BEAR CREEK RESERVOIR

CLEAN LAKES STUDY

DRCOG
DENVER REGIONAL COUNCIL OF GOVERNMENTS

BEAR CREEK RESERVOIR CLEAN LAKE STUDY

DENVER REGIONAL COUNCIL OF GOVERNMENTS
2480 West 26th Avenue, Suite 200B
Denver, Colorado 80211

In Cooperation With

Colorado Department of Health
Water Quality Control Division
4210 East 11th Street
Denver, Colorado 80220

and

Jefferson County Mountain Water Quality Association

and

City of Lakewood

Preparation of this report was funded in part by a Clean Lake Grant from the U.S. Environmental Protection Agency.

ABSTRACT

TITLE: Bear Creek Reservoir Clean Lake Study

AUTHOR: Denver Regional Council of Governments

SUBJECT: A diagnostic and feasibility technical report describing the opportunities to protect the beneficial uses of Bear Creek Reservoir and watershed in Denver, Colorado

DATE: December, 1990

SOURCE OF COPIES: Public Affairs Office
Denver Regional Council of Governments
2480 West 26th Avenue, Suite 200B
Denver, Colorado 80211
(303) 455-1000

NUMBER OF PAGES: 142

ABSTRACT: This report diagnoses the existing water quality and biological characteristics of Bear Creek Reservoir and watershed with emphasis on the trophic condition of the reservoir. Nitrogen and phosphorus loadings have produced high chlorophyll α levels which, in conjunction with excessive sediment loadings, have caused the reservoir to be highly eutrophic. The report discusses sources of these nutrient and sediment loadings from the watershed. Methods and feasible alternatives to control the eutrophication process were identified for inclusion in a basin management plan. Recommendations are made on limits of phosphorus and chlorophyll α which will protect the beneficial uses of the reservoir. A separate technical appendix was made to augment this report which contains seasonal water quality data, water quality trend plots and checklists of plants and animals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report is the latest in a series of water quality studies of the Bear Creek Basin. The Denver Regional Council of Governments (DRCOG) initiated a basin water quality assessment of Bear Creek Basin in 1985. A task force was established by DRCOG composed of members of the Jefferson County Mountain Water Quality Association, the City of Lakewood and the Water Quality Control Division (WQCD). The initial focus of the basin study was to characterize existing and projected stream and reservoir water quality data, assess future land use activities and patterns, develop projections of population, employment and wastewater flows, evaluate the system of wastewater treatment facilities and establish a basin water quality management plan. An Environmental Protection Agency (EPA) Clean Lake grant was awarded in 1988 allowing DRCOG to conduct a study of Bear Creek Reservoir. The objective of the Clean Lake Study was to characterize the water quality and identify potential environmental problems in both Bear Creek Reservoir and its associated watershed.

DESCRIPTION OF BASIN

Bear Creek Basin is located within Jefferson County and is defined as the hydrologic boundaries to Bear Creek Reservoir. The major hydraulic features are Bear Creek and Turkey Creek, associated tributaries and Bear Creek Reservoir. These main streams flow year round with water diverted for both domestic water supply and agricultural use. The total area of the basin, excluding the reservoir, is 83,665 acres. The reservoir is located in the lower portion of the watershed at an elevation of 5600 feet. The mountains forming the upper boundary are at an average elevation of 10,000 feet. Precipitation in the Bear Creek Basin was estimated to equal, in an average year, about 290,000 Ac–ft per year. Groundwater storage was estimated to be about 21,000 Ac–ft which is roughly half of the yearly runoff of about 42,000 Ac–ft, as measured at Bear Creek Reservoir.

Bear Creek Reservoir was constructed as a flood control facility owned by the U.S. Army Corps of Engineers. The reservoir gate was initially closed in the summer of 1977. The multipurpose pool volume has remained constant at about 1927 Ac–ft with a surface area of 110 acres. The average inflow (60 cfs) to the reservoir is generally equal to the outflow (55 cfs) with some loss in the reservoir due to evaporation.

The basin is largely undeveloped with the community of Evergreen being the major urbanized area. The other urbanized areas include Kittredge, El Rancho, Genesee, Idledale and the Town of Morrison, and unincorporated developments of Riva Chase (Forest Hills Metropolitan District), Conifer Center, Marshdale, Indian Hills, Tiny Town, Brook Forest, Hiwan Country Club, Aspen Park, Willowbrook and several other small developments without specific names.

There are five major types of land use found in Bear Creek Basin: Commercial/industrial, open space, single–family residential, multi–family residential and single–family on large lot residential. Open space and large lot development are the two principal land use types and account for 95 percent of the basin land use. Single family and commercial development account for 4 percent of the basin land use. This land use trend is projected to continue through 2010 with a small increase in the percentage of single and multiple family development.

Although land use patterns are not anticipated to change dramatically in the next 20 years, population and employment will significantly increase by 2010. Population in both sewered and non-sewered areas will increase from 29,700 in 1988 to about 53,000 in 2010. Employment will show even greater increases between 1988 and 2010 due to anticipated commercial development. These population and employment increases will result in extensive construction activities within the watershed. There will also be a corresponding increase in wastewater flows from wastewater treatment facilities and individual septic systems.

PUBLIC PERCEPTION

User surveys provided a means to determine the public perceptions about Bear Creek Park, reservoir and associated watershed. The surveys also identified the primary recreational activities and user recommended changes to recreational opportunities in the Park and watershed. The user population for Bear Creek Park was generally from Jefferson County with the majority of visitors from specific census tracts in the City of Lakewood. The majority of Park users went to the reservoir for fishing activities. The Lakewood residents also went to the reservoir for picnicking related activities. The major reason for use of the Park was the distance with most visitors residing within 10 miles of the reservoir.

Conditions identified by users which could affect water quality or recreational opportunity in the Park and within the reservoir were dead fish, litter, sedimentation and algal growth. Construction activity associated with the section of C–470 highway crossing Bear Creek had caused a substantial quantity of sedimentation. Problems associated with erosion in the watershed were recognized by both Park users and residents in the Basin. Basin residents and groups interviewed at the Denver Parks also believed septic system failures were a major contributor to watershed pollution. Most of the respondents did not have a clear perception of the factors affecting water quality in either the streams or the reservoir.

Bear Creek Park was recognized by users as an important recreational waterbody in the metropolitan region. Many of the users believed the reservoir was slightly polluted, but still required improvements to enhance the fishery potential. Improvements in the recreational opportunity, water quality and fishery potential would help to make Bear Creek Park and reservoir a higher use recreational waterbody, according to survey respondents.

EXISTING CONDITIONS

Water rights play an important role in the water quality planning for the Basin because several diversions can divert a substantial portion of the stream flows before Bear Creek Reservoir. A complex system of water rights control flows in Bear Creek, Turkey Creek and Bear Creek Reservoir. Changes in storage levels in the reservoir could affect water quality management strategies and alter the existing physical, chemical and biological characteristics of the reservoir. An important assumption made in this study was no change in the pool volume from existing conditions, which assumes similar water rights administration.

The Colorado Division of Wildlife conducted a standard stream survey in Bear Creek during March 1987, which found a good population of rainbow trout in Bear Creek at the east Swede Gulch station with an estimated total yield of 122 pounds/acre. The rainbow trout population declined substantially downstream with only 4 pounds/acre found at Morrison. Trout found below 6 inches are considered to have reproduced within the stream system. Forty-seven percent of the rainbow trout in Bear Creek were below 6 inches. Therefore, Bear Creek can be considered as a reproducing rainbow trout fishery.

Nutrient and sediment loadings are derived from both point and nonpoint sources. The point source loads are derived from a series of wastewater treatment facilities: Evergreen, West Jefferson County, Kittridge, Genesee, Forest Hills Metro, Morrison, Willowbrook, Conifer and several other small facilities. These facilities provide secondary treatment with discharges into both Bear and Turkey Creeks. The nonpoint source loadings are a result of urban runoff, construction activities, grazing land management, and to a lesser extent, agriculture and past mining operations. Analyses of water quality data shows both point and nonpoint source control strategies will be required to reduce source loadings.

The annual point source contribution of nitrate from all wastewater facilities was about 30,000 pounds per year with about 9,000 pounds diverted by ditch systems. The annual phosphorus load from these facilities was about 15,000 pounds with about 4,500 pounds diverted by ditch systems. Although the ammonia load from effluent is about 12,000 pounds, about 45 percent of this nitrogen species is converted into nitrate before entering the reservoir.

There are about 2,600,000 pounds of particulate matter as suspended solids reaching the reservoir on an annual basis. The suspended sediment load is derived from basin erosion associated with development, highway construction and stream bank erosion. The contribution from all point sources is very small (about 0.4%). The upstream value (above all discharges) accounts for 1.5 percent of the total load.

The ammonia load is primarily from point sources with an upstream value of 43 pounds per year. The upstream concentrations and loads of nitrate and total phosphorus are relatively low at 296 pounds and 66 pounds, respectively. The annual nitrate load to the reservoir was about 115,000 pounds, with about 27 percent from point sources. The annual total phosphorus load was about 32,400 pounds with 33 percent from point sources.

Total septic system wastewater contributes about 1,800 Ac-ft per year to the basin water budget, which is about 4 percent of the annual surface runoff. The septic system annual flow is anticipated to increase to about 2,350 Ac-ft by the year 2010, which would be about 6 percent of the annual surface flow. In contrast, the 1989 existing wastewater treatment facilities contribute about 4 percent of the annual surface flow with an estimated increase to 9 percent by 2010. There are about 22,000 pounds of nonpoint source phosphorus discharged into the reservoir on an annual basis. Assuming that there is about 90 percent filtering of septic effluent constituents before reaching waterways, then the septic system contribution portion of the nonpoint source load is about 31 percent of the total poundage.

The groundwater nutrient data shows some nutrient enrichment of the Turkey Creek aquifer with nutrient loading occurring in the fall and winter months. This nutrient loading appears to be caused by septic system effluent discharging into Turkey Creek. There is also phosphorus enrichment of the Bear Creek alluvial aquifer which may be related to septic system effluent.

The hydraulic evaluation of the reservoir shows some short-circuiting of inflows across the surface of the reservoir. Surface flow patterns are significantly affected by the prevailing wind conditions which affected the top 5m of the water column. There are separate flow patterns between the reservoir arms and the central pool. Flow velocities were generally higher in the top of water column, between 1 and 2m.

A bathymetric survey quantified the existing contours and compared changes to the original contour map. There have been some changes in contours, particularly in the reservoir arms. The shoreline has been filled along the stream inlets with subsequent deposition in the arms of 0.5 to 1.5m. Some areas of the central pool adjacent to the outlet structure are deeper than when the reservoir was constructed. This deepening can be attributed to scouring and/or water weight deformation. There has been no significant infilling in the central pool of the reservoir.

Sedimentation deposits are formed at the mouths of both Bear and Turkey creeks. These depositional features are sediment deltas and show typical depositional features of river deltas. Aerial photographs of the reservoir system in 1978 show no delta formation. From 1979 to 1988 there was rapid delta formation at both creek mouths.

Bear Creek Reservoir and watershed water quality were quantified over a one–year period. The monitoring program was designed to provide detailed information for a few sites in the watershed and at the reservoir. The reservoir stations were sampled at increments in the water column to provide both time–series and spatial data. The watershed stations were selected to define water quality characterizations for upper and lower portions of the watershed along two mainstem streams and on the mainstem of Bear Creek below the reservoir. The routine watershed and reservoir monitoring program was supplemented by special data collection programs of more limited scope which were designed to provide specific data about fisheries, precipitation quality, alluvial groundwater quality, storm event loading and spring runoff quality in selected tributaries.

The mean reservoir (entire water column) total phosphorus was 154 μg/ℓ with the growing season and photic zone mean at 111 μg/ℓ and aphotic zone mean of 329 μg/ℓ. The mean chlorophyll α in the photic zone for the growing season was about 19 μg/ℓ. The mean secchi depth was 1.7m. The maximum chlorophyll α value was 98 μg/ℓ. There was a mean nitrate value for the photic zone of 113 μg/ℓ compared to the aphotic level of 71 μg/ℓ. Fecal coliform ranged from 0 to 20 counts/ 100ml with higher levels of total coliform bacteria.

The residence of water in the reservoir affects algal production by controlling nutrient loading. In the peak spring runoff period the reservoir volume is replaced about five times. By the summer growing season this replacement rate is about monthly. In the fall and winter periods, this replacement rate averages 2 months.

There were several significant algal blooms which occurred in the reservoir during the monitoring period. These blooms were composed of a number of phytoplanktonic species from the families Cryptophyta, Cyanophyta, Chlorophyta, Chysophyta, Bacillariophyta and Pyrrophyta. The composition of species varied throughout the growing season.

In April, May and June, the dominate genera were Cryptomonas, Navicula and Stephanodiscus. The dominance of the Navicula and Stephanodiscus genera decreased in July with the disappearance of Navicula species. The dominate genera in July, August, September and October were Aphanizomenon, Microcystis, Cryptomonas and Asterionella. The Aphanizomenon has the appearance of grass clipping and extensively covered of the reservoir surface. Aphanizomenon cell counts were measured in excess of 4,000,000 counts/ml during the bloom period. The phytoplankton populations decreased significantly by November with Cryptomonas as the dominate genera. There was a small bloom of Cryptomonas under the ice in February. Extensive nutrient loading also occurred at this time.

There was one dominate attached aquatic plant which was a species of Elodea. This is a common species in front range reservoirs. A distinct algal mat covering the sediments in the mid to late-summer periods. The matting algal was characteristic of a Schizothrix species. The aquatic plant coverage which occurred between May and October was generally confined to the upper slopes of the reservoir at depths of less than 2m. The areas of higher coverage were associated with the shallower inflows at the mouths of Bear and Turkey Creeks. Aquatic plant coverages of 80 percentage of the substrate were measured in July and August adjacent to the stream mouths.

The reservoir can be considered to be homogeneous in terms of zooplankton composition. Diacyclops thomasi, Skistodiaptomus pallidus and Daphnia pulex are all common and widely distributed in North America. The calanoid copepod, S. pallidus, is widely distributed in the east and great plains states. Although it has not been regarded as common in Colorado, it has shown a relatively dramatic range expansion in the last 40 to 50 years. The other two species are common in other lakes and reservoirs in Colorado.

There are seven fish species common to the reservoir with three species of sport fish: rainbow trout, smallmouth bass and tiger muskie. Axial muscle samples were analyzed for total mercury from a selection of fish caught in the reservoir. The analysis was done as a screening for bioaccumulation of metals in predatory and filter feeder fish in the reservoir food-chain. The mercury results showed levels which are slightly higher than expected background concentrations. None of the total mercury concentrations in the axial muscle sample exceeded the U.S. Federal Food and Drug Administration action level.

Information on the plants and animals found within Bear Creek Park was tabulated from a number of sources and from site surveys. A checklist of common trees, shrubs, herbs, grasses and grass-like plants is included in the study.

PROBLEM SUMMARY

The major water quality problems in Bear Creek Reservoir and associated watershed are summarized as following:

1. The reservoir has a trophic status which ranges from eutrophic to hypertrophic and generally has poor water quality. Periodically, the reservoir is not meeting its recreation, aquatic life and water supply beneficial use classifications as designated by the WQCC.

2. The trophic status of the reservoir is caused by excessive loadings of phosphorus and nitrogen which result in algal blooms throughout the growing season and under ice conditions, excessive aquatic plant biomass, an anoxic hypolimnion, internal

phosphorus loading under anoxic conditions, potential for fish kills, elevated concentrations of metals in fish tissue, limited zooplankton diversity and release of nutrients from bottom sediments. The U.S. Army Corp of Engineers' annual reports have listed water quality problems in Bear Creek Reservoir with metals and nutrients periodically exceeding EPA standards. The metals problems were not confirmed by this study, but a future monitoring program for metals has been proposed by the management agencies.

3. Point source loadings for phosphorus account for about 70 percent of the load reaching the reservoir in the summer growing season. There will be a need to reduce phosphorus concentrations in wastewater effluent discharges with emphasis on the summer growing season. This point source control could be required year-round, if there is a increase in reservoir detention as a result of water rights.

4. Nonpoint source loadings of nutrients and sediments have a significant effect on reservoir and stream quality.

5. Erosion occurring in the watershed has resulted in significant bedload deposition in the reservoir and very high suspended sediment loads discharged into the reservoir. There is a re-suspension of bottom sediments in the reservoir which can contribute nutrients back into the water column.

6. The alluvial groundwater aquifers have elevated concentrations of nutrients compared to surface waters. The Turkey Creek alluvial aquifer has higher nitrate and phosphorus levels compared to Bear Creek.

7. Septic system failures commonly occur in the Basin as identified by the Jefferson County Health Department. The future land use shows an increase in large lot development which could result in more individual disposal systems. Septic systems are anticipated to affect water quality in both streams and the reservoir.

