship between total phosphorus concentration and phytoplankton biomass (chlorophyll a) has been well studied.[26] In cases where phosphorus is the limiting nutrient, slight increases in phosphorus to a lake result in disproportionately large increases in algal productivity as measured by chlorophyll a.[27]

Because of the crucial role of phosphorus in driving the process of eutrophication, and the conclusion that this nutrient does limit algal growth in Cherry Creek Reservoir,[28] the ability to estimate future levels and their impact on water quality is paramount. Comparison of future levels resulting from the various management options is possible through water quality modeling. Such comparisons allow for decisions to be made regarding future management policy.

Numerous models have been developed over the last decade that predict ambient total phosphorus concentration from loading data. These models are based upon the initial model proposed by Vollenweider in 1968[29] and have utilized a large data base collected from 1972 through 1975 as a part of the

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[25] S. C. Hern, *et al.*, "Modifications of Models Predicting Trophic State of Lakes . . .", Environmental Monitoring Systems Laboratory, Las Vegas, Nevada, EPA-600/3-81-001, 1981.

[26] J. Kolff and R. Knoechel, "Phytoplankton and Their Dynamics in Oligotrophic and Eutrophic Lakes", Ann. Review Ecol. Sys., 9:475-495, 1978.

[27] S. C. Hern, *et al.*, 1981.

[28] Colorado Department of Health, October 1983.

[29] R. A. Vollenweider, "The Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication" OECD, Paris, Tech. Rep. DAS/CSI/68.27:1-159, 1968.

National Eutrophication Survey. These models are empirical in nature and assume a steady state condition in the reservoir. They have been widely employed to evaluate present phosphorus loading and water quality, and the effects of reduced loading on future water quality.[30]

The principal differences between models have to do with each ones' means of estimating phosphorus losses to sediments. It was felt that early models overestimated total phosphorus concentrations, especially in artificial lakes, due to their inability to account for losses of phosphorus to sediments. Models were developed that had a variable sedimentation coefficient using data from artificial lakes only.

Since the development of simple empirical models that estimate inlake total phosphorus concentrations, numerous other models have been formulated that predict chlorophyll a and secchi disc depth. These other parameters are helpful in evaluating the impacts of increased nutrient loading on eutrophication and water quality. However, it is still difficult to assess changes in beneficial uses of a lake caused by eutrophication with these models. Specific questions relating to effects on beneficial uses such as swimming and fishing are difficult to answer. Such questions include: What changes might be expected in fish fauna? Will the water quality still be appealing to swimmers? How much is dissolved oxygen likely to be lowered? And, to what extent will aquatic vegetation become a nuisance? Answers to these and other questions can only be made in broad terms in most cases. The ultimate question of what kind of total phosphorus or chlorophyll a would be permissible to sustain an array of beneficial uses must be answered with information besides that obtainable from these models.

Total phosphorus, chlorophyll a, and secchi disc depth were all predicted in the modeling effort. Total phosphorus predicted by one model is used in another to estimate chlorophyll a. This, in turn, is then used in a third model to predict secchi disc depth. In general, the more eutrophic the water body, the higher the total phosphorus and chlorophyll a levels, and the smaller the secchi depth. Cholorophyll a is a measure of the quantity of planktonic algae in

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[30] D. E. Canfield and R. W. Bachmann, "Prediction of Total Phosphorus Concentrations, Chlorophyll a and Secchi Depts for Natural and Artificial Lakes, Can. J. Fish. Aquatic Sci. 38:414-423, 1980.

the water column which is directly related to phosphorous. Secchi disc depth measures water clarity; the more algae in the water, the less transparent it will be and the smaller the secchi depth.

The models used in this study were selected by the CDH. Specific details of the models and reasons for their selection can be found in their report.[31]

SCOPE

All possible combinations of wastewater treatment options and nonpoint control strategies evaluated in this study were modeled. These scenarios are shown in Table 32, Chapter VI. It can be seen that there are fifteen combinations of wastewater and nonpoint control options which can be evaluated using both DRCOG and developer projections, resulting in 30 possible scenarios each year, and 120 scenarios total for 1985, 1990, 2000, and 2010. Estimates of total phosphorus, chlorophyll a, and secchi depth were made for all scenarios each year.

It is important to note that DRCOG wastewater flow projections were used with DRCOG nonpoint projections, and developer wastewater with developer nonpoint projections. Also, the ETL is for transmission of already-treated wastewater around the reservoir. This does not necessarily involve treatment at a single, regional facility. Lastly, effluent characteristics used for land application were recommended by the Clean Lakes Technical Review Committee and are based on current literature values.[32,33] Land application refers to slow-rate systems only. Rapid-rate systems such as infiltration basins were assumed to produce effluent the equivalent of phosphorus removal with filtration (0.2 mg/L total phosphorus).

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[31]Colorado Department of Health, October 1983.

[32]E. L. Koerner and D. A. Haws, "Long Term Effects of Land Application of Domestic Wastewater - Roswell, New Mexico", U.S. Environmental Protection Agency, EPA 600/2-79-047, 1979.

[33]U.S. Environmental Protection Agency, "Process Design Manual for Land Treatment of Municipal Wastewater", U.S. EPA, EPA 625/1-77-008, 1977.

MODELING METHODOLOGY

The modeling methodology and equations used are summarized in this section. The phosphorus model selected by the CDH was a derivative of the Vollenweider model with a variable sedimentation coefficient developed by Canfield and Bachmann.[34] This model was adjusted to Cherry Creek Reservoir using monitored data. The resulting equation is shown below:

$$TP = \frac{L}{Z\left[k\left(0.114\left(\frac{L}{Z}\right)^{0.589}\right) + p\right]} \qquad (1)$$

where: TP = inlake total phosphorus concentration (ug/l),
L = total phosphorus loading (mg/m^2/year),
Z = mean lake depth (meters),
p = flushing rate (annual inflow/lake volume), and
k = adjustment factor (2.3 for Cherry Creek Reservoir).

This equation predicted 1982 conditions with fairly close accuracy and was thought to provide reasonable estimates of future inlake phosophorus concentrations. Predicted total phosphorus was then used to predict chlorophyll a levels using the equation developed by Jones and Bachmann[35]:

log Chlor. a (ug/L) = -1.09 + 1.46 log Tot. Phosphorus(ug/L). (2)

This equation predicted 1982 conditions closely. Chlorophyll a predicted by it were then used to estimate secchi disc depth based upon the equation by Carlson.[36] This equation yielded reasonable estimates of monitored secchi depth and is presented below:

ln secchi depth(m) = 2.04 - 0.68 ln chlor. a (ug/L). (3)

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[34] E. E. Canfield and R. W. Bachmann, 1980.

[35] J. R. Jones and R. W. Bachman, "Prediction of Phosphorus and Chlorophyll Levels in Lakes", J. Water Pollu. Control Fed. 48(9):2176-2182, 1976.

[36] R. E. Carlson, "A Trophic State Index for Lakes", Limnol. and Oceanogr., 22:361-369, 1977.

Model Inputs

Annual total phosphorus and hydraulic loads for each management option presented in Tables 38 through 40 (Chapter VII) were input to the phosphorus model, Equation (1). Nonpoint (stormflow) loads were reduced by 25 or 50 percent for those scenarios which include nonpoint control (Table 32).

Phosphorus loads were expressed per unit of reservoir surface as is required by the model. Both reservoir surface area and mean depth were varied in the future depending upon the inflow. Inflows from scenarios were added to 1982 baseline conditions, and a surface area and mean depth calculated using rating curves.[37] Recreational pool level was not exceeded; once reached, it was assumed that surplus water would be released from the reservoir. Historically, releases from Cherry Creek Reservoir have been rare, and there are no scheduled releases to satisfy water rights or downstream flow requirements.

Inflow to the reservoir is gross inflow and includes groundwater contributions. Evaporative and seepage losses from the reservoir are not accounted for in the model.

Average precipitation conditions were used for all years. Baseflow and groundwater conditions monitored in 1982 were assumed constant and used in the future. Modeling inputs of total phosphorus and inflow are shown for all scenarios in Table 41.

Modeling Results

Results of the modeling effort are shown in Table 42. Scenarios numbered 1 through 15 correspond to DRCOG growth projections; numbers 16 through 30 are using developer projections.

Several important findings can be noted from the results in Table 42. First of all, DRCOG and developer projections resulted in a significant range of chlorophyll a, total phosphorus, and secchi disc depth projections for the same management scenario. The difference between projections was greatest for those scenarios which included secondary wastewater treatment with discharge. A range of over 21 ug/L was found between DRCOG and developer projections for secondary treatment with discharge and no nonpoint control (scenarios 3 and 18).

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[37] Colorado Department of Health, October 1983.

TABLE 41

PROJECTIONS OF CHERRY CREEK RESERVOIR TOTAL PHOSPHORUS LOADING AND INFLOW FOR RESERVOIR MODELING[1]

		1985		1990		2000		2010	
NO.	SCENARIO DESCRIPTION[2]	P Load gm/M²/yr	Net Inflow M^3x10^7	P Load gm/M²/yr	Net Inflow M^3x10^7	P Load gm/M²/yr	Net Inflow M^3x10^7	P Load gm/M²/yr	Net Inflow M^3x10^7
	DRCOG Projections								
1	No nonpoint control, 0.2 mg/L phosphorus in wastewater	1.06	.499	1.48	.996	2.39	1.90	3.57	3.08
2	No nonpoint control, 1.0 mg/L phosphorus in wastewater	2.30	.499	3.64	.997	5.89	1.90	8.53	3.08
3	No nonpoint control, 4.0 mg/L phosphorus in wastewater	6.93	.499	11.8	.997	19.0	1.90	27.1	3.08
4	No nonpoint control, land application, 0.1 mg/l phosphorus[3]	.859	.232	1.07	.530	1.73	1.15	2.64	2.01
5	No nonpoint control, Effluent Transmission Line (ETL)	.795	.035	.974	.0630	1.52	.392	2.33	.936
6	25% nonpoint control, 0.2 mg/L phosphorus in wastewater	1.04	.499	1.41	.997	2.17	1.90	3.15	3.08
7	25% nonpoint control, 1.0 mg/L phosphorus in wastewater	2.27	.499	3.57	.997	5.67	1.90	8.11	3.08
8	25% nonpoint control, 4.0 mg/L phosphorus in wastewater	6.90	.184	11.7	.682	18.8	1.59	26.7	2.76
9.	25% Nonpoint control, land application, 0.1 mg/L phosphorus[3]	.834	.232	1.00	.530	1.52	1.15	2.22	2.01
10	25% nonpoint control, Effluent Transmission Line (ETL)	.769	.035	.900	.0630	1.30	.392	1.91	.936
11	50% nonpoint control, 0.2 mg/L phosphorus in wastewater	1.01	.499	1.34	.997	1.96	1.90	2.73	3.08
12	50% nonpoint control, 1.0 mg/L phosphorus in wastewater	2.25	.499	3.50	.997	5.46	1.90	7.69	3.08
13	50% nonpoint control, 4.0 mg/L phosphorus in wastewater	6.88	.184	11.6	.682	18.6	1.59	26.3	2.76
14	50% nonpoint control, land application, 0.1 mg/L phosphorus[3]	.809	.232	.931	.530	1.30	1.15	1.80	2.01
15	50% nonpoint control, Effluent Transmission Line (ETL)	.743	.035	.826	.0630	1.08	.392	1.49	.936
16	No nonpoint control, 0.2 mg/L phosphorus in wastewater	1.30	.562	2.40	1.67	4.69	3.89	6.94	6.03
17	No nonpoint control, 1.0 mg/L phosphorus in wastewater	2.38	.562	5.20	1.67	10.5	3.89	15.0	6.03
18	No nonpoint control, 4.0 mg/L phosphorus in wastewater	6.51	.247	13.7	1.36	28.1	3.57	39.4	5.71
19.	No nonpoint control, land application, 0.1 mg/L phosphorus[3]	1.09	.325	1.87	1.08	3.60	2.64	5.43	4.30
20	No nonpoint control, Effluent Transmission Line (ETL)	1.06	.088	1.70	.47	3.24	1.39	4.93	2.56
21	25% nonpoint control, 0.2 mg/L phosphorus in wastewater	1.21	.562	2.14	1.67	4.03	3.89	5.87	6.03
22	25% nonpoint control, 1.0 mg/L phosphorus in wastewater	2.29	.562	4.94	1.67	9.84	3.89	13.9	6.03
23	25% nonpoint control, 4.0 mg/L phosphorus in wastewater	6.42	.247	13.4	1.36	27.4	3.57	38.3	5.71
24	25% nonpoint control, land application, 0.1 mg/l phosphorus[3]	1.00	.325	1.61	1.08	2.96	2.64	4.36	4.30
25	25% nonpoint control, Effluent Transmission Line (ETL)	.966	.088	1.44	.475	2.59	1.39	3.86	2.56
26	50% nonpoint control, 0.2 mg/L phosphorus in wastewater	1.11	.562	1.88	1.67	3.40	3.89	4.80	6.03
27	50% nonpoint control, 1.0 mg/L phosphorus in wastewater	2.20	.621	4.67	1.41	9.19	2.90	12.8	4.70
28	50% nonpoint control, 4.0 mg/L phosphorus in wastewater	6.33	.247	15.7	1.36	26.8	3.57	36.7	5.71
29	50% nonpoint control, land application, 0.1 mg/L phosphorus[3]	.906	.325	1.35	1.08	2.31	2.64	3.29	4.30
30	50% nonpoint control, Effluent Transmission Line (ETL)	.897	.088	1.18	.475	1.95	1.39	2.79	2.56

1. Projections based upon: wastewater flow projections in Technical Memorandum No. 4, nonpoint projections in Technical Memorandum No. 6, and reduced nonpoint loads in Technical Memorandum No. 5.

2. Scenarios described in detail in Chapter VI. Assumed no reduction in nonpoint volume by control.

3. Land application defined as 0.1 mg/l total phosphorus in effluent and 50% of wastewater lost through crop consumptive use and evaporation.

TABLE 42

MODELING PROJECTIONS OF TOTAL PHOSPHORUS, CHLOROPHYLL *a*, AND SECCHI DISC DEPTH FOR CHERRY CREEK RESERVOIR[1]

NO.	SCENARIO DESCRIPTION[2]	1985 TP (ug/L)	1985 Chlor a (ug/L)	1985 Secchi Depth (m)	1990 TP (ug/L)	1990 Chlor a (ug/L)	1990 Secchi Depth (m)	2000 TP (ug/L)	2000 Chlor a (ug/L)	2000 Secchi Depth (m)	2010 TP (ug/L)	2010 Chlor a (ug/L)	2010 Secchi Depth (m)
	DRCOG Projections												
1	No nonpoint control, 0.2 mg/L phosphorus in wastewater	32.9	13.3	1.3	36.7	15.6	1.2	43.3	19.9	1.0	49.7	24.4	0.9
2	No nonpoint control, 1.0 mg/L phosphorus in wastewater	46.0	21.7	0.9	54.7	28.1	0.8	65.4	36.4	0.7	74.8	44.3	0.6
3	No nonpoint control, 4.0 mg/L phosphorus in wastewater	73.4	43.0	0.6	90.6	58.5	0.5	109	77.0	0.4	125	93.9	0.4
4	No nonpoint control, land application, 0.1 mg/l phosphorus[3]	31.2	12.4	1.4	33.0	13.4	1.3	39.0	17.1	1.1	45.1	21.2	1.0
5	No nonpoint control, Effluent Transmission Line (ETL)	31.2	12.4	1.4	33.3	13.6	1.3	38.7	16.9	1.1	45.1	21.1	1.0
6	25% nonpoint control, 0.2 mg/L phosphorus in wastewater	32.6	13.1	1.3	35.9	15.1	1.2	41.4	18.7	1.1	46.8	22.3	0.9
7	25% nonpoint control, 1.0 mg/L phosphorus in wastewater	45.7	21.6	1.0	54.3	27.7	0.8	64.4	35.5	0.7	73.1	42.8	0.6
8	25% nonpoint control, 4.0 mg/L phosphorus in wastewater	73.3	43.0	0.6	90.3	58.3	0.5	109	76.4	0.4	124	93.0	0.4
9.	25% Nonpoint control, land application, 0.1 mg/L phosphorus[3]	30.8	12.1	1.4	32.0	12.8	1.4	36.7	15.7	1.2	41.6	18.8	1.1
10	25% nonpoint control, Effluent Transmission Line (ETL)	30.8	12.1	1.4	32.2	12.9	1.4	36.3	15.4	1.2	41.3	18.6	1.1
11	50% nonpoint control, 0.2 mg/L phosphorus in wastewater	32.2	12.9	1.4	35.0	14.6	1.2	39.4	17.4	1.1	43.6	20.6	1.0
12	50% nonpoint control, 1.0 mg/L phosphorus in wastewater	45.5	21.4	1.0	53.8	27.4	0.8	63.2	34.6	0.7	71.4	41.3	0.6
13	50% nonpoint control, 4.0 mg/L phosphorus in wastewater	73.2	42.9	0.6	90.1	58.1	0.5	108	75.9	0.5	124	92.1	0.4
14	50% nonpoint control, land application, 0.1 mg/L phosphorus[3]	30.3	11.8	1.4	31.0	12.2	1.4	34.2	14.1	1.3	37.6	16.3	1.2
15	50% nonpoint control Effluent Transmission Line (ETL)	30.4	11.9	1.4	31.1	12.3	1.4	33.6	13.7	1.3	37.0	15.8	1.2

Table 42 continued

MODELING PROJECTIONS OF TOTAL PHOSPHORUS, CHLOROPHYLL a, AND SECCHI DISC DEPTH FOR CHERRY CREEK RESERVOIR[1]

		1985			1990			2000			2010		
NO.	SCENARIO DESCRIPTION[2]	TP (ug/L)	Chlor a (ug/L)	Secchi Depth (m)	TP (ug/L)	Chlor a (ug/L)	Secchi Depth (m)	TP (ug/L)	Chlor a (ug/L)	Secchi Depth (m)	TP (ug/L)	Chlor a (ug/L)	Secchi Depth (m)
	Developer Projections												
16	No nonpoint control, 0.2 mg/L phosphorus in wastewater	35.8	15.1	1.2	43.9	20.3	1.0	55.1	28.3	0.8	62.8	34.3	0.7
17	No nonpoint control, 1.0 mg/L phosphorus in wastewater	46.5	22.1	0.9	62.4	33.9	0.7	80.7	49.4	0.5	91.4	59.3	0.5
18	No nonpoint control, 4.0 mg/L phosphorus in wastewater	71.4	41.3	0.6	95.3	63.0	0.5	126	94.5	0.3	143	114	0.3
19.	No nonpoint control, land application, 0.1 mg/L phosphorus[3]	33.8	13.9	1.3	40.6	18.1	1.1	50.8	25.2	0.9	58.4	30.8	0.8
20	No nonpoint control, Effluent Transmission Line (ETL)	34.2	14.1	1.3	40.5	18.0	1.1	51.1	25.4	0.9	59.0	31.3	0.7
21	25% nonpoint control, 0.2 mg/L phosphorus in wastewater	34.6	14.4	1.3	41.6	18.8	1.1	51.1	25.4	0.9	57.7	30.3	0.8
22	25% nonpoint control, 1.0 mg/L phosphorus in wastewater	45.8	21.6	1.0	61.0	32.8	0.7	78.3	47.4	0.6	88.2	56.3	0.5
23	25% nonpoint control, 4.0 mg/L phosphorus in wastewater	70.9	41.0	0.6	94.5	62.3	0.5	125	93.1	0.4	141	112	0.3
24	25% nonpoint control, land application, 0.1 mg/l phosphorus[3]	32.6	13.2	1.3	37.9	16.4	1.2	46.2	21.9	0.9	52.4	26.3	0.8
25	25% nonpoint control, Effluent Transmission Line (ETL)	32.9	13.3	1.3	37.6	16.2	1.2	46.2	21.9	0.9	52.7	26.5	0.8
26	50% nonpoint control, 0.2 mg/L phosphorus in wastewater	33.4	13.7	1.3	39.2	17.2	1.1	46.9	22.4	0.9	52.0	26.0	0.8
27	50% nonpoint control, 1.0 mg/L phosphorus in wastewater	44.8	20.9	1.0	60.1	32.1	0.7	77.8	46.8	0.6	87.1	55.3	0.5
28	50% nonpoint control, 4.0 mg/L phosphorus in wastewater	70.5	40.6	0.6	101	68.6	0.4	123	91.7	0.4	138	108	0.3
29	50% nonpoint control, land application, 0.1 mg/L phosphorus[3]	31.3	12.4	1.4	35.0	14.6	1.2	41.0	18.4	1.1	45.5	21.4	1.0
30	50% nonpoint control, Effluent Transmission Line (ETL)	31.5	12.5	1.4	34.5	14.3	1.3	40.5	18.1	1.1	45.1	21.2	1.0

1. Based upon projections of total phosphorus loading and inflow in Table 2.
2. Scenarios described in detail in Chapter VI.