MANAGEMENT

Four water quality models were developed and calibrated with monitoring data for Bear Creek Reservoir. These models can be used in unison to predict how various management strategies could affect water quality in the reservoir. The Dillon-Rigler model defines phosphorus loading to the reservoir. It is used to predict changes in seasonal mean phosphorus concentrations resulting from variation in phosphorus loading from the watershed.

The total phosphorus (TP) and total nitrogen (TN) unifying nutrient-chlorophyll α relationship models based on the TN:TP ratio define algal biomass productivity as related to nutrient concentrations. A TP model is presented for the summer season and photic zone which relates mean chlorophyll α and total phosphorus.

The nuisance bloom frequency model defines user impairment indices for the summer season. This model defines the frequency of nuisance blooms and establishes a range for frequency reduction. This nuisance bloom frequency is related to the public perceptions of reservoir water quality. A reduction in bloom frequency is used as the trigger for determining a percentage decrease in watershed phosphorus loading.

The four water quality models developed for Bear Creek Reservoir could be useful management tools for a water quality program directed toward a nuisance bloom control program. Management strategies for this program could then systematically result in phosphorus load reduction as related to nuisance bloom frequency.

The existing water quality data shows Bear Creek Reservoir to have use impairment. Keeping the reservoir at status quo was determined by the Task Force not to be a preferred option and improvement to water quality would be necessary for both the watershed and reservoir. The public surveys showed a desire by Park users for improved recreational opportunities at the Park and within the reservoir.

One recommended goal for consideration in a future management program for the reservoir is to reduce the probability that the reservoir is hypertrophic/eutrophic as defined by algal bloom frequency. The reduction of nuisance blooms exceeding 20 ug/l in the summer growing season by fifty percent would change the reservoir trophic status and balance the system between mesotrophic and eutrophic. A future management plan could recommend that this objective be defined as a staged process which will require several years for full implementation.

Based on the goal and water quality characteristics, management alternatives were identified for both the reservoir and watershed. The major reservoir alternatives selected from all available alternatives by the Task Force for consideration in the future management program were structural controls designed to reduce nutrient impacts, aerate the water column and decrease sedimentation: hypolimnetic aeration (with maintenance of natural stratification patterns); hypolimnetic withdrawal (as related to reservoir operation); phosphorus precipitation and inactivation; nutrient diversion; sediment delta stabilization and sediment trapping.

There are five structural alternatives which could be used in a future watershed management program: two types of erosion control (tributary and in-stream); septic system discharges; stormwater management in urbanized areas; and use of wetlands for nutrient control. Stormwater management is estimated to be the most costly program to initiate and maintain. Wetland and in-stream erosion control are moderately expensive but potentially effective control strategies. Since tributary erosion control is a low cost strategy, it could be the first type of strategy applied to the watershed.

Nonpoint source control strategies should be an integral component of the overall watershed management program. This program could be directed at prevention of nonpoint source problems with a restoration and protection portion designed to reduce existing problems. Nonpoint source controls should focus on erosion and sedimentation problems with the implementation of source control strategies to reduce nutrients before they are discharged into waterways.

Septic system wastewater flows could account for 75 percent of the nonpoint source contribution of phosphorus. Insufficient data are available on the performance of system systems in Bear Creek Basin to accurately estimate the actual total nutrient contribution from these systems. However, the problem is significant and warrants action. Therefore, the Task

Force recommends that all future septic systems built in Bear Creek Basin should not contribute pollutants to any gulch, stream or other waterbody. Those existing systems which are currently contributing pollutants should be upgraded when economically or technically feasible.

The existing system of major wastewater treatment facilities, which include Evergreen, West Jefferson County, Kittredge, Genesee, Forest Hills Metro, Morrison, Willowbrook, Jefferson County Schools and Conifer, will be needed for wastewater service in the future. El Rancho wastewater treatment will be provided by the Kittredge facility. The smaller wastewater treatment systems for Brookforest, Davidson Lodge and Tiny Town require further evaluation on the continued need for these systems. The preference of wastewater service providers is to develop a management process which could be used by the WQCD for permit compliance.

The study identified significant water quality problems in Bear Creek Reservoir which has classified the waterbody as eutrophic/hypertrophic. There is extensive algal production in the reservoir during the summer season which is caused by loading of excessive quantities of phosphorus from the watershed. These algal blooms are affecting recreational and aquatic life uses in the reservoir. Point and nonpoint source controls will be required to improve the water quality in the reservoir. A series of management strategies have been proposed which will be considered in the development of a basin management plan. This plan is being developed by the Jefferson County Mountain Water Quality Association and the City of Lakewood in cooperation with DRCOG. The management plan is projected to be completed in 1991 and submitted as a Clean Water Plan amendment in 1992.

A seperate technical appendix document was prepared for this study which contains seven specific appendices on wastewater effluent data, seasonal water quality data, water quality trend plots and checklists of plants and animals. Tables and figures contained in the technical appendix are referenced by an alphnumeric letter designation.

I. STUDY NEED

SCOPE OF PROJECT

The Denver Regional Council of Governments (DRCOG) initiated a basin water quality assessment of Bear Creek Basin in 1985. The initial focus of the basin study was to characterize existing and projected stream and reservoir water quality data, assess future land use activities and patterns, develop projections of population, employment and wastewater flows, evaluate the system of wastewater treatment facilities and establish a basin water quality management plan.

A Task Force was established by DRCOG composed of members of the Jefferson County Mountain Water Quality Association, the City of Lakewood and the Water Quality Control Division (WQCD). Based on existing water quality data and data generated by the WQCD, the Task Force determined there was a potential for water quality degradation in Bear Creek Reservoir and the associated watershed. The WQCD received an Environmental Protection Agency (EPA) Clean Lake grant and contracted with DRCOG to conduct the study. The objective of the Clean Lake Study was to characterize the water quality and identify potential water quality problems in both Bear Creek Reservoir and its associated watershed. Data from the Clean Lake Study would be used to develop restoration and control programs.

PREVIOUS STUDIES

Prior to the Clean Lake Study there were several problems identified in the watershed and at the reservoir which needed to be assessed in the Clean Lake Study. These identified problems were characterized in seven DRCOG technical memorandums, summaries of Task Force meetings, and the first year report from the WQCD (WQCD, 1988). The DRCOG technical memoranda address the following issues:

(1.1 – Planning Scenario Development) – Defines basin boundaries, land use data as provided by local governments, growth projections from 1985 to 2010, wastewater flow projections and sources, preliminary nonpoint source contribution based on the Denver Urban Runoff Program (DURP) model (DRCOG, 1973), and anticipated land use patterns.

(1.2.1 Hydrologic Evaluation of Bear Creek and inflows to Bear Creek Reservoir) – Discusses hydraulics of Bear Creek and general hydrology of Bear Creek Reservoir and assesses stream water rights patterns.

(1.2.2 – Water Quality Problem Identification/Sampling Results) – Provides a summary of WQCD water quality data sampling program with chemical, physical and biological data for stream and reservoir sites. This water quality data set provided the basis for the Clean Lake Grant application.

(1.2.3 – Nonpoint Source Assessment) – Presented nonpoint source phosphorus loading results and concluded nonpoint source impacts to the reservoir could not be fully evaluated from existing data.

(1.2.5 – Assessment of Reservoir Models) – Discussed reservoir modeling for nutrients, primarily phosphorus. The preferred model presented for consideration was the Canfield/Bachmann model.

(1.3 – Defined Service Area Scenarios) – Discussed service area alternatives in relation to existing water quality and land use projections through 2010. Several developments with higher densities, still on septic systems, were identified as potential water quality problem areas.

(1.4 – Wastewater Treatment Alternatives) – Discussed nutrient load budgets and suggested techniques for management.

The WQCD produced a preliminary wasteload allocation for Bear Creek (WQCD, 1988). This report assessed the assimilative capacity of Bear Creek and evaluated ammonia concentrations under existing and future conditions. At existing flow rates and effluent quality, a QUAL2 modeling of Bear Creek showed no ammonia problem. Future projections showed a potential for ammonia concentrations to exceed the in-stream standard. The Task Force was concerned about this projected model result because of the questionable data available for modeling. The WQCD first year report (WQCD, 1988) summarized the water quality problems, present and projected growth patterns, wasteload allocation modeling, wastewater treatment alternatives, and water quality models which could be used for Bear Creek Reservoir.

PREVIOUSLY IDENTIFIED PROBLEMS

A tabulation of water quality problems and related issues was defined in the Clean Lake Grant application. The reservoir was identified as potentially eutrophic as evident by measured thermal stratification, low hypolimnion oxygen concentrations in summer months, high chlorophyll α measurements in summer months, and low transparency of water column. These conditions affected two major beneficial uses as recognized by the Colorado classification system: recreation and aquatic life. Additionally, the Colorado Division of Wildlife had reported problems in maintaining a quality fishery and listed Bear Creek Reservoir as a poor fishery.

The major water quality problems and issues identified by one or more of the following agencies DRCOG, local governments, and the WQCD prior to the Clean Lake Study were as follows:

1. There were observed phytoplankton (algal) blooms;

2. Fish kills were reported for the reservoir;

3. Fishing quality and potential steadily declined;

4. The quality of fish flesh was reported as periodically poor;

5. Macrophyte and filamentous algae periodically accumulated along the shoreline;

6. There was a decline in visitation and usage of Bear Creek Park;

7. High turbidity in streams, particularly during peak runoff;

8. Sediments were infilling the reservoir as evident by the sediment delta build-up at the stream mouths;

9. Visible stream bank erosion on both Bear Creek and Turkey Creek;

10. Point source loadings from the wastewater treatment facilities maybe excessive;

11. Existing and potential for groundwater contamination from failed septic systems;

12. Increasing use of leach fields and septic systems in the basin;

13. Nonpoint source loadings at high levels from many sources;

14. Effect of future growth on stream standards;

15. Effectiveness of management control techniques and practices.

16. Water quality was too poor for swimming which is included in the City of Lakewood master plan for Bear Creek Reservoir.

17. Potential drinking water supply issues.

Nutrient loading from the wastewater treatment facilities had not been collectively evaluated in either the streams or reservoir. There was also a potential for sediments and nutrients reaching the reservoir from a combination of other point and nonpoint sources which had not been identified. The Jefferson County Health Department had reported numerous failures of individual septic systems with groundwater contamination in the area of Indian Hills. Construction activities in the mountainous areas were causing erosion and subsequent sediment accumulation and deposition in streams and tributaries.

The WQCD (1988) had modeled long-term water quality trends in Bear Creek and identified a future potential for violation of the in-stream ammonia standard. Additional analysis was required to confirm or refute this model data.

II. PUBLIC USER SURVEYS

The water quality standards and classification currently in effect for Bear Creek Reservoir are designed to protect beneficial uses. The limnological investigation of the reservoir and watershed has shown that these uses are impaired by existing water quality trends. User surveys were needed to assess the public reaction to water quality trends and correlate this public perception to measured water quality trends. The Clean Lake Program requires proposed control alternatives and other management programs be evaluated in relation to preferred recreational uses and opportunities, while recognizing that protection of environmental resources must ultimately be based upon the value judgements of people or organizations who either use or have a designated responsibility for these resources.

The public reaction to perceived water quality has been important in the metropolitan area in setting standards on reservoirs and other waterbodies. Visitors to Bear Creek Park, residents in Bear Creek Basin, visitors to Bear Creek and Turkey creek watersheds and residents from the City of Lakewood were surveyed to identify perceptions about Bear Creek Reservoir, Park and watershed. There were four objectives which the surveys were designed to assess:

- The current and historic user population's socio-economic patterns;
- The attitudes, beliefs and behavior with regard to various aesthetic characteristics of the reservoir water quality;
- The recreational uses and opportunities within the basin;
- Recommended changes to recreational facilities, water quality characteristics and fee structures for Park.

The data obtained from the surveys can be used to identify management and planning components for various uses of the Park and watershed.

There is a need for additional quality recreational facilities in the metropolitan region. The demand for water-oriented recreational opportunities has increased rapidly in recent years. There are over 2 million visitors using Cherry Creek Reservoir and Chatfield Reservoir on a yearly basis. While the visitor population is less at 120,000 for Bear Creek Park, there is a growing use of this recreational facility. This is due to a decrease in the amount of recreational water space available in relation to the increasing user population.

Water quality studies in the last 10 years have shown many of the recreational waterbodies in the metropolitan region and elsewhere in Colorado have been moderately to severely polluted from a wide variety of sources. Although a large part of this pollution is a direct result of man-induced perturbations, there is also a considerable amount of indirect natural degradation. This pollution has effected beneficial uses and public acceptance of these waterbodies. The public surveys conducted for Cherry Creek Reservoir and Chatfield Reservoir have shown a demand for high quality recreational waters with diverse recreational opportunities (WQCD, 1982).

SURVEY METHODS

Surveys were patterned after questionnaires developed for the Cherry Creek and Chatfield Clean Lakes Studies (WQCD, 1982). These questionnaires were designed to characterize water quality as perceived by the public for various recreational uses and relate these perceptions to actual water quality trends. The questionnaires also defined the user population. Although these surveys were both comprehensive and definitive, the entire questionnaire was too extensive for general completion. Key questions and elements of the survey were selected for the Bear Creek User Surveys.

There were four types of surveys conducted for the Clean Lakes Study: reservoir users, self completion and personal interviews; Bear Creek Basin residents, self completion; Bear Creek watershed, personal interviews; and residents of the City of Lakewood, general circulation news letter questionnaire.

The City of Lakewood Park's personnel were used to conduct the reservoir interviews and distribution of surveys within the Park. DRCOG staff provided training to Park personnel managers for interviews and surveys. DRCOG staff conducted interviews in the Bear Creek Basin at the Denver Parks locations. A total of 900 questionnaires with return mailers were mailed to residents within Bear Creek Basin by local governments. The City of Lakewood survey was distributed through the City Newsletter in August 1988.

There was a total of 200 usable interviews and self completed surveys obtained from Bear Creek Park users. A majority of the surveys and all interviews were completed from April to October, 1988. There were only 23 questionnaires returned from residents in Bear Creek Basin with 13 from Genesee, 2 from Morrison, 7 from Evergreen and 1 from Jefferson County. There were 20 groups of people interviewed at the Denver Parks during June, July and August 1988. Most of these groups were from the City and County of Denver or City of Lakewood. There was a distinct reluctance by most people at these Denver Parks to cooperate in survey completion. The City of Lakewood returned 486 questionnaires and provided the most recommendations for additional or improved recreational opportunities. There were also numerous telephone calls from Lakewood residents about the Bear Creek study.

The reservoir questionnaires had seven sections: general user information and population distribution; historical uses at the Park and within the watershed; current uses at the Park; previously observed conditions at the Park and for the reservoir; currently observed conditions at the Park or for the reservoir; biological resources; and recommendations. There was a total of 21 questions which provided 37 types of direct information. The interview surveys provided additional information from a prioritization of specific questions. The questionnaire for the Basin residents was similar to the reservoir questionnaire with more emphasis on conditions and recreation trends in the watershed. The Lakewood survey was an abbreviated version of the reservoir survey which focused on historical uses; previously identified conditions; and recommendations.

The lack of response from Basin residents made statistical analyses of the returned questionnaires not as effective as analyses of the reservoir and City of Lakewood surveys. The reservoir and Lakewood surveys were encoded for statistical analyses. The data sets were processed with the Statistical Analysis System (SAS Institute, 1982) frequencies procedures. One–way and two–way frequency analyses were run on the data sets.

The one–way frequencies provide a response summary of each question, including multiple responses. Two–way or multi–way frequency analyses provides a means to statistically interrelate responses to various questions. Generally, the perceptions of respondents will be reflected throughout the survey and be dependent on a number of factors. Cross–tabulation of responses can often identify some of these factors which interrelate among respondents. Additionally, these cross–tabulations provide a conceptual framework of the general public perception of seeming unrelated topics. As an example, those respondents who infrequently visit the Park have a different overall view of the reservoir water quality as compared with the more frequent visitors. This type of information is essential in understanding how the general public will react to proposed management programs.

RESERVOIR SURVEY

The averaged visitation from 1983 through 1988 was 120,500 per year with existing facilities. The 1988 visitation was estimated to be below the average at about 115,000 visitors. The City of Lakewood has only completed phase I recreation facilities which limits existing visitation activities. Additional activities are planned for the near future which should increase Park use.

The City of Lakewood determined the peak day carrying–capacity and activity mix of the Park as part of the phase II facilities improvement for an in progress Park Master Planning project. The peak day carrying capacity was calculated from the facility design capacity method. This method assumes peak facility day use is equal to design day capacity based on re creation criteria developed for Colorado. The design day capacity was then expressed in terms of activity days. There were 14 activities designated for the Park which included the new proposed activities of swimming and golf. There are 10,282 total activity days which represents a total peak day carrying capacity of 7909.