Table 42 also shows that the range of chlorophyll a levels projected for all scenarios is large, and depends upon the degree of phosphorus removed. The highest chlorophyll a is projected with discharge of secondary wastewater and no nonpoint control (93.9 ug/L and 114.0 ug/L for DRCOG and developer projections). Conversely, the lowest chlorophyll a is projected with treated wastewater routed around the reservoir (ETL) and 50 percent nonpoint control. It is important to note that none of the scenarios evaluated can maintain the level of chlorophyll a equal to or below the 1982 mean growing season concentration of 10.7 ug/L, even in 1985. Under the most stringent conditions evaluated using the ETL and 50 percent nonpoint control, chlorophyll a is projected at the lowest to be 11.9 ug/L in 1985 (DRCOG projections); but if growth is realized that follows developer projections, chlorophyll a is projected to reach 12.5 ug/L this same year. Projections of chlorophyll a from this scenario in the year 2010 range from 15.8 ug/L to 21.2 ug/L for DRCOG and developer projections, respectively.

While no scenario evaluated can keep chlorophyll a levels at or below 1982 conditions, advanced treatment to 0.2 mg/L total phosphorus, land application, and the ETL all are projected to limit increases in chlorophyll a to reasonable levels in the future. None of these management options would result in a doubling of 1982 chlorophyll a, for example, until after 1990 even with no control of nonpoint. If DRCOG projections are realized, these options would still keep chlorophyll a below 20.0 ug/L up to 2000. Any chlorophyll a level of over 10.0 ug/L would most correctly classify Cherry Creek Reservoir as being in a eutrophic state. A doubling of chlorophyll a is used for example only for data interpretation in this section. A permissible level based upon literature and the monitoring program data is addressed in Chapter II.

It should be noted that the management options selected for evaluation represent current state-of-the-art technologies. Obviously, advances in technology in the future are possible that would reduce loading to the reservoir. This would retard the eutrophication process and diminish chlorophyll a levels. In regards to the model results, this would be manifested by projections being realized at a future date. One way of addressing technological changes is through continued update and re-evaluation of study results at specified future dates.

The last major finding which can be seen from Table 3 is that nonpoint control does result in significant reductions in chlorophyll a levels. The greatest decrease is seen with

50 percent control which may reduce the total phosphorus and cholorophyll a concentrations in the year 2010 by as much as 25 and 32 percent, respectively. This finding is significant because it demonstrates that there are possible "trade-offs" between wastewater and nonpoint controls. For example, reduction of nonpoint sources would allow for increases in wastewater flow to achieve the same level of water quality. Many questions relating to forms of phosphorus between these sources and their bioavailability would need to be answered before such trade-offs could occur.

This analysis of water-quality-related impacts of management options has not considered the costs to obtain each option nor the water quality goals. These variables must be considered to recommend a suitable treatment level. Control of phosphorus to low levels such as are obtainable with an ETL and 50 percent nonpoint control may protect water quality, but is expensive. Conversely, less expensive measures were evaluated such as secondary treatment with discharge, but degrade water quality. An analysis of model results and their costs and water quality goals is presented in Chapter IX.

IX. EVALUATION OF MANAGEMENT OPTIONS

The evaluation of water quality management options described in Chapter VI is dependent upon three variables: the resulting in-lake chlorophyll a of each option, the cost of each option, and the relationship of each option to the recommended water quality goals. The chlorophyll a results appear in Chapter VIII, the costs of the options and water quality goals appear in Chapter VI. This chapter evaluates the management options based upon these three variables.

Each water quality management option was ranked according to the cost of the system from least expensive to most expensive. The options were also ranked according to the resulting in-lake chlorophyll a, from the lowest concentration to the highest concentration. Finally, cost and chlorophyll a were combined to produce a ranking which allows consideration of both economics and water quality.

In this Chapter, rankings are presented for the year 2010 only, as this time frame closely reflects a 20-year planning period. Ranking the options for the years 1985, 1990, and 2000 would closely resemble the year 2010 rankings and, therefore, would be redundant. The rankings for the year 2010 are based on model results and cost information which are related to DRCOG and developer projections of growth in the basin. The system costs and chlorophyll a in the reservoir reflect the existing and proposed developments as of May, 1983.

RANKING BY COST

Costs of all the water quality management scenarios appear in Table 43. These costs represent the equivalent annual cost of each scenario. A description of the scenarios appears in Chapter VI, Table 33.

Ranking of the water quality management scenarios by cost appear in Table 44 for DRCOG projections and in Table 45 for developer projections. The costs in were taken from Table 43 and simply put in order from least expensive to most expensive.

Table 43

Equivalent Annual Costs (millions of dollars) for Cherry Creek Reservoir

Scenario[2]	1985 Non-point[3]	1985 Point[4]	1985 Total	1990 Non-point	1990 Point	1990 Total	2000 Non-point	2000 Point	2000 Total	2010[1] Non-point	2010[1] Point	2010[1] Total
1 No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	-	6.72	6.72	-	9.46	9.46	-	12.3	12.3	-	14.5	14.5
2 No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	-	6.02	6.02	-	8.69	8.69	-	11.45	11.45	-	14.45	14.45
3 No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	-	5.68	5.68	-	8.16	8.16	-	10.79	10.79	-	13.0	13.0
4 No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	-	7.18	7.18	-	10.39	10.39	-	14.80	14.80	-	17.8	17.8
5 No nonpoint phosphorus removal, effluent transmission line	-	5.68	14.6	-	8.16	17.1	-	10.79	19.7	-	13.0	21.9
6 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	0.64	6.72	7.36	0.77	9.46	10.23	0.94	12.3	13.24	1.10	14.5	15.6
7 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	0.64	6.02	6.66	0.77	8.69	9.46	0.94	11.45	12.39	1.10	14.45	15.55
8 25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	0.64	5.68	6.32	0.77	8.16	8.93	0.94	10.79	11.73	1.10	13.0	14.1
9 25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	0.64	7.18	7.82	0.77	10.39	11.16	0.94	14.80	15.74	1.10	17.8	18.9
10 25% nonpoint phosphorus removal, effluent transmission line	0.64	5.68	15.2	0.77	8.16	17.8	0.94	10.79	20.6	1.10	13.0	23.0
11 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	0.68	6.72	7.40	0.82	9.46	10.28	1.00	12.3	13.3	1.16	14.5	15.66
12 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	0.68	6.02	6.70	0.82	8.69	9.51	1.00	11.45	12.45	1.16	14.45	15.61
13 50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	0.68	5.68	6.36	0.82	8.16	8.98	1.00	10.79	11.79	1.16	13.0	14.16
14 50% nonpoint phosphorus removal, land applicatin, 0.1 mg/l phosphorus in effluent	0.68	7.18	7.86	0.82	10.39	11.21	1.00	14.80	15.8	1.16	17.8	18.96

Table 43 continued

Equivalent Annual Costs (millions of dollars) for Cherry Creek Reservoir

Scenario[2]	1985 Non-point[3]	1985 Point[4]	1985 Total	1990 Non-point	1990 Point	1990 Total	2000 Non-point	2000 Point	2000 Total	2010[1] Non-point	2010[1] Point	2010[1] Total
15 50% nonpoint phosphorus removal, effluent transmission line	0.68	5.68	15.3	0.82	8.16	17.9	1.00	10.79	20.7	1.16	13.0	23.06
16 No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	-	6.75	6.75	-	12.0	12.0	-	17.64	17.64	-	21.31	21.31
17 No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	-	6.33	6.33	-	11.55	11.55	-	16.98	16.98	-	20.22	20.22
18 No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	-	5.79	5.79	-	10.61	10.61	-	15.94	15.94	-	18.89	18.89
19 No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus	-	6.64	6.64	-	14.39	14.39	-	21.61	21.61	-	26.39	26.39
20 No nonpoint phosphorus removal, effluent transmission line	-	5.79	19.7	-	10.61	24.5	-	15.94	29.8	-	18.89	32.76
21 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	0.80	6.75	7.55	1.06	12.0	13.06	1.34	17.64	18.98	1.57	21.31	22.88
22 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	0.80	6.33	7.13	1.06	11.55	12.61	1.34	16.98	18.32	1.57	20.22	21.79
23 25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	0.80	5.79	6.59	1.06	10.61	11.67	1.34	15.94	17.28	1.57	18.99	20.46
24 25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	0.80	6.64	7.44	1.06	14.39	15.45	1.34	21.61	22.95	1.57	26.39	27.96
25 25% nonpoint phosphorus removal, effluent transmission line	0.80	5.79	20.5	1.06	10.61	25.1	1.34	15.94	31.2	1.57	18.89	34.33
26 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	0.85	6.75	7.60	1.13	12.0	13.13	1.42	17.64	19.06	1.67	21.31	22.98
27 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	0.85	6.33	7.18	1.13	11.55	12.68	1.42	16.98	18.40	1.67	20.22	21.89
28 50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	0.85	5.79	6.64	1.13	10.61	11.74	1.42	15.94	17.36	1.67	18.89	20.56
29 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	0.85	6.64	7.49	1.13	14.39	15.52	1.42	21.61	23.03	1.67	26.39	28.06

Table 43 continued

Equivalent Annual Costs (millions of dollars) for Cherry Creek Reservoir

Scenario[2]	1985 Non-point[3]	1985 Point[4]	1985 Total	1990 Non-point	1990 Point	1990 Total	2000 Non-point	2000 Point	2000 Total	2010[1] Non-point	2010[1] Point	2010[1] Total
30 50% nonpoint phosphorus removal, effluent transmission line	0.85	5.79	20.54	1.13	10.61	25.6	1.42	15.94	31.3	1.67	18.89	34.44

[1]Point source costs listed in scenarios 5, 10, 15, 20, 25, and 30 include the cost of secondary treatment facility and an effluent transmission line (ETL) connecting all facilities and routing effluent around the reservoir. See Chapter VI for explanation. Equivalent annual cost of the ETL is \$8.9 x 10^6 for scenarios 1-15, and \$13.9 x 10^6 for scenarios 16-30.