The visitation patterns at other U.S. Army Corps of Engineers reservoirs can be used to predict future visitation based on peak day carrying capacity. The following assumptions were used to determine estimated annual visitation:

- 9 peak days per peak month
- 60 percent of peak month visitation occurs on 9 peak days
- 20 percent of the annual visitation occurs in the peak month.

Estimated future Park visitation ranges from 435,000 to 593,000 annual visitation, dependent on the development of Phase II activity types.

Based on the annual visitation, about one percent of the visiting groups to the Park were surveyed or interviewed. This percentage is considered to be a representative sampling of a user population. The complete data tables for the reservoir survey are shown in a technical memorandum on Public and Users Surveys (DRCOG, 1990).

One–way frequency response analyses from the reservoir survey showed a tendency for smaller groups to visit the Park with the average stay varying between three to five hours. Fishing activity averaged about two hours per person with other activities associated with the fishing. The majority of visitors were from Jefferson County (about 47 percent) with a large number from Denver County (about 30 percent). The majority of Jefferson County visitors were from the City of Lakewood (about 88 percent). These results are consistent with a survey conducted by the U.S. Army Corps of Engineers in 1985.

The frequency of visitation to the Park was generally low with about 50 percent of the survey respondents having been to the Park five or fewer times. Cherry Creek and Chatfield reservoirs in comparison have a high frequency of visitors which have visited the facilities more than 25 times. The primary historic and current recreational activity was fishing with 87 percent of respondents engaging in this activity.

Visitation to Bear Creek Basin increased after the Park was established in 1983, although the frequency of visitation remained low. The primary activities were picnic related with some fishing. It was interesting to note the number of respondents who fished along Turkey Creek which is not considered as a fishery.

The reason most visitors identified for going to Bear Creek Park was the close distance. The U.S. Army Corps of Engineers survey showed most visitors were from three census zones in the City of Lakewood (Figure 1). These zones are within five miles of the reservoir. The Denver County residents were generally from the southwest part of the County and were within ten miles of the reservoir. The zones of origin for populations using Bear Creek, Chatfield and Cherry Creek showed very little overlap. There is a small percentage of the metropolitan population which visits all the recreational areas. The majority of recreational users for a given facility are related to distance from the facility and the transportation accessibility.

The Park recreational facilities were rated from average to good with no change in recreational opportunity since their last visit. Although there were a number of criticisms about recreational facilities and opportunities, the majority of respondents would return to the Park in the future. The recommendations for Park changes or improvement as recorded in the questionnaire are shown in Table 1. The recommendations are identified for three frequencies of response: high, moderate and low. Those recommendations which were rated high were common to both the Lakewood and reservoir surveys.

The most frequent recommended improvement was related to fishing and included more fish, better regulation, access to shoreline locations and additional boat usage. The remaining recommendations were generally related to adding, improving or modifying recreational facilities within the Park. The major criticism of the Park facilities was lack of picnic shelters in either the form of shade trees or physical structures. Table 1 also contains recommendations as recorded in the questionnaires for changes and improvements within Bear Creek Basin as related to recreational opportunities. Those recommendation shown in Table 1 with high frequency responses should be considered when the management programs are developed for both the watershed and reservoir.

Figure 1.

Major Residence Areas for Bear Creek Reservoir and Park Users. The shaded area represents areas identified by the U.S. Army Corps of Engineers as major residence zones in a 1985 survey.

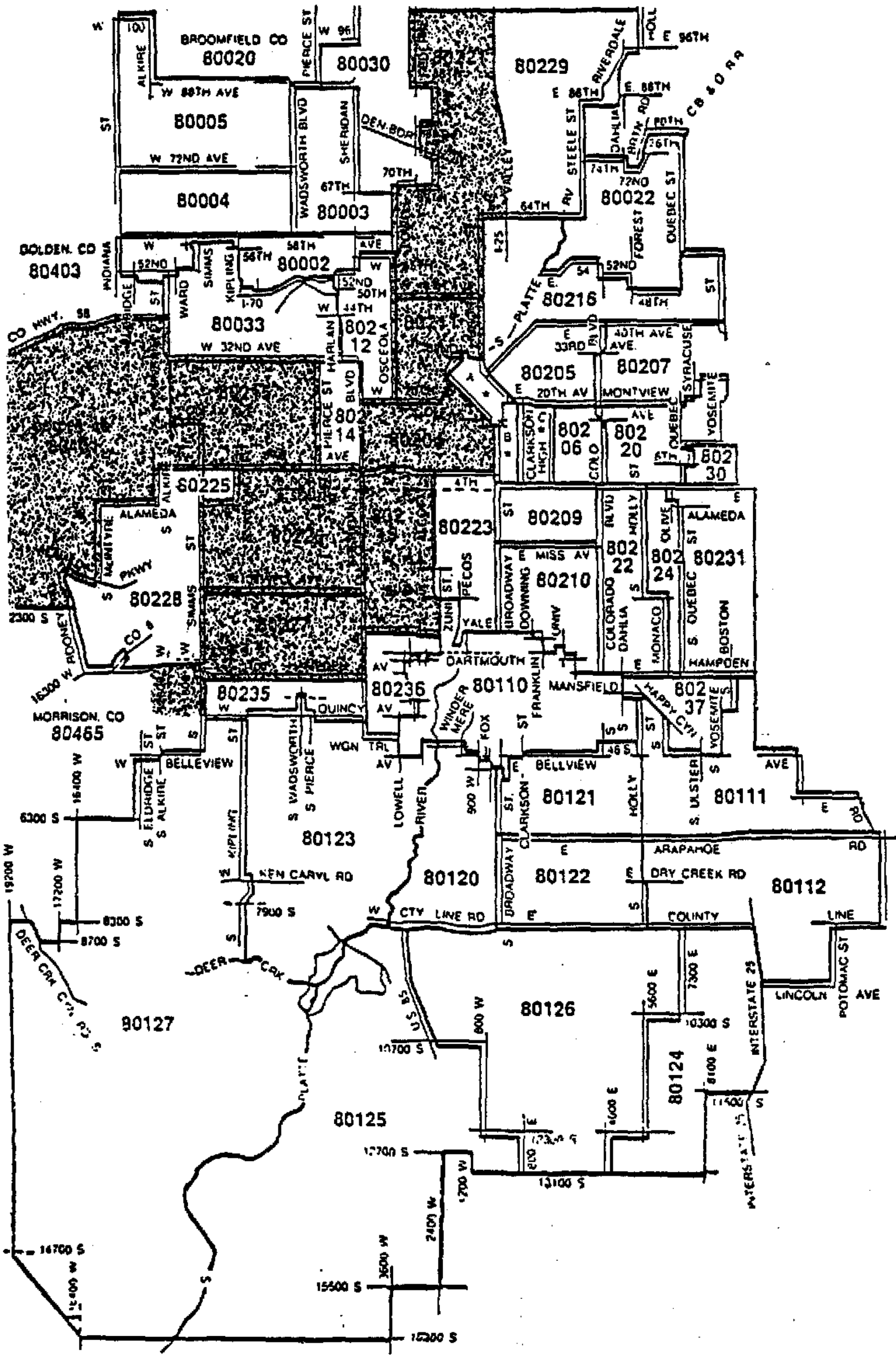


Table 1. Survey Recommendations for Improvements to Bear Creek Park and Watershed

BEAR CREEK PARK

RECOMMENDED IMPROVEMENTS	FREQUENCY
Improve Fishing Quality and Increase Stocking/Baitshop	High
Add Wildlife Observation Areas	High
Planting of Additional Trees for Shade	High
Addition of Shelters for Picnic Areas	High
Addition of Picnic Tables at Fishing Areas	High
Open Reservoir to Swimming (Swim Beach at Reservoir)	High
Improve Water Supply for General Use at Picnic Areas	High
Increase Number of Restrooms	High
Improve Water Quality	High
Increase Number of Camping Areas with Facilities	High
Improve Access for Handicapped	Moderate
Extend Bicycle Path to Bear Creek Lake Park	Moderate
Maintain Archery Range	Moderate
Improve Litter Control and Pickup	Moderate
Add Overnight Horse Camping with Facilities	Moderate
Longer Hours of Operation	Moderate
Septic System Dump for RV Campers	Low
Addition of Children Playground	Low
Boat Rentals and Boat Dock	Low
Allow Bigger Boats and Waterskiing on Reservoir	Low
Lower Entrance Fees	Low
Identify Points of Interest (Geological, Biological)	Low
Impose Additional Size Limits on Fish	Low
Addition of July 4 Fireworks Show	Low
Improvement and Better Maintenance of Roads	Low
Increase Amount of Flow Through Reservoir (Pool Size)	Low
Build City Golf Course	Low
Allow Unrestricted Fishing Access Around Reservoir	Low
Allow Bear Creek Park to Remain Natural	Low
Improved Insect and Rodent Control	Low
Addition of Rifle Range	Low
Addition of Organized Group Activities	Low

Table 1. Continued

BEAR CREEK WATERSHED

RECOMMENDED IMPROVEMENTS	FREQUENCY
Improve Fishing Quality and Increase Stocking	High
Preserve Natural Setting of Streams	High
Extend Bicycle Paths (Separate from hiking trails)	High
Control Erosion and Other Sources of Stream Degradation	High
Improve Handicap Access	Moderate
Prevent/Limit Construction/Development Near Streams	Moderate
Increase Stocking of Fish and Fish Habitat	Moderate
Enforcement of Litter Laws	Moderate
Addition of more Parking Space Along Streams/Access	Moderate
Improve Horse Facilities	Moderate
Improve Trails	Low
Identify Points of Interest (Geological, Biological)	Low
Improve General Access	Low
Additional Picnic Tables and Areas	Low
Additional Shelters	Low
Improve Water Quality and Stream Habitat	Low
Control Small Rodents	Low

There were several questions directed at those engaged in fishing related activities. There were 219 respondents who fished with 61 percent catching fish. The fishing quality was rated from fair to poor with generally little change in quality since the last visit. Twenty percent of the respondents were fishing at the reservoir for the first time.

The quality of fishing in the reservoir was an area of concern by fisherman interviewed with recommendations made on improving fishing quality. About 20 percent of the users surveyed at the reservoir believed the fishery quality had declined significantly in recent years. There was an interest to see the reservoir become a sustainable fishery with more fish species available. Fishermen were willing to pay an increased Park fee, if this income was used for water quality and fishery improvements.

The catch data from these respondents is shown in Table 2. Rainbow trout make a majority of the catch. The trout fishery is put and take with the Division of Wildlife stocking 10,000 to 20,000 fish during the survey period. The average catch for rainbows was about two fish per hour. There were a few rainbows caught which exceeded 20 inches, which indicates some fish are surviving for more than one season in the reservoir. There were a few smallmouth bass caught with only three fish in the keepable size range (greater than 15 inches). There were seven tiger muskie caught, including a Colorado record for the survey period. Tiger muskie in excess of 40 inches are known to be in the reservoir, although the numbers present are considered low. A large number of smaller tiger muskie were stocked in the reservoir in 1988, but catch information from 1989 does not indicate an increase in the number of tiger muskie caught.

The major historically observed conditions which could affect water quality or recreational opportunity in the Park and within the reservoir were dead fish, litter, mud and siltation, and algal growth. Twenty-three percent of the respondents did not identify any conditions which could affect water quality. The current conditions during the survey period were dead fish, algal growth and litter with 32 percent of the respondents not identifying any conditions affecting water quality. The major problem in the Park was litter. There were numerous complaints about the Colorado Highway Department causing erosion along a section of the new C-470 highway. There was an erosion problem associated with construction across Bear Creek.

The water appearance was generally assessed as either brown or green. The water quality was classified by 71 percent of the respondents as clean/green and of good quality. The public perception of the water quality during the survey period was better than shown by the water quality data. The green appearance of the water is related to the chlorophyll α production which gives the reservoir a hypertrophic status. This green appearance is generally not equated to a water quality problem by the public. It is important to note for the survey period that swimming was not a permitted activity. A swimmer user group is known to be more sensitive to water appearance compared with a fishing user group.

Perceived water quality problems in the reservoir as identified in the surveys were generally related to recreational use or the presence of excessive algal growth. There were many respondents who were either not sure of causes or did not perceive any significant water quality problems. The major problem identified in the watershed interviews was related

Table 2. Fish Catch Data from Reservoir Surveys

Type of Fish	Size Class 6-12 Inch	Fish/ Person*	Size Class > 13 Inch	Total Catch	Fish/ Hour
Smallmouth Bass	38	0.2	3	41	0.09
Rainbow Trout	523	2.4	354	877	2.00
Sunfish	18	0.1	0	18	0.04
Suckers	9	<0.1	11	23	0.05
Tigermuskie	0	0	7	7	0.02

*There were 219 fisherman who completed surveys while fishing at Bear Creek Reservoir with the average time spent fishing at 2 hours. Those fisherman who spent longer than 2 hours at the reservoir were generally doing other recreational activities in conjunction with fishing.

to natural erosion in streams and man–induced construction. There were 73 percent of the respondents who were not sure of causes as related to water quality.

The algal blooms were viewed as a nuisance and a sign of pollution, but not as a major reason to stop usage of the Park facility. The algal blooms were also associated with an odor problem which was a concern to interviewed (DRCOG, 1990) users. The major causes effecting algal growth as viewed by the public were sedimentation and chemicals producing the algal growth. Wastewater treatment facilities were not perceived by Park users as a major source of pollution.

A majority of the respondents would be willing to pay increased entrance fees for Park visitation if these fees were used to improve recreational opportunities. An increase up to $1.00 would be generally acceptable to improve water quality, recreation facilities and fishing.

The multi–way frequency data set combined surveys from both survey procedures: personal interviews and self completed questionnaires. There were five types of multi–way frequency analyses which were assessed for the entire reservoir data set:

- The frequency of visitation;
- County of origin;
- Place of origin in Jefferson County;
- Time of stay at Park;
- Recreational activity.

The frequency of visitation to the Park when compared with responses showed this analysis variable affected the perception of the respondent. This analysis showed a correlation between frequency of visitation, perceived water quality and recreational uses. Infrequent visitors generally found the recreational opportunities to be more limited than those who visited the Park more frequently.

The cross–tabulation between county of origin or place of origin in Jefferson County and responses did not show a distinct difference in perceived water quality and recreational use. There was a trend for residents of Lakewood to be less critical of water quality and recreational opportunities. The time spent at a recreational activity was variable and not dependent on water quality, type of activity or recreational facilities.

The cross–tabulation between recreational use and responses was biased toward fishing use, due to the majority of participants involved in this activity. As a result, there were no definitive response trends among various recreational user groups. However, there were two primary activity groups which could be delineated for Park use:

- Fishing and related activities;
- Picnicking and related activities.

Those engaged in fishing activities were more responsive to identification of water quality trends, while those who went to the Park to picnic were more responsive to recreational facilities. The picnic group made more frequent recommendations for additional picnic tables and shelters for these tables. The addition of shade at picnic sites included physical structures and trees. The picnic group also was critical of the fresh water supply at picnic areas. The fishing group recommended greater access to reservoir shoreline, increased boating activities, baitshop and improved fishing quality.

LAKEWOOD SURVEY

The returned Lakewood surveys were completed by residents who had either visited the reservoir and Park or the watershed. There were 18 respondents out of a total of 486 who had not visited the reservoir but had been through the watershed. The frequency of visitation to the reservoir was generally fewer than 12 visits (about 61 percent). There was about 20 percent of the respondents who had been to the Park more than 25 times.

There were three primary reasons for Lakewood residents to visit the Park:

- Fishing and related activities (38 percent);
- Bike riding, jogging and other fitness activities (18 percent);
- Picnicking and related activities (16 percent).

The remaining recreational activities were divided among boating and sailboarding (10 percent), hiking (5 percent), horseback riding (4 per cent), camping (1 percent), archery (1 percent) and a general other group which were looking for *a place to get away* (8 percent). Over 90 percent of the respondents went to the Park because of the closeness with most visitors residing within 10 miles of the reservoir (Figure 1).

The recreational facilities were generally found average to good (about 70 percent) with 15 percent of the respondents finding the area excellent and 14 percent finding the area poor. The reservoir water quality was also rated from average to good with 39 percent of the respondents finding the quality as clean/green and good. Only 29 percent of the respondents found the water quality poor. These perceptions are related to the type of activity (i.e., fishing and time of year).

The response to improving the recreational opportunity was variable with responses directed at both water quality improvement, fishery enhancement and additional facilities. A larger reservoir capacity was favored by 19 percent of the respondents. The recommendations for improvements to the reservoir, Park and watershed were incorporated into Table 1.

There were a number of recommendations made to improve the recreational opportunities. The major areas of improvement were directed toward improved picnic facilities with a need for shelters, shade and potable water. There were a number of respondents who preferred the natural setting of the Park and believed it would be more beneficial to improve existing facilities with out adding new recreational activities. There were many respondents who wanted to see a bike path developed through the Park with connections to outside paths.