[2]Scenarios 1-15 refer to DRCOG growth projections; 16-30 refer to developer growth projections.

[3]Cost of nonpoint options obtained from TM #5 and Table 5 in TM #7.

[4]Cost of point source options obtained from TM #4 and Table 1-4 in TM #7.

Table 44

Ranking of Water Quality Management Scenarios

by Cost[1]

Year 2010, DRCOG Projections

Rank	Cost (millions of dollars)	Scenario
1	13.0	(3) No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
2	14.1	(8) 25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
3	14.16	(13) 50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
4	14.45	(2) No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
5	14.5	(1) No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
6	15.55	(7) 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
7	15.6	(6) 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
8	15.61	(12) 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
9	15.66	(11) 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
10	17.8	(4) No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
11	18.9	(9) 25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
12	18.96	(14) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
13	21.9	(5) No nonpoint phosphorus removal, effluent transmisslin line
14	23.0	(10) 25% nonpoint phosphorus removal, effluent transmisslin line
15	23.06	(15) 50% nonpoint phosphorus removal, effluent transmisslin line

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1 Equivalent annual costs. Cost information by scenario appears in Technical Memorandum No. 7.

Table 45

Ranking of Water Quality Management Scenarios by Cost[1]

Year 2010, Developer Projections

Rank	Cost (millions of dollars)	Scenario
1	18.89	(18) No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
2	20.22	(17) No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
3	20.46	(23) 25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
4	20.56	(28) 50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
5	21.31	(16) No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
6	21.79	(22) 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
7	21.89	(27) 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
8	22.88	(21) 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
9	22.98	(26) 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
10	26.39	(19) No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
11	27.96	(24) 25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
12	28.06	(29) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
13	32.76	(20) No nonpoint phosphorus removal, effluent transmission line
14	34.33	(25) 25% nonpoint phosphorus removal, effluent transmission line
15	34.44	(30) 50% nonpoint phosphorus removal, effluent transmission line

[1] Equivalent annual costs. Cost information by scenario appears in Technical Memorandum No. 7.

As can be seen, the least expensive scenario under either DRCOG or developer projections is discharging secondary treated wastewater with no control of the nonpoint phosphorus. The most expensive scenario in both projections is the effluent transmission line with 50 percent control of the nonpoint phosphorus. Without respect to water quality conditions, the most economical water quality management scenario would be the discharge of secondary treated effluent with no control of the nonpoint phosphorus loading. However, this is irrespective of the water quality conditions in the reservoir and as such, economics cannot be used alone to select appropriate management options.

RANKING BY CHLOROPHYLL a

Ranking of the scenarios by the resulting in-lake chlorophyll a concentration places the emphasis on water quality conditions. The chlorophyll a concentration by scenario for the year 2010 appears in Chapter VIII, Table 42. Actual ranking of the scenarios by chlorophyll a appears in Tables 46 and 47 for DRCOG and developer projections. The scenarios are ranked from the least amount of chlorophyll a to the most chlorophyll a.

Ranking of the scenarios by chlorophyll a results in a wide range in the chlorophyll a concentration produced by the management options. Interestingly, the scenario which resulted in the least chlorophyll a was also the scenario which was the most expensive, and the scenario which resulted in the highest concentration of chlorophyll a was the least expensive. Therefore, the optimal water quality scenario cannot be selected on cost or chlorophyll a alone.

COMBINED RANKING

A system was devised whereby the water quality management scenarios were ranked according to a cost/water quality benefit methodology. In devising this methodology, equal weight was given to the cost factor and the chlorophyll a factor. This was done by simply multiplying the actual chlorophyll a data (in ug/L) by the actual costs in (millions of dollars) which resulted in combined rankings taking into both cost plus water quality. This method resulted in combined rankings which were rounded off to discrete whole numbers which easily distinguished one scenario from another. The scenarios were then ranked according to the whole number values. Tables 48 and 49 present these rankings for DRCOG and developer projections.

Table 46

Ranking of Water Quality Management Scenarios

by Chlorophyll a

Year 2010, DRCOG Projections

Rank	Chlorophyll a (ug/L)	Scenario
1	15.8	(15) 50% nonpoint phosphorus removal, effluent transmission line
2	16.3	(14) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
3	18.6	(10) 25% nonpoint phosphorus removal, effluent transmission line
4	18.8	(9) 25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
5	20.6	(11) 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
6	21.1	(5) No nonpoint phosphorus removal, effluent transmission line
7	21.1	(4) No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
8	22.3	(6) 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
9	24.4	(1) No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
10	41.3	(12) 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
11	42.8	(7) 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
12	44.3	(2) No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
13	92.1	(13) 50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
14	93.0	(8) 25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
15	93.9	(3) No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent

Table 47

Ranking of Water Quality Management Scenarios

by Chlorophyll a

Year 2010, Developer Projections

Rank	Chlorophyll a (ug/L)	Scenario
1	21.2	(30) 50% nonpoint phosphorus removal, effluent transmission line
2	21.4	(29) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
3	26.0	(26) 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
4	26.3	(24) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
5	26.5	(25) 25% nonpoint phosphorus removal, effluent transmission line
6	30.3	(21) 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
7	30.8	(19) No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent
8	31.3	(20) No nonpoint phosphorus removal, effluent transmission line
9	34.3	(16) No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent
10	55.3	(27) 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
11	56.3	(22) 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
12	59.3	(17) No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent
13	108.0	(28) 50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
14	112.0	(23) 25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent
15	114.0	(18) No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent

Table 48

Ranking of Water Quality Management Scenarios
by Cost and Chlorophyll *a*
Year 2010, DRCOG Projections

Rank	Scenario	Cost (Millions of dollars)	Chlorophyll *a* (ug/L)	Total Points[1]
1	(14) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	18.98	16.3	309
2	(11) 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	15.66	20.6	323
3	(6) 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	15.6	22.3	348
4	(1) No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	14.5	24.4	354
5	(9) 25% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	18.9	18.8	355
6	(15) 50% nonpoint phosphorus removal, effluent transmission line	23.06	15.8	364
7	(4) No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	17.8	21.1	377
8	(10) 25% nonpoint phosphorus removal, effluent transmission line	23.0	18.6	428
9	(5) No nonpoint phosphorus removal, effluent transmission line	21.9	21.1	462
10	(2) No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	14.45	44.3	640

Table 48 continued

11	(12)	50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	15.61	41.3	645
12	(7)	25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	15.55	42.8	666
13	(3)	No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	13.0	93.9	1221
14	(13)	50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	14.16	92.1	1304
15	(8)	25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	14.1	93.0	1311

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1 Total points equals cost (millions of dollars) times chlorophyll a (ug/L).

Tables 48 and 49 help to balance water quality management scenarios as to cost and reservoir protection. However, before any management scenario is selected, it is appropriate to relate the scenarios to the water quality goals for the reservoir. Then, scenarios which should meet the reservoir goals can be considered further. Implicit in Tables 6 and 7 is the goal of acceptable water quality conditions at a reasonable cost.

EVALUATION OF MANAGEMENT OPTIONS

Using the 11-40 ug/L chlorophyll a range described in Chapter II as a criterion for selecting appropriate water quality management scenarios, one can identify those scenarios which fall within this range. Advanced wastewater treatment with phosphorus removal, slow-rate land application, and the ETL all fall within this range. Also, 50 percent control of the phosphorus in nonpoint urban runoff is effective in significantly reducing the chlorophyll a. This leads to the conclusion that three wastewater treatment options and one nonpoint control option are capable of meeting the 11-40 ug/L chlorophyll a range. These options are shown in Table 50:

Table 49

Ranking of Water Quality Management Scenarios
by Cost and Chlorophyll a
Year 2010, Developer Projections

Rank	Scenario	Cost (Millions of dollars)	Chlorophyll a (ug/L)	Total Points[1]
1	(26) 50% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	22.98	26.0	597
2	(29) 50% nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	28.06	21.4	600
3	(21) 25% nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	22.88	30.3	693
4	(30) 50% nonpoint phosphorus removal, effluent transmission line	34.44	21.2	730
5	(16) No nonpoint phosphorus removal, 0.2 mg/L phosphorus in effluent	21.31	34.3	731
6	(24) 25% nonpoint phosphorus removal, land application 0.1 mg/L phosphorus in effluent	27.96	26.3	735
7	(19) No nonpoint phosphorus removal, land application, 0.1 mg/L phosphorus in effluent	26.39	30.8	813
8	(25) 25% nonpoint phosphorus removal, effluent transmission line	34.33	26.5	910
9	(20) No nonpoint phosphorus removal, effluent transmission line	32.76	31.3	1025
10	(17) No nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	20.22	59.3	1199
11	(27) 50% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	21.89	55.3	1211
12	(22) 25% nonpoint phosphorus removal, 1.0 mg/L phosphorus in effluent	21.79	56.3	1227

Table 49 continued

13	(18)	No nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	18.89	114	2153
14	(28)	50% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	20.56	108	2220
15	(23)	25% nonpoint phosphorus removal, 4.0 mg/L phosphorus in effluent	20.46	112	2292

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1 Total points equals cost (millions of dollars) times chlorophyll a (ug/L).

Table 50

Water Quality Management Options Capable of Meeting the 11-40 ug/L Chlorophyll a Criteria[1]

1. Slow-rate Land Application.
2. Advanced Wastewater Treatment with Phosphorus Removal and Discharge (with Filtration).
3. Secondary Treatment with Rapid Infiltration.[2]
4. Effluent Transmission Line.
5. 50 Percent Phosphorus Removal in Nonpoint Urban Runoff Used in Conjunction with any of the Three Wastewater Options Listed Above.