Most Park users would be willing to pay a small increase in Park fees for improvement of recreational facilities and opportunities.

Cross–tabulation statistical analysis were made between frequency of visitation and responses. Those respondents who were visiting the watershed infrequently (first time users) and those who frequently went to the watershed were engaged in a wide variety of activities. The major activities of moderately frequent visitors (visits from 6 to 25 times) were fishing and picnicking. The primary reason for visiting the watershed was distance which was not related to frequency of visits.

The more frequent visitors to Bear Creek found the water quality in the watershed to be generally average, while Turkey Creek was rated poorer. Most respondents were not sure of the water quality in Turkey Creek. The major recommendations for improvement of the entire watershed were divided among responses as follows:

- Improve quality of wastewater treatment facility discharge (24 per cent);
- Increase fishing quality (16 percent);
- Leave the watershed in natural setting or minimize change (12 per cent);
- Improve the stream habitat (11 percent);
- Control septic system discharges (9 percent);
- Develop an erosion control program (5 percent);
- Addition of new recreational areas and improve access to streams (3 percent).

The frequency of visitation to the reservoir was correlated to public perceptions about recreational opportunities and water quality. The more infrequent visitors went to the reservoir to fish, while those who made more frequent visits expanded their recreational activities. The more frequent visitors to the Park were less likely to use the picnic areas, compared with the low frequency visitation. This suggests picnic facilities are not meeting the needs of the visitors. The recommendations in Table 1 show a high frequency response to improvement of picnic facilities. There is a 42 per cent visitation rate in the one to five times range which shows some respondents did not return to the Park to use recreational facilities (i.e. archery). The infrequent and frequent visitors to the Park went primarily because the distance was close. The improvement of recreational opportunity and frequency of visitation did not show any distinct trends.

III. AREA CHARACTERIZATION

WATERSHED AND RESERVOIR GENERAL HYDROLOGIC FEATURES

Bear Creek Basin is located within Jefferson County and is defined as the hydrologic boundaries to Bear Creek Reservoir (Figure 2). The major hydraulic features are Bear Creek and Turkey Creek, associated tributaries and Bear Creek Reservoir. These main streams flow year round with water diverted for both domestic water supply and agricultural use. The total area of the basin, excluding the reservoir, is 83,665 acres. The surface area of the reservoir is 110 acres. The watershed terrain is generally mountainous with distinct hydrologic sub-basins. The reservoir is located in the lower portion of the watershed at an elevation of 5600 feet (Figure 2). The upper mountains are at an elevation of 10,000 feet.

The average annual temperature in Bear Creek Basin is 50 °F (10 °C) with extremes which vary from -40 °F (-40 °C) in the winter to 100 °F (38 °C). The average annual precipitation for the Basin is 18 inches with higher amounts in the upper basin (up to 25 inches) and lower amounts near Bear Creek Reservoir (up to 10 inches). Precipitation in the form of thunderstorms are a frequent occurrence in the spring months with the greatest precipitation generally occurring in May. There is an average snow accumulation above 8,000 feet of about 30 inches with spring melt generally peaking in late May and June.

Precipitation in the Bear Creek Basin was estimated to equal, in an aver age year, about 290,000 Ac-ft per year. Groundwater storage was estimated to be about 21,000 Ac-ft which is roughly half of the yearly runoff of about 42,000 Ac-ft, as measured at Bear Creek Reservoir.

The bedrock in most of Jefferson County is composed of metamorphic rocks with magmatic intrusions that formed large granite masses. The granite intrusions are generally resistant to erosion and therefore they are prominent features in the mountainous region. The metamorphic rocks are more readily eroded by streams and other runoff sources. The tectonic activities which formed the mountain regions also created an extensive system of faults and fractures. The fracture and fault zones define areas which are eroded by running water.

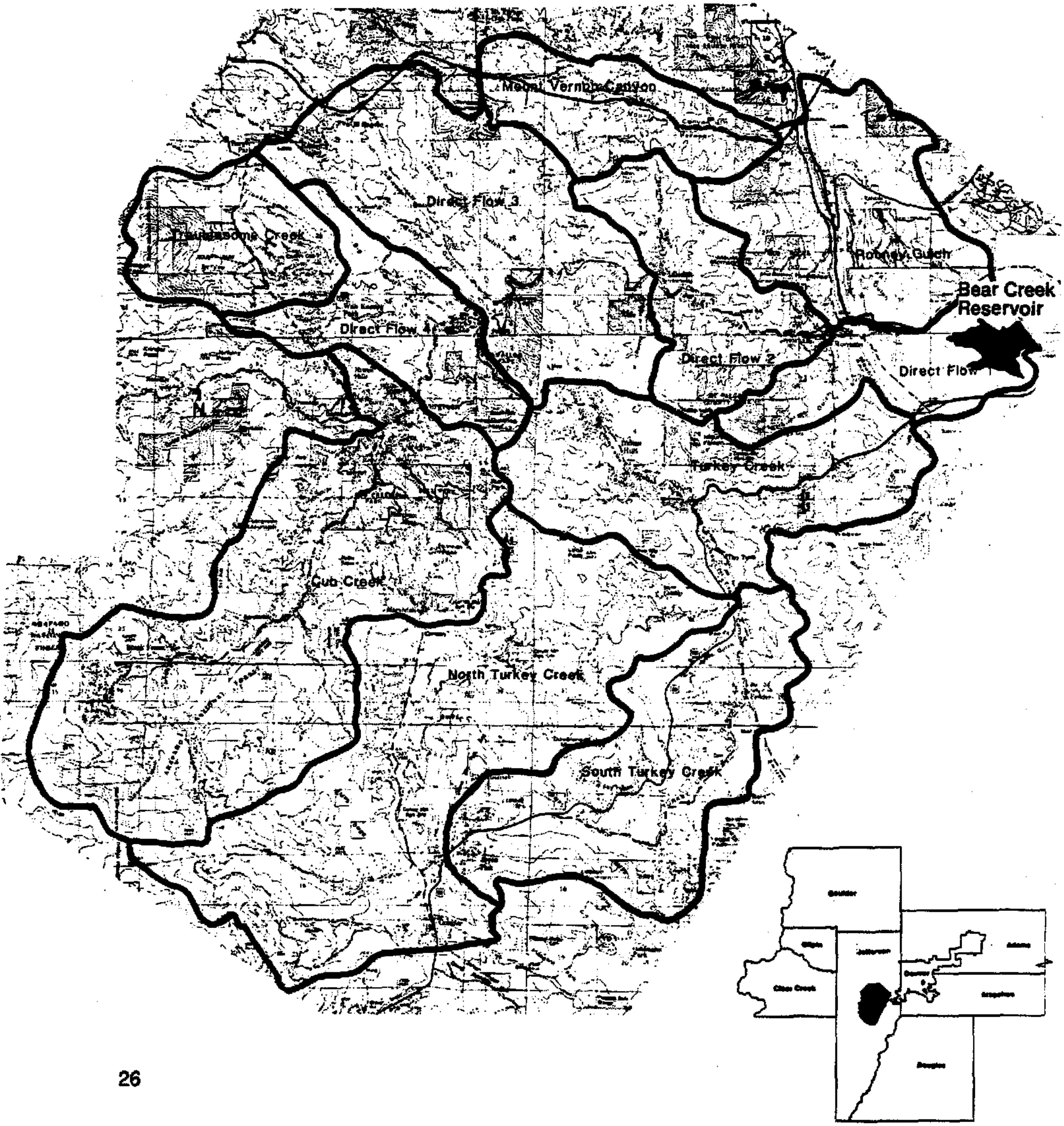
Fractured bedrock in Bear Creek Basin constitutes the principal groundwater aquifer. There are two types of groundwater associated with the principal Basin aquifer. There is the deeper fractured bedrock storage which is characterized by small yields, lower storage volumes, large water level fluctuations and lower recharge rates. The other groundwater type is the alluvial aquifer confined to the lower valley areas. The alluvial aquifer has greater storage capacity, greater yields and more stable water level fluctuations. There is direct recharge from surface runoff features. This hydraulic connection makes the alluvial aquifer system more susceptible to surface pollutants.

The geologic control effecting both supply and water quality in the mountainous part of Jefferson County is described in a report by Hofstra and Hall (1975). This report estimated yields and storage of water in streams and groundwater aquifers and characterizes water quality trends.

Figure 2.

Bear Creek Basin

The Bear Creek Reservoir is located at the lower portion of the watershed. The wetlands demonstration project is proposed for Direct Flow Number 1 near the reservoir.



The water budget for Bear Creek watershed estimates the general movement of water into the Basin, storage, evapotranspiration and outflow. The water budget is estimated as follows:

	VOLUME (Ac-Ft)	PERCENT OF TOTAL	INCHES
Precipitation	290,000	100	18.0
Surface runoff	42,000	7.8	1.4
Baseflow-Groundwater	9,000	3.2	0.6
Evapotranspiration	257,000	89.0	16.0
Groundwater storage-fractured	18,000	6.1	1.1
Groundwater storage-alluvial	4,000	1.3	0.2

LAND USE PATTERNS

A preliminary planning scenario for development in Bear Creek Basin was addressed by DRCOG (1986). This technical memorandum evaluated land use data supplied by the local governments and developed growth projections from 1985 to 2010. These projections were reviewed in 1988 and a new set of population, employment and wastewater flow projections were incorporated into the Clean Water Plan (DRCOG, 1989).

The mountainous terrain of the Basin reduces the amount of readily available land for development. There is a tendency for development to be confined to the alluvial valley floors and along major drainage systems. There are many acres in the Basin which have extremely steep slopes or restricted access. Development of these areas requires a substantial engineering effort. The existing land use pattern was used as a means to sub-divide the Basin for planning.

The basin was divided into 11 sub-basins for planning purposes. The sub-basins were selected by major drainage systems (Figure 2). The total acreage in each sub-basin was determined as follows:

SUB-BASIN	TOTAL ACRES
Direct Flow Number 1	5,119
Direct Flow Number 2	4,459
Direct Flow Number 3	9,490

Direct Flow Number 4	3,967
Cub Creek	16,097
Troublesome Gulch	3,967
Turkey Creek	8,228
North Turkey Creek	15,735
South Turkey Creek	8,323
Mount Vernon Canyon	3,719
Rooney Gulch	4,700
TOTAL BASIN ACREAGE	83,665

There are five major types of land use found in Bear Creek Basin: Commercial/industrial, open space, single–family residential, multi– family residential and single–family on large lot residential. These categories coincide with land use export coefficients for stormwater pollutant loading as devised in the Denver Urban Runoff Program (DRCOG, 1983).

Existing land use information was taken largely from Jefferson County Planning Department's land use inventories. The number of existing dwelling units was found by multiplying calculated sub–basin acreage for each land use category by the average density (DRCOG, 1986). The average existing household size, as determined by DRCOG, was 2.73 persons per household with an average 2010 density estimate of 2.65 persons per household. This information was compared to existing community plans and adjusted accordingly.

A major premises of these plans was a minimum 5–acre lot size for development outside of a projected water and sanitation district with a minimum 1–acre lot size for areas with wastewater service. A minimum 5–acre lot size is required by Jefferson County for development of on–site individual disposal systems.

The basin is largely undeveloped with the Town of Evergreen being the major urbanized area. The other urbanized areas include the Towns of Kittredge, El Rancho, Genesee, Idledale and Morrison, and unincorporated developments of Riva Chase (Forest Hills Metropolitan District), Conifer Center, Marshdale, Indian Hills, Tiny Town, Brook Forest, Hiwan Country Club, Aspen Park, Willowbrook and several other small developments.

Open space and large lot development are the two principle land use types and account for 95 percent of the basin land use. Single family and commercial development account for 4 percent of the basin land use. This land use trend is projected to continue through 2010 with a small in crease in the percentage of single and multiple family development (Table 3).

Table 3. Projected Total Acres of Land Use Types.

LAND USE TYPE	1985 (ACRES)	1990 (ACRES)	2000 (ACRES)	2010 (ACRES)
SINGLE FAMILY	1,889	2,057	2,395	2,732
MULTI-FAMILY	65	75	94	113
LARGE LOT/OPEN SPACE	79,888	79,407	78,659	78,019
COMMERICAL	1,823	2,018	2,409	2,801

POPULATION, EMPLOYMENT AND WASTEWATER FLOW PROJECTIONS

Population and employment projections were developed for Bear Creek Basin for a planning period extending to the year 2010 (DRCOG, 1986). Projections were made for the years 1985, 1990, 2000 and 2010. The 1985 projections were updated in 1988 and incorporated in the Clean Water Plan (DRCOG, 1989).

Population estimates were derived through an extensive survey of existing occupied dwelling units, census records, school pupil enrollment, a vacancy survey, U.S. Postal Service records and vital statistics. Surveys of the area shown in-migration can be attributed to choice as opposed to other exogenous factors such as employment. In projecting 2010 population values, multiple regressions values were derived for area population trends. A 30-year time series was generated from the tabulated information which took into account land availability and zoning constraints. Adjustments were made for areas anticipated to have employment-generating activities (ie. C-470 corridor).

Employment estimates were generated from land use information, an industrial survey and other community or county sources. The bulk of employment is generated by small industries. Future activity center employment was estimated and incorporated into the projections. Adjustments were also made to reflect future market conditions.

The population and employment projections were reviewed by the Task Force and adjustments were made for specific areas based on additional information. The updated population and employment projections were used to determine the entire wastewater flow in the Basin. This flow was divided among individual disposal systems and wastewater treatment systems. The wastewater treatment facility flows are annually updated in the Clean Water Plan to reflect existing conditions (DRCOG, 1989). The facility flow records are maintained as part of the NPDES permit system by the WQCD. Those flows which are not recorded for treatment systems can be assumed as the total septic system wastewater component.

Although land use patterns are not anticipated to change significantly in the next 20 years, population and employment will significantly increase by 2010 (Table 4). Population in both sewered and non-sewered areas will increase from 29,720 in 1988 to 52,975 in 2010. The sewered population is anticipated to increase through 2010 by 58 percent, while the

Table 4. Population, employment and wastewater flows for Bear Creek Basin. The wastewater service areas for the major facilities are shown for the planning years 1985, 1990, 2000 and 2010. The non-sewered projections reflect the large lot development in Jefferson County for the basin.

	1985			1990			2000			2010		
	Pop.	Emp.	WW Flow	Pop.	Emp.	WW Flow	Pop.	Emp.	WW Flow	Pop.	Emp.	WW Flow
W. Jeffco	3,115	900	0.30	3,660	980	0.35	5,070	1,170	0.47	7,010	1,400	0.65
Evergreen	5,710	1,700	0.60	6,195	1,790	0.59	7,285	1,985	0.69	8,570	2,200	0.81
Genesee	3,165	200	0.30	3,400	250	0.30	4,515	390	0.40	4,515	600	0.41
Kittredge	780	250	0.03	840	300	0.08	970	420	0.10	1,125	600	0.12
Morrison	600	200	0.06	760	330	0.08	1,235	890	0.14	2,000	2,400	0.25
Willowbrook	400	100	0.04	450	120	0.04	560	180	0.05	700	270	0.07
El Rancho*	-0-	95	.01	20	165	0.05	135	500	0.10	900	1,500	0.15
Mt. Carbon	-0-	-0-	-0-	-0-	30	0.001	-0-	400	0.02	6,200	5,500	0.72
Conifer	-0-	-0-	-0-	75	40	0.007	130	50	0.013	200	60	0.02
Forest Hills	-0-	-0-	-0-	50	5	0.004	330	20	0.03	415	25	0.04
Mountain	-0-	-0-	-0-	800	100	0.07	1,100	100	0.10	1,100	100	0.10
Non-Sewered	15,950	2,850	1.50	16,725	3,750	1.60	18,400	6,510	1.80	20,240	11,295	2.10

*The El Rancho area will send wastewater flows to the Kittredge facility; wasteflows are greater than indicated by population and employment projections due to large volume of transient visitors.

non-sewered population will increase by 22 percent. Employment will show even greater increases between 1988 and 2010 due to anticipated commercial development. These population and employment increases will result in extensive construction activities within the watershed. There will also be a corresponding increase in wastewater flows from Publicly Owned Treatment Works (POTWs) and septic systems discharging into the streams and tributaries. The projected 2010 wastewater flows are shown in Table 4. The facilities included in Table 4 reflect the anticipated system of facilities required to meet municipal needs.

RESERVOIR AND USES

Bear Creek Reservoir is a flood control facility owned by the U.S. Army Corps of Engineers. The reservoir gate was initially closed in the summer of 1977. The multipurpose pool volume has an average storage capacity of about 1927 Ac-ft with a surface area of 110 acres. The reservoir maintains a static pool level with minor fluctuations dependent on inflows. A summary of engineering data for Bear Creek Reservoir is shown in Table 5.

Bear Creek is the major inflow with an 80-year average flow at the Morrison gage of 54 cubic feet per second (cfs) and from 1986 to 1989 an average of 64 cfs (Table 6). There is a water supply diversion below the Morrison gage which can reduce flows in Bear Creek to near zero in the late summer and fall months. The mean 1986 to 1989 flow into Bear Creek Reservoir was 55 cfs. Bear Creek is a gaining stream from Evergreen Reservoir to the Morrison gaging station. The Harriman and Ward diversions reduced the Bear Creek flow an average of 16 cfs between 1986 to 1989. Bear Creek below the reservoir to the mouth at the South Platte River is a gaining stream with an average increase of 25 cfs.

Turkey Creek is the other major inflow into the reservoir. Turkey Creek flows range from 4 cfs in dry years to 20 cfs in more normal years with a mean 1986 to 1989 flow of 12 cfs. Turkey Creek has been gaged only in recent years.

The City of Lakewood leases the Bear Creek Park surrounding the reservoir for recreational uses from the U.S. Army Corps of Engineers. The lease requires the City of Lakewood to manage the Park in such a manner as to meet the requirements of the Clean Water Act (1972). The Army Corps of Engineers is responsible for operation of the reservoir.

The stream classifications and standards for Bear Creek Basin are shown in Table 7 (CDH, 1990). The reservoir is classified as Class 1 Cold Water Aquatic Life, water supply and agriculture. The reservoir is not directly being used as a water supply. The reservoir is currently classified by the Water Quality Control Commission (WQCC) as Class 1 Recreation with a goal qualifier, which does allow for bodily contact. In 1989, the WQCC, over the opposition of the Jefferson County Mountain Water Quality Association, City of Lakewood and DRCOG, changed the Recreation Classification from Class II (no bodily contact) to Class I with a goal qualifier upon the recommendation of the WQCD.

WATER RIGHTS

Water rights play an important role in the water quality planning for the Basin because several of the ditch systems can divert a substantial portion of the stream flows before Bear Creek

Table 5. Summary of Engineering Data for Bear Creek Reservoir*

	Engineering Data	
GENERAL		
Location of dam	3 mi. S.W. of Denver, Colo.	
River and river mile	Bear Creek	R.M. 8
Drainage area (sq. mi.)	236	
Reservoir length (mi.)	0.5 at el. 5558	
Location of Damtender	At Chatfield Dam	
Travel time to Missouri River	2 weeks	
Max. discharge of record	8,600 cfs	July 1896
Project cost(1)	$61,700,000	
DAM AND EMBANKMENT		
Top of dam -- ft. MSL	5689.5	
Length of dam -- ft.	5,300 -- main 2,100 -- South	
Height of dam -- ft.	179.5 -- main 65 -- South	
Stream bed -- ft. MSL	5,510	
Abutment formation	Clay, shale, siltstone, sandstone	
Type of fill	Rolled earth	
Fill quantity in cu. yds.	11,346,000--main 770,000--South	
Date of closure	Jul. 1977	
Date of initial fill (base F.C.)	May 1979	
SPILLWAY		
Discharge capacity -- cfs	153,500 cfs at el. 5685.5	
Crest elev. -- ft. MSL	5667.0	
Width -- ft.	800	
Gates, number, size, type	Ungated earth channel	
RESERVOIR ELEV. AND AREA		
Maximum pool	5684.5	1237a.
Top of flood control pool	5635.5	715.a.
Top of multipurpose pool	5558.0	107a.
Top of inactive pool	5528.0	17a.
STORAGE ZONES (Elev.-Capacity)		
Surcharge	5635.5-5684.5	47,350AF
Flood Control	5558.0-5635.5	28,757AF
Multipurpose	5528.0-5558.0	1,857AF
Inactive	5510-5528.0	70AF
Gross (top of flood control pool)		30,684AF
OUTLET WORKS		
Number and size -- conduits	1--7 ft. circular--upstream 1--7x10.5 ft.--downstream	
Conduit length -- ft.	1690 ft. Ungated drop inlet--el. 5558.	
Number -- size -- type gates	2--3x6 ft. hydraulic slide 2--1x1 ft. slide--gate on gate	
Discharge capacity	2,160 cfs at el. 5667	
POWER INSTALLATION		
	none	

*U.S. Engineer District - Omaha Corps of Engineer Dams

(1) Costs are as of 9-30-80

Table 6. Gage flow data for Bear Creek Basin from 1986 to 1989. The Bear Creek and Turkey Creek stations are located in the Bear Creek Park and monitored inflows to the reservoir.

Gage	Records	Total Monthly Flow (cfs)	Total Monthly Flow (acre-ft)	Mean Daily Flow (cfs)	Average Daily Flow (MGD)	Minimum Daily Flow (cfs)
Evergreen	24	1551	3075	51	33	34
Morrison	24	1957	3881	64	41	41
Bear Creek	33	1449	2874	48	31	24
Turkey Creek	33	373	739	12	8	6
Reservoir Outflow	32	1662	3296	55	35	26
Bear Creek Sheridan	24	2430	4820	80	51	40

Table 7. Stream Classifications and Water Quality Standards for Bear Creek Basin as Identified by the Water Quality Control Commission

STREAM CLASSIFICATIONS AND WATER QUALITY STANDARDS

Basin: BEAR CREEK STREAM SEGMENT DESCRIPTION	Rec. CLASS 1	Rec. CLASS 2	Aquatic Life CL1 COLD	Aquatic Life CL1 WARM	Aquatic Life CL2 COLD	Aquatic Life CL2 WARM	WATER SUPPLY	AGRICULTURE	PHYSICAL AND BIOLOGICAL	INORGANIC mg/l	METALS mg/l	
Mainstem of Bear Creek from the source to Harrison Ditch. WQCC Segment 1a		X	X				X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	NH_3 = 0.02 Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = 0.05 Cadmium = 0.0007 Chromium (tri) = 0.05 Chromium (hex) = 0.025 Copper = 0.006 Lead = 0.004 Iron (sol) = 0.3 Manganese (sol) = .05	Mercury = 0.00005 Nickel = 0.05 Selenium = 0.01 Silver = 0.0001 Zinc = 0.06 Iron = 1.0 Manganese (tot) = 1.0
Mainstem of Bear Creek from Harrison Ditch to the inlet of Bear Creek Reservoir WQCC Segment 1b		X			X		X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	NH_3 = 0.02 Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = 0.05 Cadmium = 0.0007 Chromium (tri) = 0.05 Chromium (hex) = 0.025 Copper = 0.006 Lead = 0.004 Iron (sol) = 0.3 Manganese (sol) = .05	Mercury = 0.00005 Nickel = 0.05 Selenium = 0.01 Silver = 0.0001 Zinc = 0.06 Iron = 1.0 Manganese (tot) = 1.0
Bear Creek Reservoir WQCC Segment 1c	X		X				X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	NH_3 = 0.02. Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = 0.05 Cadmium = 0.0007 Chromium (tri) = 0.05 Chromium (hex) = 0.025 Copper = 0.006 Lead = 0.004 Iron (sol) = 0.3 Manganese (sol) = .05	Mercury = 0.00005 Nickel = 0.05 Selenium = 0.01 Silver = 0.0001 Zinc = 0.06 Iron = 1.0 Manganese (tot) = 1.0
Mainstem of Bear Creek from the outlet of Bear Creek Reservoir to the confluence with the South Platte River WQCC Segment 2		X		X			X	X	D.O. = 5.0 mg/l pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	NH_3 = 0.06. Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.5 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = 0.05 Cadmium = 0.001 Chromium (tri) = 0.05 Chromium (hex) = 0.025 Copper = 0.01 Lead = 0.025 Iron (sol) = 0.3 Manganese (sol) = .05	Mercury = 0.00005 Nickel = .1 Selenium = 0.01 Silver = 0.0001 Zinc = 0.12 Iron = 1.0 Manganese (tot) = 1.0
All tributaries to Bear Creek, including all lakes and reservoirs, from the source to a point immediately below the confluence with Cub Creek WQCC Segment 3		X	X				X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 200/100 ml	NH_3 = 0.02. Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = TVS Cadmium = TVS Chromium (tri) = TVS Chromium (hex) = TVS Copper = TVS Lead = TVS Iron (sol) = TVS Manganese (sol) = TVS	Mercury = TVS Nickel = TVS Selenium = TVS Silver = TVS Zinc = TVS Iron = TVS Manganese (tot) = TVS
All tributaries to Bear Creek, including all lakes and reservoirs from a point immediately below the confluence with Cub Creek to the confluence with the South Platte River, except for specific listing in segments 4b, 4c, 5 and 6. WQCC Segment 4a		X				X	X	X	D.O. = 5.0 mg/l pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	Cyanide (tot) = .02 S as H_2S = 0.05 Boron = 0.75 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0 Manganese (sol) = .05	Arsenic = 0.05 Cadmium = .01 Chromium (tri) = 0.05 Chromium (hex) = 0.05 Copper = 1.0 Lead = 0.05 Iron (sol) = 0.3	Mercury = 0.002 Selenium = 0.01 Silver = 0.05 Zinc = 5.0
Swede Gulch, including all ponds, lakes, and reservoirs, from its headwaters of its confluence with Kerr Gulch. WQCC Segment 4b	X				X		X	X	D.O. = 6.0 mg/l pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	NH_3 = 0.02. Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = TVS Cadmium = TVS Chromium (tri) = TVS Chromium (hex) = TVS Copper = TVS Lead = TVS Iron (sol) = TVS Manganese (sol) = TVS	Mercury = TVS Nickel = TVS Selenium = TVS Silver = TVS Zinc = TVS
Swede Gulch, including all ponds, lakes, and reservoirs, from its confluence with Kerr Gulch to its confluence with Bear Creek WQCC Segment 4c	X				X		X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 200/100 ml	NH_3 = 0.02. Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = TVS Cadmium = TVS Chromium (tri) = TVS Chromium (hex) = TVS Copper = TVS Lead = TVS Iron (sol) = TVS Manganese (sol) = TVS	Mercury = TVS Nickel = TVS Selenium = TVS Silver = TVS Zinc = TVS
Mainstem of Turkey Creek, including all tributaries, lakes and reservoirs, from the source to the confluence with Bear Creek, except for specific listing in segment 6 WQCC Segment 5		X			X		X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 2000/100 ml	Cyanide (tot) = 0.2 S as H_2S = 0.05 Boron = 0.75 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = TVS Cadmium = TVS Chromium (tri) = TVS Chromium (hex) = TVS Copper = TVS Lead = TVS Iron (sol) = TVS Manganese (sol) = TVS	Mercury = TVS Nickel = TVS Selenium = TVS Silver = TVS Zinc = TVS
Mainstem of North Turkey Creek, from the source to the confluence with Turkey Creek WQCC Segment 6	X		X				X	X	D.O. = 6.0 mg/l 7.0 mg/l (spawning) pH = 6.5 - 9.0 Fecal Coliforms = 200/100 ml	NH_3 = 0.02. Residual C12 = 0.003 Cyanide (free) = .005 S as H_2S = 0.002 Boron = 0.75 Nitrite = 0.05 Nitrate = 10.0 Chloride = 250.0 Sulfate = 250.0	Arsenic = 0.05 Cadmium = 0.0004 Chromium (tri) = 0.05 Chromium (hex) = 0.025 Copper = 0.005 Lead = 0.004 Iron (sol) = 0.3 Manganese (sol) = .05	Mercury = 0.00005 Selenium = 0.01 Silver = 0.0001 Zinc = 5.0 Iron = 1.0 Manganese (tot) = 1.0

Reservoir. Changes in storage levels in the reservoir could effect water quality management strategies and alter the existing physical, chemical and biological characteristics of the reservoir. Therefore, all planning activities must consider the interaction from water rights.

A complex system of water rights control flows in Bear Creek, Turkey Creek and Bear Creek Reservoir. A simplified version of the water rights in the Basin is shown in Figure 3. The water rights for Bear Creek were summarized by DRCOG (1987) for use in wastewater management planning.

Although the reservoir was constructed as a flood control structure, it also serves as a municipal water storage system. This stored water is use-designated for agricultural and drinking water supply, as well as augmentation water supply. Storage rights have been decreed to the Town of Morrison, Indian Hills Water District, the Genesee water and Sanitation District, the Evergreen Metropolitan District, Mount Carbon Metropolitan District and the City of Lakewood.

In 1988, the water right requests for storage totaled 2025 Ac–ft in what is now the flood control pool. There are requests for additional storage space in the reservoir which could change the permanent pool level. The reservoir operations maintain an outflow to match inflow and keep the pool at a fixed volume. Evaporation losses are allocated among the storage rights. There is a groundwater inflow which does not appear to be significant. The annual total inflow to the reservoir during the monitoring period was 41,827 Ac–ft with a total outflow of 39,659 Ac–ft. The annual reservoir surface level remained constant. Therefore, the evapotranspiration loss was 2,168 Ac–ft or 5 percent of the total inflow during the monitoring period.

The assumption used for planning purposes in determining storage rights has been that the permanent pool and the storage accounts are full at the beginning of the water year (October 1) and inflow storage, releases to Bear Creek and evaporative losses will be made based on this condition. Storable flows in excess of releases from the water right accounts and evaporative losses will be credited to storage accounts up to the maximum allowable account contents. Evaporative losses were assigned percentages based on entity allocations.

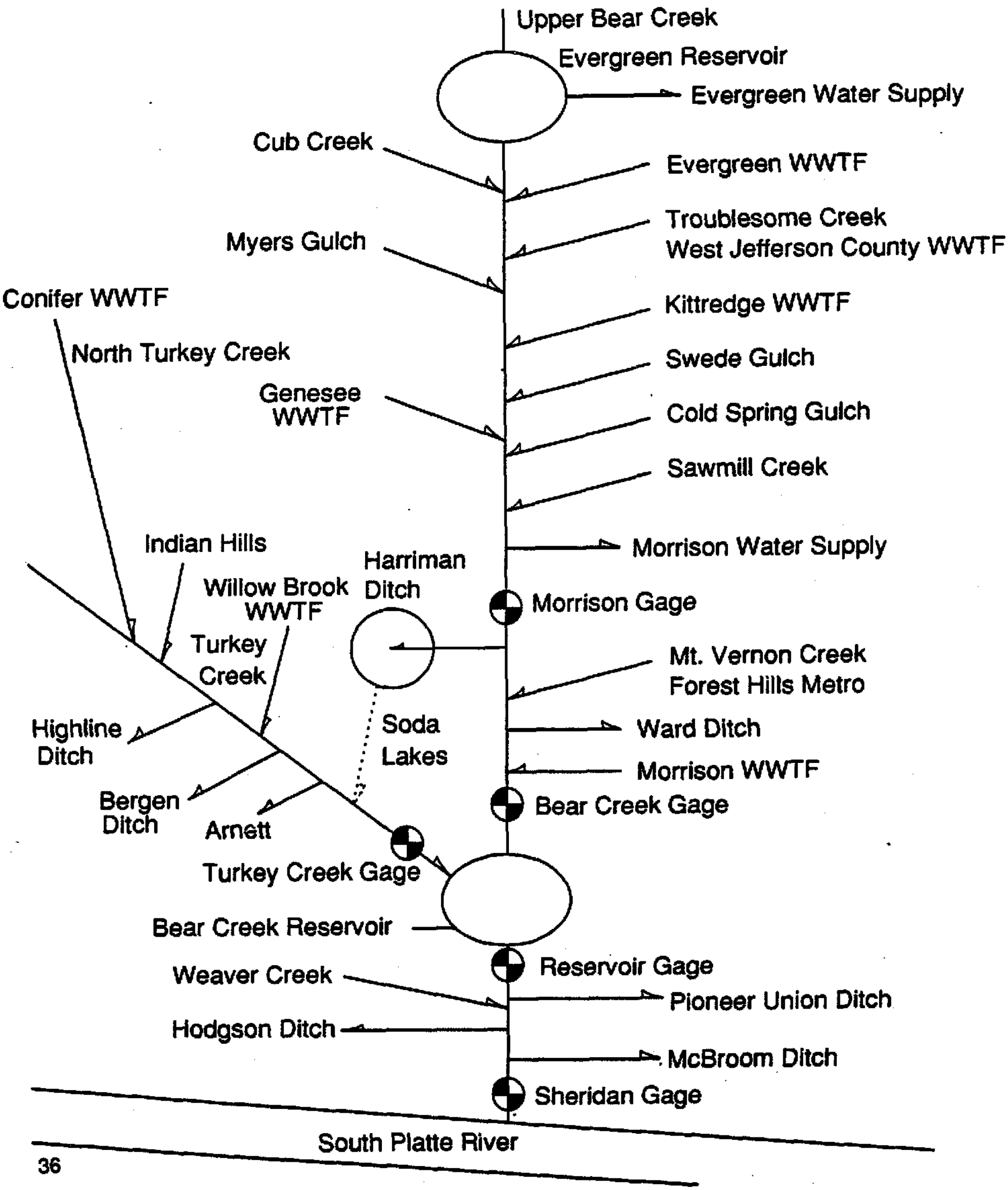
The storage issue is still under consideration by the water court and the U.S. Army of Corps of Engineers. The out–come of storage changes could not be taken into account in model studies at this time. The water quality models can be applied to projected changes in storage volume, once this information is determined by the water court.