(1) Based on modeling results presented in Chapter VII for the year 2010.

(2) Secondary treatment with rapid infiltration was assumed to be equivalent to advanced treatment with phosphorus removal and filtration prior to discharge.

In comparing these options to the rankings which appear in Tables 48 and 49, they are consistent with the number 1 and 2 rankings except for the ETL. It becomes obvious that these options which fall within the 11-40 ug/L chlorophyll a range are also the most preferred options based on water quality benefits and cost. With respect to the water quality goals described in Chapter II, these preferred options relate to maintaining the present beneficial uses of the reservoir but defining an acceptable trophic status.

Figures 11 and 12 serve to graphically depict the information in Tables 48 and 49. These figures show chlorophyll a versus cost for each water quality management scenario, based on DRCOG and developer projections. These graphs help to eliminate management scenarios based on excessive chlorophyll a or high costs. For example, the scenarios which include secondary treatment and discharge result in chlorophyll a levels which are excessive.

Also, advanced treatment and discharge without filtration improves the chlorophyll a significantly over secondary treatment, but for a little more money, the chlorophyll a can be reduced even further by advanced treatment and discharge with filtration. Using DRCOG projections, reducing the chlorophyll a by 74 percent only costs an additional 10 percent when comparing the secondary treatment to advanced treatment of phosphorus removal with filtration. It appears to be cost effective to require advanced treatment when comparing decreases in chlorophyll a to increases in cost. Since the advanced forms of wastewater treatment (phosphorus removal with or without filtration) are relatively comparable in cost ($14.5 million and $14.45 million, respectively) but show a significant decrease in chlorophyll a (24.4 ug/L and 44.3 ug/L respectively), it is more cost effective to require advanced treatment with phosphorus removal and filtration.

Cost alone is another factor by which options should be eliminated. In reviewing the cost information and Figures 11 and 12, it is apparent that the scenarios fall within a narrow cost range except for the effluent transmission line. All other scenarios fall within a cost range of $13 to $18 million, but the ETL costs at least $4 to $5 million above this. Therefore, the ETL was eliminated as an option due to high costs along with other constraints mentioned earlier in this report.

Control of phosphorus in nonpoint runoff appears to produce significant improvement in the chlorophyll a levels. Referencing Figures 11 and 12 again, removing 50 percent of the phosphorus from urban runoff reduces year 2010 chlorophyll a values by 15-30 percent. As indicated in Table 43, the cost to control 50 percent of the phosphorus ranges from $1.1 to $1.67 million per year based on the amount of developed acreage in the basin. Since the 15-30 percent phosphorus reduction resulting from 50 percent nonpoint control is essentially equivalent to reducing wastewater flows by 6-10 mgd at a cost of $4-8 million per year, controlling phosphorus in nonpoint is more cost effective. However, trade-offs between point and nonpoint source controls can be realized.

FIGURE 11

COMPARISON OF COST VS. CHLOROPHYLL a IN THE YEAR 2010 FOR CHERRY CREEK RESERVOIR

(DRCOG PROJECTIONS)

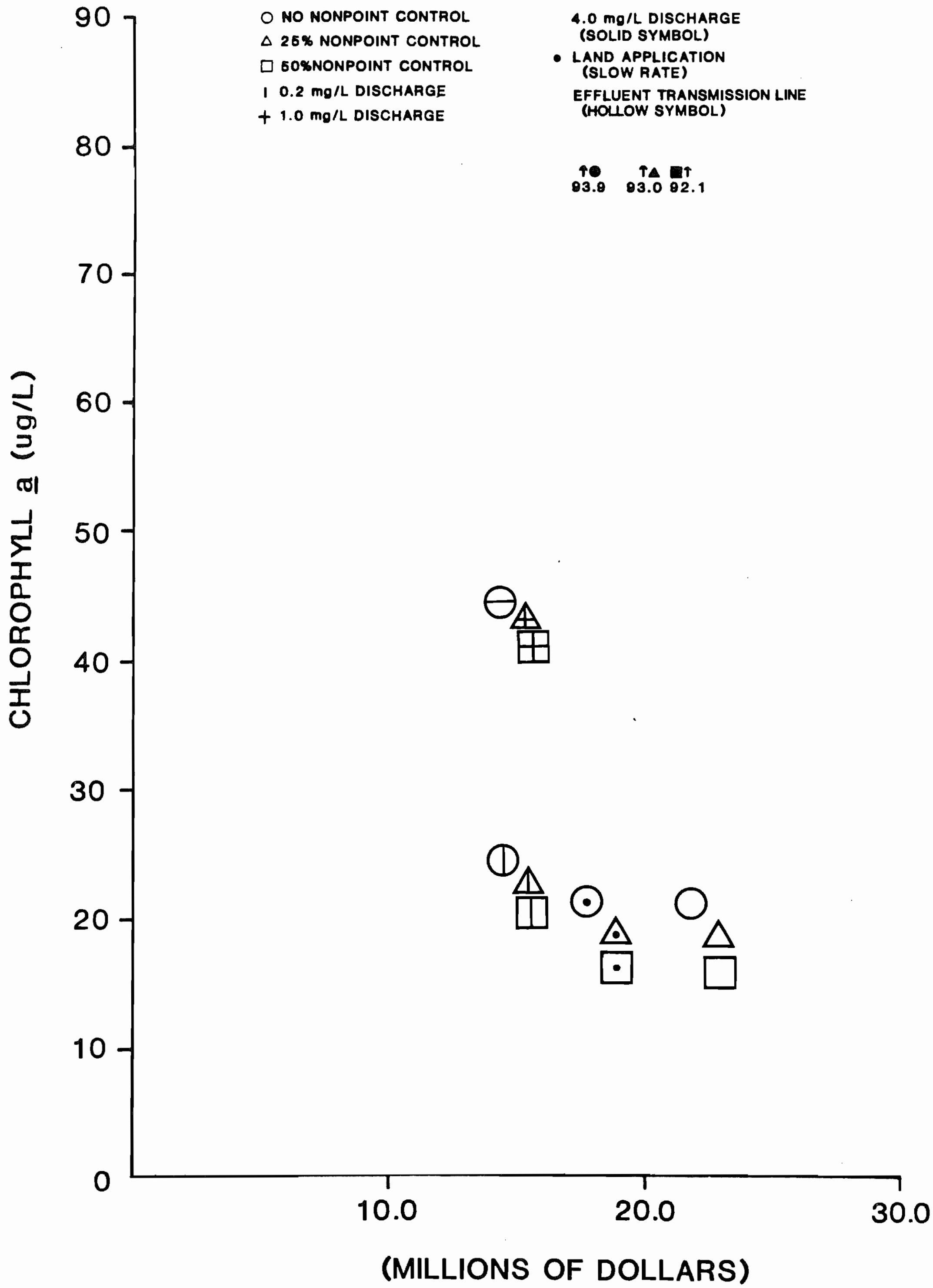
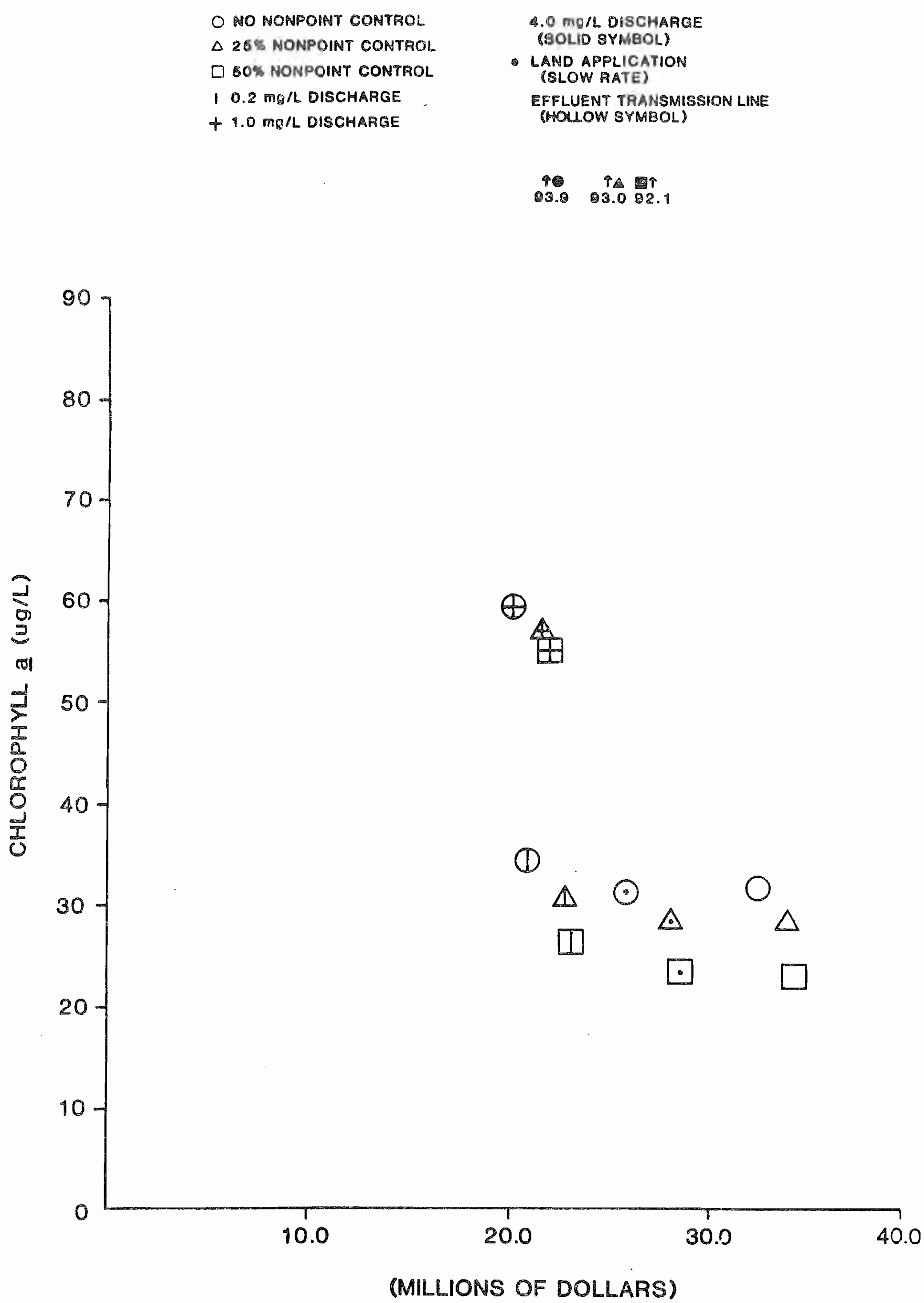