In order of their seniority, top five water rights on Bear Creek are: McBroom Ditch (City of Englewood), Simonton Ditch (City of Denver), Hodgson Ditch (Evergreen), Warrior Ditch (Town of Morrison) and Pioneer Union Ditch (Town of Morrison). Except for McBroom Ditch, all water diverted to these ditches is normally carried in the Harriman Ditch.

The Harriman diversion is located below the Morrison USGS gaging station. This diversion removed about 45 percent of the Bear Creek flow in the summer of 1988 during the water quality monitoring program. The annual average diversion is about 30 percent. Water rights can allow the Harriman diversion to remove all flows not decreed to the Ward and Pioneer Union Ditches. The Morrison wastewater treatment facility has a water right which would allow

Figure 3.

Simplified line diagram of water rights on Bear and Turkey Creeks in the Bear Creek Basin.



them to discharge effluent above the Harriman Ditch to meet water right exchange requirements. The effluent discharge is currently below the diversion.

Water diverted into the Harriman Ditch is transferred to a series of reservoirs which are part of the water right system. The reservoirs include Bowles, Johnston, Henry, J.B. Grant A, J.B. Grant B, J.B. Grant C, Interlaken No. 1, Interlaken No. 2, Soda Lake No. 1, Soda Lake No. 2 and Marston. Most of these reservoirs are recognized in the Clean Water Plan as urban lakes which have regional importance.

Water flow from Soda Lakes can be diverted back into Turkey Creek as part of an exchange program by the Denver Water Board. There was some re lease, about 20 cfs for 10 to 12 days, during the water quality monitoring program. No water quality samples were taken during the release period.

The Ward Ditch is the last diversion above Bear Creek Reservoir. This ditch takes 5 to 6 cfs flow from Bear Creek, but leaks about 1.25 cfs back to the reservoir. The Pioneer Union Ditch is located below the reservoir at the stilling pool. This ditch has been taking 5 cfs flow for 24 hours every 10 days and is planning to take 2 cfs continuously. The Hodgson Ditch is located 2.5 miles below the reservoir and it takes 2.5 cfs continuously. There has been about 4 to 5 cfs of natural spring flow or seepage reported above this diversion and below the Pioneer Union diversion Ditch. The McBroom Ditch is located 6 miles below the reservoir and it takes 1 cfs continuously. There has been about 8–10 cfs of natural spring flow or seepage between the Hodgson and McBroom diversions.

There is also a potential for substantial diversion of flows from Turkey Creek. The independent Highline ditch can divert 3 cfs from the Creek for use on the Willowbrook golf course. The Bergen ditch is a junior right below the Independent Highline Ditch which can divert 3 to 4 cfs, if available, and in priority. The Arnett (Harriman) Ditch , which carries Warrior Ditch flows, is the last ditch on Turkey Creek and it can take all flows over 0.5 cfs.

DRCOG (1987) evaluated diversion in Bear Creek from 1977 to 1984. These years were chosen because they coincide with reservoir filling and re presents set of wet, dry and average years. In comparing streamflow, diverted flow and reservoir inflow, the diverted flow equalled the streamflow for 14 percent of the months. This suggests that the entire streamflow was diverted for a portion of these months. No consistent pattern was observed for when diversions occurred on an annual basis. Some water was always diverted in the summer months of May, June, July, August and September, but the amount diverted was very variable. There were diversions in the other months, presumably to satisfy winter or storage rights. The type of water year does not effect the diversions. The average annual diverted flow from Bear Creek was measured at 11,595 Ac–ft per year.

In order to better understand the flow patterns into Bear Creek Reservoir, USGS gaging stations were placed on Bear Creek in May 1986 and Turkey Creek in April 1986 below all diversion points. These stations provided records of actual reservoir inflow (USGS, 1987; 1988; 1989). Based on data from these gaging stations, the annual stream in–flow to the reservoir for the 1988–1989 monitoring period was 33,153 Ac–ft with 29 percent of the flow diverted before discharge into the reservoir.

The average inflow from Turkey Creek as measured at the gaging station from April 1986 to 1989 was found to be greater than previously estimated by the district water commissioner with an average of 8900 Ac–ft in water year 1988. The maximum discharge was measured on May 5, 1987 at 149 cfs, while the minimum was measured on September 6, 1989 at 0.32 cfs. The minimum flow represents a time period when maximum diversion of Turkey Creek occurred.

IV. WATER QUALITY CHARACTERIZATION

MONITORING PROGRAM

Design of the Study

Bear Creek Reservoir and watershed water quality were quantified over a one-year period. The monitoring program was designed to provide detailed information for a few sites in the watershed and at the reservoir. The reservoir stations were sampled at increments in the water column to provide time-series and spatial data. The watershed stations were selected to define water quality characterizations for upper and lower portions of the watershed along two mainstem streams and on the mainstem of Bear Creek below the reservoir.

Watershed and reservoir sampling stations were monitored on a monthly basis for the spring, fall and winter periods with twice monthly sampling for the summer period (May through August). This routine watershed and reservoir monitoring program was supplemented by special data collection programs of more limited scope which were designed to provide specific data about precipitation, groundwater, storm event and tributary stream quality.

Reservoir and watershed stations were monitored from April 1988 through March 1989. A summary of analytical coverage for different kinds of sample programs in the watershed and at the reservoir are shown in Table 8. A summary of the sampling dates for the various sampling programs is shown in Table 9.

The watershed routine monitoring program provided time-series data sets which could be used to evaluate system trends. A tributary stream sampling program provided a spatial evaluation of spring runoff quality at 18 sites within the watershed. Three storm events were monitored in the lower portion of the watershed on Bear Creek and Turkey Creek. These storm monitoring sets assessed changes in water quality at three to four points along the runoff hydrography for each storm.

In view of the geology and hydrology of the Bear Creek Basin, groundwater movement was not anticipated to be a major component of nutrient transfer to the reservoir. However, a groundwater program was initiated to verify this assumption. The quality of alluvial groundwater in the Bear Creek and Turkey Creek drainages were measured in shallow wells along the western edge of the Park. A limited time series groundwater data set was generated for the monitoring year.

There were three sampling stations located within the reservoir. These stations were sampled at selected depths from the top to the bottom of the water column. Vertical profiles were obtained for temperature and dissolved oxygen. Two special studies were done to supplement reservoir data: a phytoplankton profile was done in May, 1988; and a complete bacteria profile was made at one station in February, 1989.

In order to characterize the physical and biological characteristics of the reservoir system, specific surveys were made for macrophytes, hydraulic features, bathymetric mapping and

Table 8. Summary of Analytical Coverage for Sample Programs

Parameter	Reservoir Stations	Routine Stream	Precipitation Station	Groundwater Stations	Tributary Stations	Storm Event
Temperature	X	X		X	X	X
Flow		X			X	X
Specific Conductance	X	X		X	X	X
Transparency	X					
Dissolved Oxygen	X	X			X	X
pH	X	X		X	X	X
Alkalinity	X	X		X	X	X
Suspended Solids	X	X			X	X
Total Coliform	X	X			X	X
Fecal Coliform	X	X		X	X	X
Reactive Phosphorus	X	X		X	X	X
Soluble Phosphorus	X	X		X	X	X
Particulate Phosphorus	X	X		X	X	X
Total Phosphorus	X	X	X	X	X	X
Ammonia-Nitrogen	X	X		X	X	X
Nitrate-Nitrogen	X	X		X	X	X
Dissolved Nitrogen	X	X	X	X	X	X
Particulate Nitrogen	X	X		X	X	X
Cholorphyll a	X					
Phytoplankton	X					

Table 9. Summary of Sampling Dates

Reservoir Stations	Routine Stream	Precip. Station	Groundwater Stations	Tributary Stations	Storm Event
-	-	Start	-	-	-
-	-	28 MAR	-	-	-
12 APR	12 APR	18 APR	-	-	-
3 MAY	3 MAY	3 MAY	-	-	2-4 MAY
-	-	-	-	17 MAY	19-20 MAY
24 MAY*	24 MAY	24 MAY	-	-	-
7 JUN	7 JUN	7 JUN	7 JUN	-	-
21 JUN	21 JUN	21 JUN	-	-	-
5 JUL	5 JUL	5 JUL	-	-	-
19 JUL	19 JUL	-	-	-	-
2 AUG	2 AUG	2 AUG	2 AUG	-	-
16 AUG	16 AUG	16 AUG	-	-	-
13 SEP*	13 SEP	13 SEP	-	-	12-15 SEP
16 OCT	16 OCT	16 OCT	-	-	-
8 NOV	8 NOV	8 NOV	8 NOV	-	-
6 DEC	6 DEC	6 DEC	6 DEC	-	-
10 JAN	10 JAN	10 JAN	-	-	-
8 FEB*	8 FEB	8 FEB	8 FEB	-	-
7 MAR	7 MAR	7 MAR	7 MAR	-	-

*-special reservoir studies were conducted in conjunction with water sampling program.

biological resources. The macrophyte surveys were designed to assess the attached water plant distribution and relative abundance in the growing season. The hydraulic data included surface area, maximum and mean depth, hydraulic residence time, changes to reservoir configuration through time, area of the watershed and other associated data as required for data analyses. The bathymetric surveys would be used to evaluate changes to reservoir con tours and assess the issue of sediment infilling. The biological communities associated with the Park were documented.

<u>Methods</u>

Watershed

There were four routine sampling stations selected for the watershed. The lower Bear Creek and Turkey Creek stations were located at the western side of the Park. The lower Bear Creek station was located at the bridge near the discharge point from Rooney Gulch. This sampling station was sited downstream of all wastewater discharge points and agricultural supply removal ditches.

The lower Turkey Creek station was located at the maintenance shop bridge near the Soda Lakes bypass. The Denver Water Board uses Soda Lakes as a water supply storage reservoir and has the ability to discharge flows into Turkey Creek via a pipeline. The station was downstream of this discharge bypass.

The upper Bear Creek station was located below Evergreen Lake in the Town of Evergreen. The site is at the confluence of Cub Creek, which drains the upper portion of the watershed, and Bear Creek. Evergreen Lake is fed by upper Bear Creek, which was not part of the study area. There are six wastewater treatment facility discharges between the upper and lower Bear Creek stations. The majority of urban development in the Bear Creek portion of the watershed also occur between these stations. There are two small wastewater treatment facilities located on Upper Bear Creek.

A stream station was sited at the discharge from Bear Creek Reservoir. This station was established as a means of assessing outflow water quality from the reservoir system. Water quality monitoring at this station was the same as the other watershed sites.

Stream samples were collected with laboratory–cleaned polyethylene sample bottles held just below the water surface at the prescribed stream stations. Bottles were faced into the current for filling. Care was taken not to disturb the stream bottom near the sampling site.

The upper Turkey Creek station was located at the confluence of North and South Turkey Creeks. The upper station location characterized water quality from a major portion of the watershed. There are several small development centers located in the upper watershed which can be classified as having urban density [greater than one dwelling unit per acre]. This upper basin has one small wastewater treatment facility. This facility discharges into North Turkey Creek. A major inflow into the mainstem of Turkey Creek below the confluence drains the Indian Hills area. This area has been previously identified by Jefferson County as having groundwater contaminated by nitrates exceeding Colorado standards. This nitrate problem has been attributed to numerous failed septic systems.

There is one wastewater treatment facility discharging into the mainstem of Turkey Creek between the upper and lower stations. An additional reason for siting the upper Turkey Creek station so low in the watershed was freezing of the stream in the winter months. The confluence station generally had year-round flows.

Groundwater quality was measured in two shallow alluvial aquifers along Turkey and Bear Creeks near the western portion of Bear Creek Park. The parameters measured included the nitrogen and phosphorus species, specific conductance, alkalinity, particulate matter, temperature and fecal coliform bacteria. Samples were taken from non-pumping water wells.

Reservoir

Three reservoir stations were sited with one station in each arm of the reservoir and one station in the deeper central pool. There were three depths sampled for the arm stations: surface (about -0.5m); mid-water (about -2m); and +1m above the bottom (about -3.5m). The central pool *index* station was profiled at seven depths: -0.5m, -2m, -3.5m, -5m, -6.5m, -8m and +1m above the bottom. Station depths were selected to characterize water quality in the epilimnion, thermocline-transition and hypolimnion. A thermal profile was made at the index station.

Bulk precipitation (combination of dryfall and wet precipitation) was continuously measured to assess the total contribution of nitrogen and phosphorus components resulting from atmospheric deposition. The monitoring site was located near the southwest corner of Bear Creek Park (maintenance shops). The atmospheric sampler was designed after the sampler described in Lewis et al. (1984).

The water quality sampling parameters and methods are shown in Table 10. Field measurements were made for temperature, transparency, light transmittance, pH and stream flow. Water temperatures were measured in the streams and at the reservoir stations with a YSI thermistor and submersible probe. Transparency of the reservoir was determined by secchi disk and optically with a submersible photometer. Light transmittance measurements were made to limits of detection with a quantum sensor. Discharge was measured by the method of velocity-weighted cross sections using a Marsh-McBirney flow meter. Initial pH measurements were made in the field for comparison with laboratory analyses. Laboratory pH measurements were made with a Radiometer pH meter and combination electrode on an un-stirred sample. The field and laboratory pH values were consistent.

Lake samples were collected with a vertical Van Dorn bottle at specific depths. Unfiltered water was transferred immediately to laboratory-cleaned polyethylene bottles. Bottles were stored in a dark cooler for transport to the laboratory. Special precautions, including taped sample bottles and a dark storage box, were taken to protect the reservoir chlorophyll α samples from exposure to light. Oxygen samples were collected by the method outlined in Standard Methods (APHA, 1985).

Samples were filtered immediately after collection through Whatman GF/C glass-fiber filters, which have an effective pore size of 0.7 um (Sheldon, 1972). The purpose of the immediate filtration was to reduce biological activity to a minimal level without the addition of preservatives which could affect chemical test procedures.

Table 10. Summary of Analytical Methods

Parameter	Units	Method
Temperature	Degree C	Thermister (APHA 1985)
Flow	Cubic ft/sec	Marsh-McBirney meter
Conductance	u Seimens	Conductance meter (APHA 1985)
Transparency	% Transmittance	Quantum sensor
Diss. Oxygen	mg/l	Winkler titration (APHA 1985)
pH	Standard Unit	pH meter (APHA 1885)
Alkalinity	mg/l	Acid titration (APHA 1985)
S. Solids	mg/l	Glassfiber filter (APHA 1985)
T. Coliform	Cts/100ml	Membrane filter (APHA 1985)
F. Coliform	Cts/100ml	Membrane filter (APHA 1985)
Reactive Phosphorus	PPB	Ascorbic acid-molybdate (Murphy and Riley 1962)
Soluble Phosphorus	PPB	Acid-molybdate/ digestion (Murphy and Riley 1962)
Partic. Phosphorus	PPB	Pyrolysis and acid-molybdate (Solorzano and Sharp 1980)
Total Phosphorus	PPB	Calculation (APHA 1985)
Ammonia-Nitrogen	PPB	Phenolhypochlorite (Grasshoff 1976)
Nitrate-Nitrogen	PPB	Chromatography (APHA 1985)
Diss. Nitrogen	PPB	Oxidation/ azo dye formation (Bendschneider and Robinson 1952)
Partic. Nitrogen	PPB	Elemental Analyzer (Pregl and Dumas method)
Cholorphyll a	ug/l	Methanol extraction (Marker et al 1980)

Phytoplankton samples were taken from the photic zone with one set of complete vertical profile samples. The samples were taken with the Van Dorn sampler. Samples were preserved in the field with Lugol's solution. Samples were counted with an inverted microscope. This allows for small cells to be identified and counted. The phytoplankton counts were replicated with good agreement between samples.

A zooplankton sample was collected from the index station with a tow-net of 37 micro-meter mesh. Three vertical samples were collected for analyses. The zooplankton were preserved in buffered formalin. Species composition and general abundance was made by viewing aliquonts through a stereo-microscope.

Bathymetric surveys of Bear Creek Reservoir were made with a recording fathometer and transducer. The transducer was clamped off the stern of the boat and was deeper than the keel to avoid affects from boat generated bubbles. Transect lines were selected with mappable beginning and ending points as seen on aerial photographs. The boat ran at a uniform speed along these transect lines by following a fixed compass reading. The depth reading was calibrated against a survey rod in four to five feet of water and a depth sounding at 30 feet. The calibration marks were used to correct for any measurable depth differences in the ranges of 0-15 feet, 0-30 feet and 0-60 feet. The readings are accurate within one inch at five feet of depth for the 0-15 feet range and six inches at 30 feet.

Strip chart recordings of bottom configurations were made for each transect. Timing marks at 30-second intervals were scribed on the recording. These timing marks were used to establish distance traveled along transect and correct for variation in boat speed. The total transect length was established from the aerial maps. There were eight transects made for the reservoir. There were two transects made along the east-west axis of the reservoir from the stream inlets to the dam. North-south transects were made across the arms and central pool.

The U.S. Army Corps of Engineers ran survey transects across the reservoir and upland areas adjacent to the reservoir. The initial surveys in 1976 and 1977 were used to produce a topographic map of the reservoir prior to filling. Subsequent U.S. Army Corps of Engineers surveys were made in September 1980, April 1984 and June 1987. These surveys were made to assess changes in topography. The Bathymetric surveys were compared against the initial topographic map and subsequent surveys.

Sediment deltas formed at the mouths of Bear Creek and Turkey Creek were surveyed. Standard survey methods were employed to measure fixed transects across the delta surfaces into the reservoir. The top-set and fore-set beds were quantified. Examination of time-series aerial photographs had shown delta migration into the reservoir. Permanent back-sights were located at both deltas and transects were run along measured distances through a fixed compass reading. Delta configurations were surveyed by DRCOG staff in August 1988 and October 1988.

Generally water currents in reservoirs are to slow for measurement with standard current meters, except at point of discharge. Flow meter measurements in the reservoir were not attempted because of the lack of success in similar reservoirs in Colorado. In order to assess gross movements of water in the reservoir and determine the presence or absence of short-circuiting, currents were measured using drift drogues.

These drogues were made of thin 0.5m sheet aluminum vanes in a cross shape (as seen in transverse section) suspended from a buoy by a length of line. The line depths could be varied to evaluate flows at various depths. The lift of the buoy was adjusted to keep surface exposure of the buoy to a minimum. Line lengths ranged from 1m to 3m. There were five buoys with varying lengths released at each inlet and in the central pool near the index station. Wind speed and direction was recorded at the time of release and for time intervals through the drogue drift period. Drogues were allowed to drift for one to three hours. Locations of buoys were recorded on maps and by triangulation with a hand-bearing compass. Movement of the drogue were recorded at interval through the drift period.

Buoy movements were mapped and distances measured from the mapped lines. Current studies were made in August 1988 with light wind conditions and October 1988 with no wind conditions. Current movements were measurable with the existing drogue design only to a maximum depth of 3m. The deeper depths had such low flow characteristics that detection of movement could not be measured using hand-bearing compass triangulation. There were measurable differences in flow directions and speeds between 1m and 2m depths.

Aquatic plant coverage was assessed by quantifying algal attachment along transects perpendicular to the shoreline. Transect lines were generally 10m or less. The transect lines were snorkeled and density and type of aquatic plant coverage recorded. The number of plants on the transect line were counted and the coverage was converted to density per square meter. Aquatic plant transect lines were run at about 20 locations around the reservoir. Surveys were made in August 1988.

In order to assess the sedimentation or infilling rate, a sediment trap system was designed for the reservoir. Sediment traps consisted of 0.5m high PVC pipes with a 5-cm internal diameter, sealed at one end with a PVC cap. Tubes were vertically attached in groups of three to rebar frames. The rebar frames had legs which kept the structure off the reservoir bottom. The tops of the tubes were at 0.75m above the substratum. The sediment tubes trap the *sediment fallout* with some re-suspension material also trapped. This re-suspension quantity is generally minimal. The sediment traps were attached to a harness and surface buoy. Traps were deployed for periods of time ranging from 30 to 60 days. There was a high trap loss from tampering during the summer fishing season. Traps were deployed at six locations in the reservoir: reservoir inlets; eastern edge of the reservoir arms; at the index station; and near the outlet structure.

The volume of wet sediment recovered from each trap was measured with an Imhoff Cone. The water was decanted-off and the sediments were dried at 125 °C for 48 hours. The dried sediments were weighted to the nearest gram. Selected samples were ashed to determine percent of organic matter (APHA, 1985).

Algal coverage estimates were made at selected points along Bear Creek and Turkey Creek within the Bear Creek Park boundary. The algal coverage of stream substrata was made in March and April 1989.

Fish collections were made on two dates: April 18 and 27, 1989. The Division of Wildlife provided assistance with both sampling programs. The first collection was made with the Division of Wildlife electro-shock boat. The reservoir was swept along the shoreline in both inlets, along the south shoreline and at the outlet structure.

The second sampling was made using an experimental gill net with varying mesh sizes. The gill net was deployed along the shoreline in both the inlet areas. Collected fish were placed in pre-cleaned plastic-wrap, placed on ice and immediately transported to the laboratory for processing.

Tissue samples were taken from the fish in the collection within 2 hours of collection using an acid-washed scalpel and de-ionized water rinse. Tissue samples were rinsed with double de-ionized water. Dorsal muscle samples were placed in pre-cleaned bags and placed in ultra-cold storage. Ten selected samples were analyzed for total mercury. The tissue was analyzed by AA-cold vapor according to the USEPA protocol (EPA 600/4-81-055). The moisture percentage between sample ranged from 49 to 61 percent.

Laboratory

The laboratory analyses were performed by Western Environmental Analysts Inc. at the Limnological Laboratory at the Colorado University, Boulder.

Conductance was measured in the laboratory with a Labline Model MC-1 meter standardized against KCl on unfiltered water samples. Measured conductance was corrected to specific conductance at 25 °C with the table in Golterman and Clymo (1969). Alkalinity was measured by potentiometric titration of a 100-ml aliquot of unfiltered sample to a fixed end point (pH 4.5) as described in Standard Methods (APHA, 1985). Dissolved oxygen concentration was determined by the azide modification of the Winkler method (APHA 1985).

The laboratory chemical methods and test procedures used in the Bear Creek study were similar to those used in the Dillon Reservoir eutrophication and land use study (Lewis et al., 1984). The test methods were also similar to those used in the Cherry Creek Reservoir and Chatfield Clean Lakes Studies (DRCOG, 1984a; 1984b). The detection levels for phosphorus compounds in the previous clean lakes studies were in the parts per million range, while they were measured in the part per billion range for this study. The detection level for phosphorus was an issue raised by the Water Quality Control Commission in recent hearings to evaluate phosphorus standards on other waterbodies in the region.

Soluble ortho-phosphorus or ortho-phosphorus was determined by an ascorbic acid-molybdate method (Murphy and Riley, 1962). A 10-cm cell was used for low detection levels of phosphorus which allowed measurement limits to one part per billion. The soluble ortho-phosphorus fraction will typically include orthophosphate and some organic phosphorus of low molecular weight (Rigler, 1968; Levine and Schindler, 1980). Total dissolved phosphorus was measured by the same technique after digestion with persulfate in an autoclave at 121 °C. Particulate phosphorus was retained on a pre-combusted filter, oxidized to orthophosphate by pyrolysis, and measured by the acid-molybdate method (Solorzano and Sharp, 1980a). Addition of particulate phosphorus and total soluble phosphorus yields total phosphorus.

Nitrate was measured by ion chromatography with a Dionex Model 2110 chromatograph and bicarbonate eluant. This ion method is highly sensitive with a low error variance. Ammonium concentrations were measured in triplicate by a modified Solorzano's phenolhypochlorite method. An indophenol blue reaction is spectrophotometrically measured with a 10–cm cell to determine ammonium. Total dissolved nitrogen was oxidized to nitrate with persulfate under alkaline conditions (modified slightly from Solorzano and Sharp, 1980b). The resultant nitrate was further reduced to nitrite with a cadmium–copper couple and measured by formation of an azo dye (Bendschneider and Robinson, 1952; Wood et al., 1967). Particulate nitrogen was retained on a tared filter, dried at 60 °C, and reweighed to the nearest 0.01 mg. Nitrogen content was measured by a modified method with a Carlo Erba Model 1106 Elemental Analyzer. The instrument was calibrated with reagent–grade EDTA and performance was checked against orchard leaves (National Bureau of Standards, Standard Reference Material No. 1571).

Samples for chlorophyll α analysis were filtered on Whatman GF/C filters and the chlorophyll α was extracted in hot methanol (Marker et al., 1980). Chlorophyll α concentrations were calculated from spectrophotometric measurements after correction for pheophytin. Occasional samples were compared with HPLC measurements to verify accuracy.

Total and fecal coliform counts were determined by the membrane filter technique as outlined in Standard Methods (APHA, 1985). The M–endo medium was used for total coliforms, and the M–FC medium was used for fecal coliforms.

Quality Assurance

A quality assurance program was conducted on the water chemistry and biological analyses. Analytical replication, field replication and spike recovery tests were conducted for selected nutrients and physical parameters (Table 11). Analytical replicates were run for about ten percent of the dissolved oxygen, nitrogen and phosphorus analyses (Table 11). Fewer replicates were run for pH, specific conductance and alkalinity. The degree of variability can be evaluated by the ratio of standard deviation to the mean which is the coefficient of variation (CV), expressed as a percent. The CV for most of the replicated parameters are low and acceptable. The highest variation occurs for total dissolved nitrogen. This variation can be attributed to the pH sensitivity of the test, but was not considered as a problem in the interpretation of the results (Lewis et al., 1984).

Field replicate samples were collected for water quality parameters (Table 11). The CV for most nutrients, dissolved oxygen, pH, specific conductance and alkalinity were very low and in acceptable limits. The CV was higher for particulate nitrogen, particulate phosphorus, ammonia nitrogen, chlorophyll α ,total suspended sediments and coliform bacteria. The particulate and coliform variations can be attributed to the distribution of particles and bacteria colonies in the streams rather to variations in test methods. According to Dr. Lewis (personnel communication), the ammonia variation was a result of the low sample concentrations and sensitivity of the method. The chlorophyll α variation is similar to the replicate tests conducted for Dillon Reservoir (Lewis et al., 1984).

Spike recovery analyses were made for specific nitrogen and phosphorus species (Table 11). The percent recovery and number of spikes are shown in Table 11. The recovery was good

Table 11. Quality Assurance Results for Selected Parameters

Analytical Replication

Parameter	Number Replicate	Mean	Standard Deviation	CV (%)
Reactive Phosphorus	45.0	95.9	1.5	1.6
Dissolved Phosphorus	45.0	112.5	2.3	2.0
Ammonia-Nitrogen	42.0	113.7	10.7	9.5
Nitrate-Nitrogen	41.0	385.1	6.9	1.8
Dissolved Nitrogen	36.0	897.4	129.2	14.4
Dissolved Oxygen	36.0	8.4	0.1	1.1
pH	7.0	7.9	0.1	1.5
Specific Conductance	8.0	437.0	3.3	0.7
Alkalinity	7.0	87.6	1.3	1.5

Field Replicates

Parameter	Number Replicate	Mean	Standard Deviation	CV (%)
Reactive Phosphorus	28.0	89.8	2.6	2.9
Dissolved Phosphorus	29.0	109.3	4.8	4.4
Particulate Phosphorus	28.0	25.7	3.0	11.7
Ammonia-Nitrogen	29.0	92.2	13.8	14.9
Nitrate-Nitrogen	26.0	364.8	4.2	1.2
Dissolved Nitrogen	27.0	963.1	92.6	9.6
Particulate Nitrogen	22.0	86.4	17.9	20.8
Dissolved Oxygen	29.0	7.7	0.3	4.2
pH	30.0	7.9	0.1	0.8
Specific Conductance	31.0	296.2	3.6	1.2
Alkalinity	30.0	69.0	3.2	4.6
Chlorophyll	12.0	12.9	1.7	13.3
Suspended Sediments	29.0	11.6	1.6	14.1
Total Coliform	11.0	12.1	4.1	33.9
Fecal Coliform	12.0	5.8	3.2	54.8

and dissolved nitrogen. These nitrogen species also showed greater variance in replication studies.

WASTEWATER FACILITIES

Nutrient and sediment loadings are derived from both point and nonpoint sources. The point source loads are derived from a series of wastewater treatment facilities: Evergreen, West Jefferson County, Kittredge, Genesee, Forest Hills Metro, Morrison, Willowbrook, Conifer and several other small facilities. These facilities are secondary treatment with discharges into Bear and Turkey Creeks. The nonpoint source loadings are a result of urban runoff, construction activities, grazing land management, and to a lesser extent, agriculture and past mining operations. Analyses of water quality data shows both point and nonpoint source control strategies will be required to reduce source loadings.

Evaluations of existing wastewater treatment facilities effluent quality were made for the Evergreen, West Jefferson County, Kittredge, Genesee, Forest Hills Metro, Morrison, Willowbrook and Conifer facilities. The effluent concentrations and annual loads (using a running average) were determined for suspended solids, biological oxygen demand (five–day), ammonia–nitrogen, nitrate–nitrogen and reactive phosphorus. Summaries of the 1988–1989 (one–year) effluent data are shown in Tables A1 to A7 for each facility.

The mean water quality of effluent for all wastewater discharges is shown in Table 12. The mean phosphorus concentration of effluent was 6.0 mg/ℓ. The mean nitrate–nitrogen concentration of effluent was 13.4 mg/ℓ which produced a mean daily load of 30 pounds. The annual and daily loads from each POTW are shown in Table 13. The streams loads to the reservoir by point and nonpoint source are tabulated in Table 14, which includes the entire point source load produced by the POTWs. A percentage of the point and nonpoint source load is diverted by the ditches. The downstream pounds shown in Table 14 represent actual loads reaching the reservoir.

Facility Quality and Loading

The load data was tabulated for total suspended solids, 5–day biological oxygen demand, ammonia–nitrogen, nitrate–nitrogen, and ortho–phosphorus (Table 13). Evergreen Metro and West Jefferson County facilities are the major dischargers of nitrate–nitrogen phosphorus. The annual point source contribution of nitrate from all wastewater facilities was about 30,000 pounds per year with about 9,000 pounds diverted by ditch systems. The annual phosphorus load from these facilities was about 15,000 pounds with about 4,500 pounds diverted by ditch systems. Although the ammonia load from effluent is about 12,000 pounds, about 45 percent of this nitrogen species is converted into nitrate before entering the reservoir. The ammonia loading is being evaluated in a stream model as part of the management report for Bear Creek Basin.

Table 14 evaluates the background contributions to the reservoir for particulate matter (suspended sediments), ammonia–nitrogen, nitrate– nitrogen and reactive phosphorus. The downstream load is based on total discharge into the reservoir excluding precipitation loadings.

Table 12. Mean Effluent Wastewater Discharge Quality at Major Treatment Facilities

		MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
EFFLUENT DISCHARGE	gpd	236,592	165,112	3,000	806600
TOTAL SUSPENDED SOLIDS	mg/l	3.6	3.8	0.4	33.0
5-DAY BIOLOGICAL OXYGEN DEMAND	mg/l	4.4	3.3	0.0	19.0
PERCENT BOD REMOVAL	%	97.3	2.3	77.0	100.0
FECAL COLIFORM	cts/100ml	328	1612	0	26800
AMMONIA	mg/l	3.1	4.7	0.0	25.3
NITRATE	mg/l	13.4	9.3	0.1	40.3
ORTHO PHOSPHORUS	mg/l	6.0	2.9	1.0	20.0
TSS LOAD	#/day	5.6	4.6	0.1	32.5
BOD LOAD	#/day	7.8	6.3	0.0	48.8
AMMONIA-NITROGEN LOAD	#/day	5.1	10.4	0.0	83.3
NITRATE-NITROGEN LOAD	#/day	30	26	0	135
ORTHO-PHOSPHORUS LOAD	#/day	11	6	1	32

Table 13. Mean Effluent Loading to Bear Creek and Turkey Creek from Wastewater Treatment Facilities

Facility	TSS	BOD	Ammonia	Nitrate	Phosphorus					
	#/day	#/year	#/day	#/year	#/day	#/year	#/day	#/year	#/day	#/year
Willowspring	2.64	965.1	2.86	1043.9	5.12	1869.9	1.35	492.4	5.30	1934.9
Forest Hills Metro	0.50	18.2	0.07	24.5	0.03	9.1	03	110	0.25	-91
Morrison	2.55	930.4	2.06	753.4	2.05	746.4	0.25	89.8	1.50	546.0
Genessee	5.67	2069.6	10.80	3942.0	12.44	4540.6	20.1	7351	4.01	1463.7
Kittredge	3.75	1366.9	2.94	1071.3	1.00	365.7	4.53	1654.2	2.62	954.5
West Jeff Co	5.76	2102.8	7.36	2687.5	3.05	1113.3	26.63	9720.0	12.62	4605.9
Evergreen Metro	6.98	2548.8	10.70	3906.2	8.27	3018.6	46.86	17105.4	13.73	5012.5
Point Source Max Load	10,001.8		13,428.8		11,679.0		36,522.8		14,608	

Table 14. Annual Loading of Sediments and Nutrients from Bear and Turkey Creeks.