FIGURE 12

COMPARISON OF COST VS. CHLOROPHYLL a IN THE YEAR 2010 FOR CHERRY CREEK RESERVOIR

(DEVELOPER PROJECTIONS)



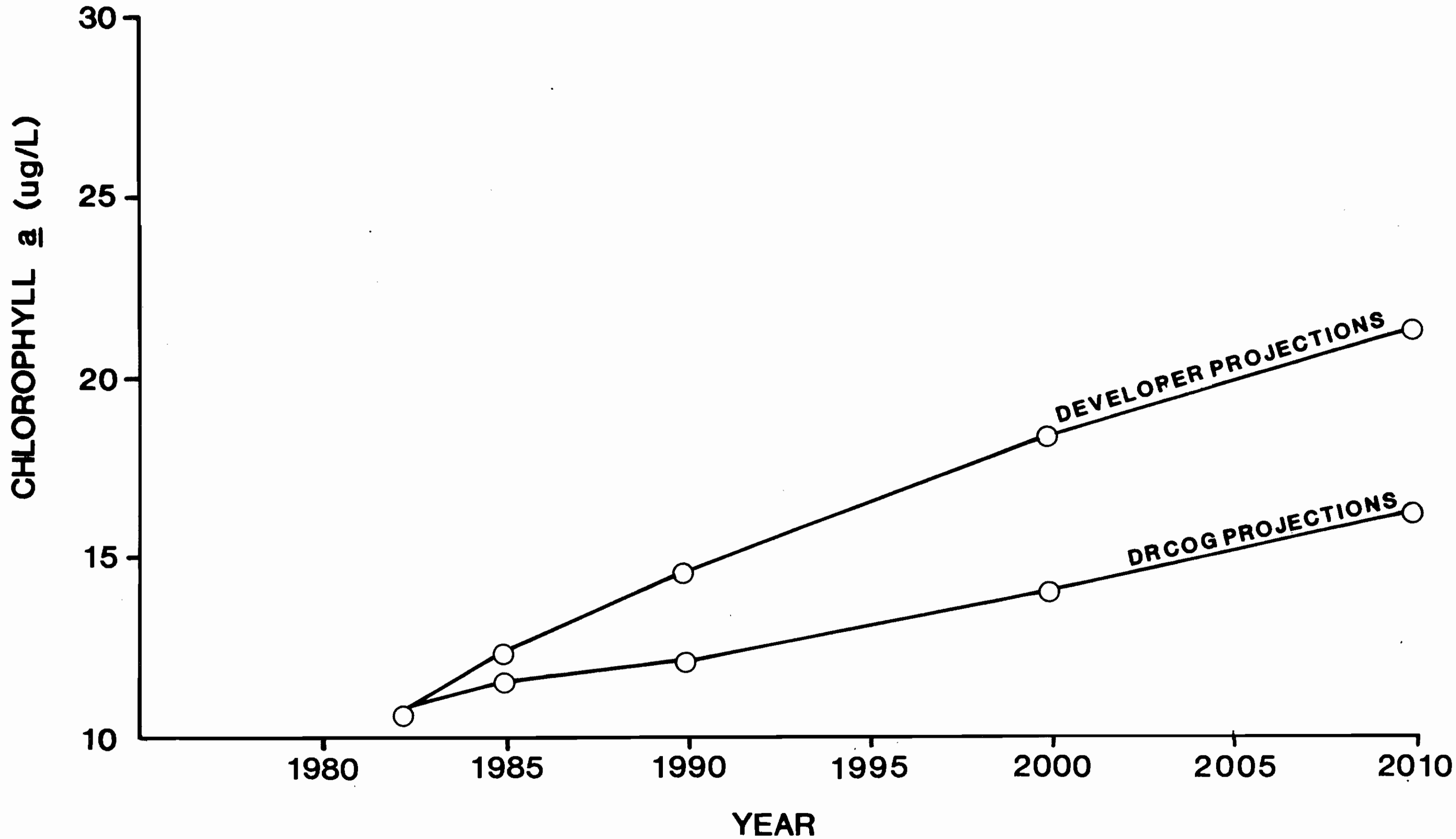
With respect to the time frame of 1985-2010, Figures 13 and 14 show how these water quality management options relate to chlorophyll a over time. As can be seen from these two figures, the maximum chlorophyll a level for any of the options is well below the upper criterion limit of 40 ug/L. The information in Figures 3 and 4 is based on the model predictions and projections of actual wastewater flow in the basin for DRCOG and developer growth projections.

From the information presented in this chapter on the evaluation of water quality management options, specific recommendations for standards will be made in Chapter IX. These recommendations will relate to establishing an appropriate chlorophyll a goal for the reservoir which relates to an in-lake total phosphorus limit. Also, recommendations will be made on appropriate effluent limits and treatment technologies which correlate to the in-lake total phosphorus concentration. The degree of nonpoint control will also be discussed.

FIGURE 13

CHLOROPHYLL a vs. TIME[1]

(SLOW RATE LAND APPLICATION)

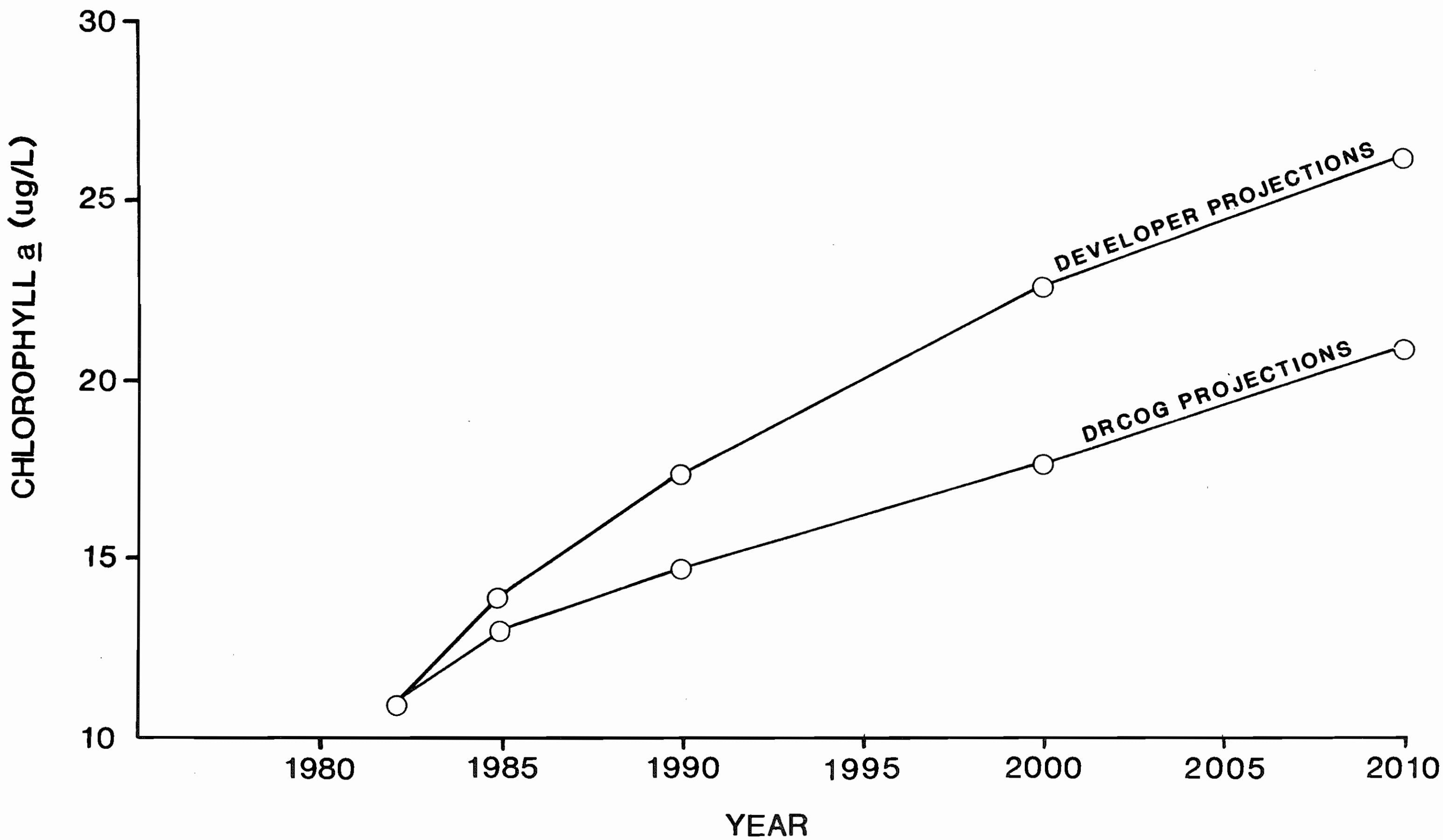


[1]ASSUMES 50% PHOSPHOSORUS REMOVAL IN NONPOINT

FIGURE 14

CHLOROPHYLL a vs. TIME[1]

(ADVANCED WASTE TREATMENT WITH DISCHARGE OR RAPID INFILTRATION)



[1]ASSUMES 50% PHOSPHOSORUS REMOVAL IN NONPOINT

X. RECOMMENDATIONS

The Cherry Creek Reservoir Clean Lakes Study is intended to identify specific water quality goals for the reservoir, establish wastewater effluent standards, define the degree of nonpoint phosphorus control required and present a summary of the findings from this study. The Basin Master Plan will define the degree of eutrophication which can be allowed in the reservoir and not impair or restrict the present beneficial uses.

GENERAL CRITERIA

In the previous chapter, a range of chlorophyll a was established which defined a range of chlorophyll a in relation to maintaining the present use classification of the reservoir. From this range of chlorophyll a, a specific chlorophyll a limit will be established for the reservoir. Since chlorophyll a is directly related to total phosphorus as described in Chapter VIII, a standard for total phosphorus in the reservoir is recommended. The standard is recommended for total phosphorus rather than chlorophyll a as the chlorophyll a is more likely to fluctuate due to climatological factors and analytical factors. By using the average growing season total phosphorus and the average growing season chlorophyll a, the relationship between these two constituents can be further verified and an appropriate standard for total phosphorus can be refined. This study will only establish a limit for chlorophyll a, as phosphorus and not chlorophyll a is a constituent of wastewater and nonpoint source runoff. Also, phosphorus has been identified as the nutrient to control in the reservoir.

With respect to establishing a strict trophic status to protect the beneficial uses of the reservoir, it may be difficult to select a specific trophic condition which guarantees the maintenance of all beneficial uses. Trophic status is not a rigid criterion for determining the water quality of a lake and its effect on uses of the lake. There are no state or national standards which define excessive eutrophication. A lake determined to be eutrophic by several indicators may still provide all the uses desired. However, uses of other lakes classified eutrophic can be severely limited. Each lake must be evaluated on an individual basis, with water quality goals tailored to the lake and its desired uses.

Since Cherry Creek Reservoir is such a significant recreational reservoir, the primary goal should be preservation of water quality suitable for Warm Water Aquatic Life and Class 1 Recreation. A highly eutrophic reservoir may eliminate both of these uses as a result of reduced transparency, odor, surface scums, and other objectionable aspects of the water. Also, as algae and weed growth increase, oxygen levels decline which can result in the loss of a sport fishery.

The reservoir modeling conducted by the CDH indicated that certain water quality management options would only slightly increase the total phosphorus and chlorophyll a. In accepting the goal of maintaining the present uses of the reservoir and defining an acceptable trophic status and chlorophyll a concentration for the reservoir, the modeling results helped to define which scenarios would fall within this goal statement. As discussed in the last chapter, a range of chlorophyll a from 11-40 ug/L should be used as a guideline from which a specific chlorophyll a limit is selected.

In an attempt to define a level of chlorophyll a which would protect the beneficial uses of the reservoir, a literature search was conducted. Unfortunately, it was not possible to locate an appropriate scientific article that related beneficial use impairment to the level of chlorophyll a or to the degree of eutrophication. All literature agree that at low levels of chlorophyll a, low productivity exists resulting in a poor fishery. At high levels of chlorophyll a, a poor fishery may also result due to extreme productivity. In between these low and high levels lies an optimal trophic condition where the level of chlorophyll a provides a productive fishery and does not impair or inhibit other recreational uses. Without specific information on chlorophyll a and beneficial uses, other states and leading liminologists were contacted to determine if they had information on an acceptable level of chlorophyll a which would not interfere with beneficial uses. Following is a summary of this information:

-- Dr. John R. Jones, Professor of Biological Sciences at the University of Missouri at Columbia, stated that no one has ever made a correlation between chlorophyll a and beneficial uses. A chlorophyll a level of 20 ug/L is well within a range which Jones feels is acceptable and would provide an excellent warm water fishery. Also, at chlorophyll a levels between 10-20 ug/L, people would not perceive a difference in the color of the water especially if the change were gradual over a period of years.[38] It is interesting to note that Jones is a leading authority on lakes and eutrophication and is one of the co-authors (Jones and Bachman) who developed the chlorophyll a model used in this study.

-- Gary L. Hergenrader, Professor of the School of Life Sciences at the University of Nebraska, Lincoln, Nebraska, stated that 20 ug/L of chlorophyll a would result in very productive fishery.[39] Hergenrader has published several articles on eutrophication of lakes.

-- The State of Minnesota reports that 55 percent of their lakes have a chlorophyll a level of 20 ug/L or less. Also, for wastewater treatment facilities that discharge into a lake or reservoir, state effluent standards limit phosphorus to 1.0 mg/L in the effluent. This phosphorus limit is a technology based limit.[40]

-- The State of Wisconsin classifies lakes which have a chlorophyll a of greater than 14 ug/L as being eutrophic; those with a chlorophyll a of less than 14 ug/L are considered either mesotrophic or oligotrophic.[41] Also, Wisconsin recognizes the Carlson index of trophic classification and has determined that a Carlson index of 60 (relates to 20 ug/L chlorophyll a) is the highest level of chlorophyll a which the state feels is acceptable for recreational purposes.

All the sources cited above referenced a chlorophyll a level of 20 ug/L as generally good, productive water quality. None of the sources indicated that there was a loss or impairment of any beneficial use at a chlorophyll a level of 20 ug/L.

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[38] Dr. John R. Jones, personal communication, December 19, 1983.

[39] G. L. Hergenrader, personal communication, December 19, 1983.

[40] Steve Heiskary, Minnesota Pollution Control Authority, personal communication, December 13, 1983.

[41] Wisconsin Department of Natural Resources, Water Quality Evaluation Section, "Lake Standards Task Force," December, 1981.

RESERVOIR RECOMMENDED CRITERIA

This study has demonstrated that several water quality management options are available which can meet a range of water quality conditions. This study has been unable to determine an exact level of chlorophyll a which would protect the beneficial uses. However, other states and well known authorities cite a value of 20 ug/L as being a healthy, productive level of chlorophyll a where none of the beneficial uses are lost. This level would maintain the present reservoir uses and most likely would not be perceived as being detrimental by users.

The goal of this study was to maintain the lake water quality to protect current reservoir uses at their present level. Also, it was necessary to define an acceptable trophic status which related to chlorophyll a and fit into the study goal. To protect the reservoir uses, values for chlorophyll a and total phosphorus should be established for Cherry Creek Reservoir. The following criteria were used to establish chlorophyll a and total phosphorus levels:

1. The limit of chlorophyll a should be within the range of 11-40 ug/L.

2. The limit should be based on economically reasonable control measures for phosphorus.

STUDY FINDINGS

With these two criteria, recommendations for establishing a nutrient standard for Cherry Creek Reservoir were made. These recommendations are based on a number of findings, which are summarized below.

Finding No. 1

The current level of chlorophyll a in the reservoir, 10.7 ug/L (mean summer growing season), indicates a slightly eutrophic condition and causes minor impacts on recreation. In Dr. Aukerman's study, some recreation visitors complained about floating scum and debris, which included algae, grease and oil, garbage and weeds. These impacts are reflected in algae scum which was identified by lake users.

Finding No. 2

It is not practical to control point and nonpoint phosphorus and nitrogen to such an extent that chlorophyll a levels in the lake will not increase over time. Even if no growth occurred in the basin, natural aging processes within the lake would gradually result in an increase in productivity. However, this natural aging process would normally occur over a much longer time frame.

Finding No. 3

The analysis of secondary treatment with discharge resulted in predictions of over 40 ug/L and should not be considered as a viable treatment alternative. It will require basin dischargers to continue treatment beyond secondary to keep chlorophyll a levels below 40 ug/L.

Finding No. 4

While diverting wastewater around the reservoir would keep chlorophyll a levels within the 11-40 ug/L range even without nonpoint controls, implementation would be very difficult because of water rights, water supply, engineering difficulties, downstream impacts, social, political, institutional complaints, and unreasonable costs.

Finding No. 5

Land application, advanced wastewater treatment with phosphorus removal and filtration, and rapid infiltration all result in chlorophyll a levels in the lake which fall within the range of 11-40 ug/L chlorophyll a.

Finding No. 6

The costs of the three methods of point source treatment are comparable. The selection of any of the three methods would represent an economically reasonable approach to phosphorus control.

Finding No. 7

The control of storm runoff for phosphorus removal results in a significant improvement in chlorophyll a levels.

As an example, removing 50 percent of the phosphorus from storm runoff reduces year 2010 chlorophyll a values by 15 to 30 percent. Since this would be equivalent to reducing wastewater flows by 6-10 mgd, trade-offs between point and nonpoint source controls can be utilized.

Finding No. 8

The costs of reducing storm runoff phosphorus loadings were evaluated for 25 and 50 percent removal. Fifty percent removal techniques result in twice as much control for essentially the same cost and, therefore, is the more cost-effective approach (presently 50 percent removal techniques represent the best technology available).

Finding No. 9

The actual chlorophyll a level varies with the volume of wastewater generated. As shown in Figures 13 and 14 in Chapter IX, a range of chlorophyll a values is illustrated for advanced wastewater treatment and land application for the years 1982-2010. The range of chlorophyll a represents the projections of growth in the basin. Using information in the two figures, the following levels of chlorophyll a can be maintained with control of 50 percent of the phosphorus in nonpoint:

Chlorophyll a level (ug/L)	Expected Period When Level Will be Reached	
	With Land Application	With AWT or Rapid Infiltration
10.7	1982	1982
15	1991 - 2004	1987 - 1988
20	2005 - post-2010	1995-2006
25	post 2010	2007 - post-2010

Finding No. 10

While chlorophyll a is the best indicator of trophic conditions in Cherry Creek Reservoir, it is not a constituent of wastewater. Since there is a relationship between phosphorus loading and chlorophyll a, discharge permits should contain phosphorus limits which will result in lake phosphorus levels which produce chlorophyll a levels below the selected limit.

Finding No. 11

The information in the Clean Lakes Study is based on known control technologies in 1983. Future improvements in the control of phosphorus from point and nonpoint sources may result in changes to the other findings presented here. This indicates the need to periodically review and update this study.

RECOMMENDED RESERVOIR STANDARD

Based on these findings, a water quality standard was recommended for Cherry Creek Reservoir. With the criterion that the lake water quality be kept at a level to protect present uses and Finding No. 11 (technology may improve in the future), it is recommended that the standard be reviewed periodically.

Since the Colorado Water Quality Control Commission (WQCC) is expected to set the standard for Cherry Creek Reservoir in 1984, it is suggested that the standard selected be adequate to protect the reservoir for conditions expected through 1995, a ten year time frame at a minimum. Using the table shown in Finding No. 9, a chlorophyll a limit of 20 ug/L would not be exceeded until after 1995 under any growth scenario presently anticipated. It has been recognized by other states and limnologists that a chlorophyll a value of 20 ug/L will protect the beneficial uses of the reservoir.

Therefore, it is recommended that the chlorophyll a goal for Cherry Creek Reservoir be set at 20 ug/L (growing season average).

Based on Finding No. 9, the WQCC should also set an in-lake phosphorus limit which can be used to determine effluent limits for wastewater treatment discharge permits. The results of the Clean Lakes Study indicate that an in-lake phosphorus limit of 44 ug/L will keep chlorophyll a below 20 ug/L.

Therefore, it is recommended that the in-lake phosphorus standard (limit) for Cherry Creek Reservoir be set at 44 ug/L (growing season average).

It is believed that these recommended standards will sufficiently protect the beneficial uses of Cherry Creek Reservoir. However, the projections of growth in the basin indicate that sometime after 1995, the wastewater flows with nonpoint controls would cause the water quality to exceed the 20 ug/L chlorophyll a limit. This allows reasonable time for additional study of lake conditions, control technologies and growth implications.

Therefore, between 1984 and 1995, the water quality in the basin and in the reservoir should be regularly monitored and the findings, recommendations, chlorophyll a goal, and in-lake phosphorus standard presented in the clean lakes study should be regularly re-evaluated.

BASIN MASTER PLAN

A number of options exist which will protect the recommended standard. This Clean Lakes Study suggests what the major options are, but the details of the Basin Master Plan are to be developed in an update to the Clean Water Plan which will follow formal adoption of the lake quality standards.

As described in the findings, three methods of wastewater treatment will be sufficient to protect the recommended standard. Slow rate land application, rapid infiltration, and advanced phosphorus removal with filtration prior to discharge would all be acceptable. Other technologies yielding equivalent effluent quality may be feasible and would be appropriate for use. the findings of this study indicate that technology based effluent limits will protect the beneficial uses of the reservoir for 10 years at a minimum. Periodic review of the actual chlorophyll a and total phosphorus concentration in the reservoir during the 10 year time frame will allow for a confirmation of the recommended standard and effluent limits. It is recommended that specific mass limits in the form of pounds per year not be imposed via the state discharge permit system. Rather, the type of treatment recommended herein should be required and concentration limits be established for enforcement purposes.

It is recommended that the Basin Master Plan specifically identify these three methods, or any other equivalent treatment method, as appropriate techniques for meeting a phosphorus effluent limit of 0.2 mg/L or better in the basin.

The specific locations, service areas, sizing, and effluent limitations of individual facilities will be shown in the updated Clean Water Plan. Since the recommended standard is not based on ultimate build-out of the basin, the staging of facilities within the Plan will be critical.

Finding No. 7 indicated that nonpoint controls were necessary to protect the recommended standard, unless point source phosphorus was significantly reduced. The recommended program for nonpoint control is a system of detention ponds and rapid infiltration basins which would remove 50 percent of the annual nonpoint phosphorus load. The update to the Clean Water Plan will need to identify the institutional system which will construct and maintain the nonpoint control system.

It is recommended that the basin master plan will develop a staging plan for implementation of nonpoint control programs capable of removing 50 percent of the annual phosphorus load from nonpoint sources and will identify the methods for implementing these programs.

IMPLEMENTATION

Implementation of any project is always the most difficult task. The recommendations on wastewater effluent limits will be implemented through the Colorado Discharge Permit System. The exact staging, standing, location, and service area of each treatment facility will be identified in the Cherry Creek Basin Master Plan which will be prepared in 1984. Once the WQCC has formally established water quality standards for the reservoir, the Master Plan will incorporate those standards into effluent limits for the facilities in the basin. Once the WQCC has acted and the Master Plan is completed, the Clean Water Plan will be amended. Implementation of future wastewater facility planning will be consistent with the Clean Water Plan. Site applications and discharge permits should be consistent with the Clean Water Plan.

The most difficult recommendation to implement is the control of 50 percent of the phosphorus in nonpoint sources. Presently, the WQCC does not have the regulatory authority to require anyone to control stormwater runoff. No institutional arrangement exists for implementing such a control program. As the situation exists now, a nonpoint control program would be voluntary, conducted by general purpose governments or each water and sanitation district. However, a voluntary program is likely to fail, resulting in stricter phosphorus control from wastewater treatment facilities.

Several options exist for implementing a nonpoint source control program. The WQCC could request legislative action to amend the Colorado Water Quality Act, to give the WQCC authority to regulate nonpoint sources of pollution. Unless this legislative action occurs, the WQCC can only regulate nonpoint source pollution through issuance of discharge permits on detention structures or any other structure which would control stormwater runoff.

Douglas and Arapahoe Counties and the cities and towns in the basin could require, through new subdivision zoning, that each development area control its stormwater runoff for water quality improvement. If properly implemented, this institutional mechanism may be the easiest solution to the problem.

Another option is to create a nonpoint control authority district which would be responsible for all nonpoint control structures. This authority, which would have to be created by new legislation, would install and maintain all nonpoint runoff control structures. Funding for this authority could be established by assessing each district, development area, or landowner on an annual basis. Until the control of phosphorus in nonpoint stormwater runoff is mandated or regulated through some regulatory body such as the WQCC, it is unlikely that a nonpoint control authority district will be established.

Recommending any nonpoint control option for implementation will also be a function of the Basin Master Plan. It is recognized that recommending water quality goals and standards for the reservoir is pointless if those goals and standards rely upon a nonpoint control program which lacks the ability to be implemented. In the best interest of providing feasible means to control wastewater and protect the reservoir, it is incumbent upon all the basin dischargers to collectively support and implement a nonpoint control program.

This study has evaluated the water quality condition of Cherry Creek Reservoir and defined its present trophic status. Water quality goals have been established for the reservoir and appropriate standards are recommended to protect the present reservoir uses. Point and nonpoint control measures are identified which should meet the recommended reservoir standard and allow for growth to occur in the basin. Implementing these control measures and adopting the recommended standards will result in an acceptable reservoir trophic status and will not impair the beneficial uses established for the reservoir.

ABBREVIATIONS

ac	acre
ac-ft	acre-foot
BMP	Best Management Practice
°C	degrees Celcius
cfs	cubic foot per second
chl*a*	chlorophyll *a*
conc	concentration
D.O.	Dissolved Oxygen
EMC	Event Mean Concentration
ft^3	cubic feet
lbs	pounds
lbs/ac	pounds per acre
lbs/ac/ro.in.	pounds per acre per runoff inch
lbs/ac/yr	pounds per acre per year
lbs/tot.A	pounds per total area
MGD	Million Gallons per Day
mg/L	milligrams per liter
ug/L	micrograms per liter
OPO4	Total Orthophosphate as Phosphorus
NO2NO3-N	Nitrite plus Nitrate as Nitrogen
pH	negative log of the Hydrogen ion concentration
PEI	Percent Effective Imperviousness
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
WWTP	Wastewater Treatment Plant

GLOSSARY

Ambient. Nonstorm periods or the periods of time surrounding storm runoff periods or events.

Baseflow. The streamflow that occurs without direct contribution from precipitation or effluent discharge.

Basin. The entire tract of land drained by a river or stream and its tributaries.

Best Management Practice (BMP). Any storm runoff control measure which is designed to reduce the impact of urban runoff on receiving waters. Includes both structural and nonstructural techniques such as retension ponds or erosion control ordinances.

Chlorophyll a. Any group of related green pigments found in photosynthetic organisms.

Daily Mean Streamflow. The average streamflow for a given day.

Detention Pond. A pond or structure which controls the flow in a channel, part of which is stored temporarily. This temporary storage commonly results in suspended material settling out of suspension to become part of the bed material.

Effective Impervious Area. Impervious area which is hydraulically connected to a conveyance structure which transports runoff away from the area. An example of an effectively impervious area would be a roof which drains onto a driveway, and is connected to a street, gutter, and storm sewer.

Event Mean Concentration. The average concentration of a constituent in the total runoff from a storm. It is calculated by dividing the total constituent load by the total runoff volume.

Fecal Coliform Bacteria. Bacteria that are present in the intestine or feces of warmblooded animals. They are often used as indicators of the sanitary quality of water.

Hydrograph. Plot or graph of instantaneous streamflow versus time.

Impervious Area. Area which does not permit infiltration of water, such as streets, sidewalks, roofs and paved parking lots.

Instantaneous Streamflow. The total flow at a cross section of a stream at a given instant in time.

Load. The total mass of a substance distributed over a surface or within a fluid medium; usually the amount of a constituent carried from a drainage basin during a given time period or in the runoff from a given storm.

Mean Annual Precipitation. The long-term average yearly precipitation at a given station.

Nonpoint Source. A source not associated with or resulting from a single location, but rather from multiple, diffuse areas of land surface or points of origin.

Nutrients. Elements or compounds particularly, nitrogen, phosphorus, or carbon which are required for growth of living organisms.

Organic Matter. Material derived from living organisms which includes complex molecules formed by partial decomposition of plant or animal matter.

Percent Effective Impervious Area (PEI). The percentage of a drainage basin which is effective impervious area.

Percolation Pit. A storm runoff control measure which consists of a hole or depression filled with course gravel or cobbles which allows percolation (or infiltration) of water. The pit is situated in permeable subsoils and is designed to filter solids from and allow rapid dissipation of stormwater.

Pervious Area. Area which allows percolation (or infiltration) of water, such as lawns or areas of porous material.

Point Source. Associated with or resulting from a single location or point of origin.

Receiving Water. Any natural body of water in which runoff or wastewater drains into; Examples include streams, rivers, lakes, bays, or estuaries.

Runoff Load. The mass of a water-quality constituent that is transported by storm runoff exclusive of baseflow.

Runoff Period. The time period from the start of a storm when streamflow begins to exceed baseflow due to storm runoff and ending with a return to baseflow conditions.

Sediment. Any solid material that is transported by, suspended in, or deposited by water; includes chemical and biochemical precipitates and organic matter.

Storm Runoff. Storm-generated land surface runoff. Storm runoff is calculated as total streamflow minus baseflow during the runoff period.

Subbasin. A part of a drainage basin that may be treated as a unit based on drainage characteristics.

Urban Runoff. Dry-weather flow or storm runoff or both from an urban drainage basin.

Unit-area Loading. The load of a substance per unit of land area, usually expressed for a given time period.

Water Year. A 12-month period beginning October 1 and ending the following September 30. The year designation is the same as the calendar year in which it ends.