Source	Particulate Matter (Pounds/year)	Total Ammonia Nitrogen (Pounds/year)	Total Nitrate Nitrogen (Pounds/year)	Ortho-Phosphorus (pounds/year)
Upstream Load (Background)	31,360	43	296	66
Point Source[1] (Actual)	10,000	11,680	30,060	14,610
Point Source[2] (Estimate)	7,000	about 5,000	21,050	10,225
Nonpoint Load (Estimate)	2,593,000	unknown	92,970	20,995
Total Load Reservoir	2,600,000	5,225	114,020	31,220

1 - Total load from point sources which does not represent the total load to the reservoir. On an annual basis, 30 percent of these pounds are diverted before reaching the reservoir.

2 - Estimated annual load which could reach the reservoir.

There is about 2,600,000 pounds of particulate matter (small fraction of entire bed–load) as suspended solids reaching the reservoir on an annual basis. The contribution from all point sources is very small (about 0.4%). The upstream value accounts for 1.5 percent of the total load. The suspended sediment load is derived from basin erosion associated with development, highway construction and stream bank erosion.

The ammonia load is primarily from point sources with an upstream value of 43 pounds per year. The upstream concentrations and loads of nitrate and total phosphorus are relatively low at 296 pounds and 66 pounds, respectively. The annual nitrate load to the reservoir was about 115,000 pounds, with about 27 percent from point sources. The annual total phosphorus as stream load was about 32,400 pounds with 33 percent from point sources. The annual total phosphorus load to Bear Creek was similar to loadings measured in Chatfield Reservoir.

Sources and quantities of phosphorus in domestic wastewater are variable and dependent on the potential sources in the service area. The phosphorus loads from the major POTW's in Bear Creek Basin were variable between facilities and for different seasons. However, similar seasonal loads were measured at facilities.

SEPTIC SYSTEMS

Since the major type of urban development occurring in their Basin is large lot with single families, there is a reliance on individual disposal systems. These systems use engineered leach fields to treat wastewater effluent.

Septic system effluent discharged into leach fields carry various constituents which may reach and degrade groundwater and surface water quality. Effluents contain natural chemicals, such as nitrate and phosphorus, and other manufactured chemicals common to households, such as cleaners and solvents. There are also bacterial and other biological constituents in the discharges. The soils in and underlying a leach field act as filter to remove various constituents in the wastewater be fore reaching the groundwater aquifer.

Soil deposition in the mountainous areas are generally thin with greater accumulations in the valleys. Most of the soils are coarse–grained, very permeable and have little filtering capacity. In areas where soil has developed on bedrock, the soil essentially has no filtering capacity. The average depth to bedrock over most of the Basin is less than 20 feet with most of the interval composed of partly decomposed bedrock. This type of soil development is unsuitable for leach field filtering.

The processed wastewater from septic systems filters into the saturated groundwater zone and then migrates into adjacent gulches and streams. Since much of the Basin has soils poorly suited for leach fields, there is a potential for a significant water quality problem related to septic systems. If the septic tank and leach field system is not functioning according to design, then septic systems pollutants can reach the streams with little or no filtering. The problems with septic systems in the mountainous regions of Jefferson County have been recognized since the early 1970's. Septic system effluents have contaminated the potable groundwater wells in the Indian Hills area. The area of Idledale also relies on septic systems for wastewater disposal. The water quality data from this area has shown common septic system failure (Holstra and Hall, 1975).

The average household produces between 200 and 250 gallons per dwelling unit of effluent when using a septic tank and leach field system (Kaplan, 1988). There are about 6,500 large lot developments using individual disposal systems in 1989 for Bear Creek Basin. Based on population and employment estimates, the estimated total effluent discharge is about 1.6 million gallons per day (MGD) from septic systems which is below the average literature estimates. Some of this septic system flow will be contributed to the groundwater system, while the remainder reaches the streams and ultimately the reservoir.

Total septic system wastewater contributes about 1,800 Ac–ft per year to the basin water budget, which is about 4 percent of the annual surface runoff. The septic system annual flow is anticipated to increase to about 2,350 Ac–ft by the year 2010, which would be about 6 percent of the annual surface flow. In contrast, the 1989 existing wastewater treatment facilities contribute about 4 percent of the annual surface flow with an estimated increase to 9 percent by 2010.

There is not a significant problem in the watershed from bacterial contamination. Although fecal coliform bacteria are periodically detected in surface waters, the mean values are below the water quality classification requirements of 200 counts per 100 ml.

There are increased bacteria levels in Turkey and Bear Creeks as measured from the headwater sampling points to the inflow into the reservoir. Although this increase can be contributed to point and nonpoint source loadings, point source are suspected of making the major contribution. Generally, the leach field systems appear to be filtering out most of the bacteria.

There is a build–up of nitrate in groundwater when individual disposal systems are used in conjunction with groundwater wells. The build–up is caused by the recycling of water between wells and septic systems. Removal of solids from the septic tanks can reduce some nitrogen by reducing ammonia concentrations. There are increasing nitrate levels occurring as a result of urban development. Nitrate concentrations in groundwater aquifers will require continued monitoring and assessment.

For planning purposes, the worst case septic system loadings were estimated from literature information which made the total volume greater than predicted from population and employment estimates. A major source of nonpoint phosphorus is suspected to come from septic systems. The average phosphorus concentration in effluent ranges from 10 to 14 mg/ℓ. This phosphorus has been associated with household use of high phosphorus detergents (Kaplan, 1988).

Assuming the worst case concentrations, the maximum amount of phosphorus from septic systems can be determined for the Basin. The unsewered population and employment in the basin was determined for the years 1985, 1990, 2000 and 2010 (Table 4). The following table is designed to bracket potential septic system phosphorus loads by assuming two levels of natural phosphorus removal and not predict the actual contribution to the reservoir:

YEAR	TOTAL VOLUME Ac-ft	PHOSPHORUS 75% FILTERED TOTAL POUNDS	% ANNUAL FLOW	PHOSPHORUS 90% FILTERED TOTAL POUNDS	% ANNUAL FLOW
1985	1700	16,000	51	6400	20
1990	1800	17,100	55	6850	22
2000	2000	19,000	61	7620	24
2010	2350	22,400	72	8950	29

A worst case estimated pounds of phosphorus produced by septic systems which assumes 25 percent of the phosphorus from leach fields reaches waterways in 1990 measured about 17,000 pounds. This contribution would be about 55 percent of the total annual phosphorus load to Bear Creek Reservoir. Since there will be a high degree of filtering occurring from leach fields and other soil layers, the total pounds of phosphorus will be less than the 17,000 pounds. If there is 90 percent removal, then the annual phosphorus load will be 6850 pounds or 22 percent of the annual load. The in-stream water quality data suggests that the percent removal of constituents from septic system effluents by leach fields is about 75 to 90 percent. The assumed average discharge of phosphorus with 90 percent removal for 2010 is about 9000 pounds or 29 percent of the annual load.

Point source loads of phosphorus account for 33 percent of the annual load in the basin. There are about 22,000 pounds of nonpoint source phosphorus discharged into the reservoir on an annual basis. Assuming that there is about 90 percent filtering of septic effluent constituents before reaching waterways, then the septic system contribution portion of the nonpoint source load is about 31 percent of the total poundage. Phosphorus loading from septic systems could be a significant factor in basin management and a phosphorus source management strategy should be considered in the management plan.

The use of individual disposal systems will continue to occur in Bear Creek Basin as a result of the land use development trend of large lots. These septic systems have the potential to adversely affect water quality throughout the basin and in Bear Creek Reservoir. Jefferson County has currently placed a moratorium on construction of new septic systems in the area of Indian Hills. In this area, there has been a health risk potential for contamination of potable waterwells from septic effluents. Other areas in the basin could show similar problems in the near future.

Jefferson County and the Jefferson County Health Department should evaluate the current septic system regulations to asses if changes could lessen the water quality affects from septic systems. The basin nonpoint source management plan will need to address septic system issues and solutions.

WATERSHED

Stream Water Quality

All major wastewater treatment facilities are located downstream of the upper Bear Creek sample site (Figure 3). The small Brookforest treatment system is located on Cub Creek. There are two small treatment facilities which discharge into the upper portions of Bear Creek. The small Conifer wastewater facility is located on upper North Turkey Creek. There are numerous septic systems located adjacent to both North and South Turkey Creeks. Statistically, the water quality at the upper Bear Creek and Turkey Creek stations were similar, which is also true of the lower stations. Water quality was significantly different between upper and lower stations. Summaries of the stream data are shown in Tables B1 to B9. There was a total of 30 sampling sets taken at the upper stations and 32 sets taken at the lower stations. Summary data was calculated by seasons which relate to water quality and flow trends. Analysis of Variance (ANOVA) was used to predict seasons and assess trends.

Although bacteria concentrations increase downstream in Turkey and Bear Creeks, no fecal coliform counts at the reservoir inflow exceeded 2,000 counts/100ml, which is the numeric limit for the reservoir. There were higher counts of total coliform bacteria with a maximum in-reservoir value of 3,400 counts/100ml. These fecal and total coliforms are contributed, in part, from the wastewater discharges at the wastewater treatment facilities in the basin as shown by the high ratio of fecal to total coliform. There are several older dwelling units in the watershed which were observed to directly contribute wastewater into the streams.

Water quality trend plots were made of all water quality data from headwaters, inflows to the reservoir, overall reservoir quality and outflow from the reservoir. Trend plots are shown in Figures F1 to F12 for the following water quality parameters: pH, temperature, dissolved oxygen, alkalinity, specific conductance, suspended sediments, total nitrogen, total dissolved nitrogen, nitrate-nitrogen, ammonia nitrogen, total phosphorus and ortho-phosphorus. The number of samples (N) are shown for each plot. The black bar in the plots represents the range of data values.

The pH showed similar patterns throughout the watershed with some elevated pH values measured in the reservoir (Figure F1). The pH of reservoir discharge water reflected patterns measured in the reservoir without the high peaks. The temperatures in the streams were generally similar with some warming of the water at the inflow to the reservoir (Figure F2). The dissolved oxygen concentrations in the streams were high with mean values ranging from 7.8 mg/ℓ in the summer to 10.3 mg/ℓ in the winter (Figure F3). Dissolved oxygen was not a problem in reservoir outflow, which generally represented eplimnion waters.

The alkalinity increases from the headwaters to the reservoir inflow (Figure F4). The specific conductance of stream water increases from the headwater to the inflow to the reservoir (Figure F5). The conductance values in the reservoir outflow were generally consistent throughout the year. The suspended sediment load in the stream showed some increases from the headwaters to the reservoir inflows (Figure F6).

The nutrient trend plots focus on several of the nitrogen and phosphorus species. Total nitrogen and total dissolved nitrogen increases from the headwaters to the reservoir inflow (Figures F7 and F8, respectively). The outflow concentrations from the reservoir generally reflected the reservoir epilimnion. Nitrate–nitrogen significantly increases from the headwaters to the reservoir inflow with the reservoir and outflow nitrate levels generally reflecting inflow concentrations (Figure F9). Ammonia–nitrogen concentrations in the watershed were generally low with slight increases in the summer and winter seasons (Figure F10). Ammonia concentrations in the outflow water were low and represented the reservoir epilimnion.

Total phosphorus is the nutrient of concern in Bear Creek Reservoir. Phosphorus is critical and is the major nutrient which triggers biomass blooms. Total phosphorus and ortho–phosphorus concentrations in the headwaters were usually very low with phosphorus as the limiting nutrient (Figures F11 and F12, respectively). The concentration of phosphorus significantly increases in the stream at the inflow to the reservoir. The phosphorus concentrations were lowest in the spring runoff season and increase through the remainder of the year.

Groundwater Quality

Groundwater quality was measured to characterize the shallow alluvial aquifers of Turkey and Bear Creeks. There was no fecal coliform bacteria contamination measured in the alluvial aquifers. The aquifer pH values ranged from 7.0 to 7.8. Particulate matter was low in both aquifers during the spring and summer seasons with distinct increases, particularly in the Bear Creek alluvial aquifer, in the winter season. The alkalinity of the Bear Creek aquifer was consistently higher than the Turkey Creek aquifer, with concentrations ranging from 96 to 183 mg/ℓ.

The total phosphorus concentrations were generally higher in the Turkey Creek alluvial aquifer with concentrations ranging from 0.040 to 0.715 mg/ℓ. The total phosphorus concentrations were the highest in the fall and winter seasons with lower values in the summer season. The phosphorus concentrations in the Bear Creek alluvial aquifer ranged from 0.003 to 0.154 mg/ℓ. The highest concentrations occurred in the spring season. The dominate phosphorus species was total dissolved phosphorus which was primarily in the reactive form.

Total dissolved nitrogen concentrations in the alluvial aquifers showed similar trends to the phosphorus species. There were, generally, higher concentrations in the Turkey Creek aquifer with winter season highs in both aquifers. The total dissolved nitrogen concentrations in the Turkey creek aquifer ranged from 0.176 to 2.110 mg/ℓ, while the Bear Creek aquifer ranged from 0.065 to 0.952 mg/ℓ. The dominate nitrogen species in both aquifers was nitrate–nitrogen.

The groundwater nutrient data shows some nutrient enrichment of the Turkey Creek aquifer with nutrient loading occurring in the fall and winter months. This nutrient loading appears to be caused by septic system effluent discharging into Turkey Creek. There is also phosphorus enrichment of the Bear Creek alluvial aquifer which may be related to septic system effluent. The actual location of these nutrient enrichment sources can not be determined from the existing data sets.

Precipitation Quality

The contribution of nutrients in the form of wet and dry precipitation was measured at the Park. *The peak phosphorus and nitrogen loadings occurred in the summer season with* minimal loading occurring in the winter and spring seasons. The monthly precipitation data for total phosphorus and total nitrogen was as follows:

SAMPLE DATE	TOTAL PHOSPHORUS (mg/m^2)	TOTAL NITROGEN (mg/m^2)
02/02/88	3.63	33
28/03/88	2.18	22
18/04/88	3.16	24
03/05/88	0.60	7
24/05/88	0.00	15
21/06/88	23.60	192
05/07/88	71.18	NA
02/08/88	6.99	71
16/08/88	2.61	67
13/09/88	12.46	NA
11/10/88	0.57	NA
08/11/88	0.67	233
06/12/88	1.42	46
10/01/89	1.84	33
08/02/89	0.59	35
07/03/89	0.43	87

The total phosphorus loading for the year was 124 mg/m^2. The total nitrogen loading for the year was 1016 mg/m^2. The surface area of the reservoir is about 110 acres. There are about 399 pounds of phosphorus loaded to the reservoir from precipitation which is about 1 percent of the annual load. There are about 3,273 pounds of nitrogen loaded to the reservoir from precipitation which is about 3 percent of the annual load. This loading is lower compared with results for Chatfield Reservoir and Cherry Creek Reservoir. In 1988, Cherry Creek Reservoir received 1,900 pounds of total phosphorus with an estimated total phosphorus load of 9,500 pounds which is about 19 percent of the annual load.

Nonpoint Source Loading

Bear Creek and Turkey Creek in the Bear Creek Basin are identified in the Colorado State Nonpoint Assessment Report (WQCD, 1989a) as being severely impacted by nonpoint runoff. These streams are listed in the Colorado Nonpoint Source Management Program (WQCD, 1989b) as being impacted by urban and construction runoff.

Nonpoint runoff affects water quality in Bear Creek, Turkey Creek and associated tributaries which results in degraded water quality in Bear Creek Reservoir. Water quality data shows excessive nutrient loading in the streams. The reservoir is directly affected by the high loadings of nitrogen and phosphorus, other nutrients and sediments from the watershed. There is over 32,000 pounds of phosphorus and 115,000 pounds of nitrogen annually loaded to the reservoir.

The suspended sediment loading for Bear Creek Reservoir is shown in Table 15. Significant quantities of sediments are transported to the reservoir under normal stream flow conditions

Table. 15. Suspended Sediment Loading for Bear Creek Reservoir.

MONTH	INFLOW VOLUME (Ac–ft)	INFLOW PARTICULATE LOAD (lbs/month)	RESERVOIR PARTICULATE LOAD (lbs/month)	OUTFLOW PARTICULATE LOAD (lbs/month)
January	1,342	62,577	15,289	30,943
February	1,467	14,206	9,630	12,744
March	2,419	493,446	65,618	62,993
April	6,854	242,205	359,758	65,000
May	13,184	1,392,966	567,558	476,004
June	6,587	222,276	100,954	127,398
July	2,849	91,579	44,824	38,398
August	2,186	44,177	40,085	22,592
September	1,226	25,541	38,910	29,531
October	1,034	11,051	18,848	24,458
November	1,259	10,109	15,266	12,602
December	1,420	12,480	16,255	17,950
TOTAL	41,827	2,622,613	1,292,995	920,963

with the annual suspended sediment load exceeding 2.6 million pounds. There is also an additional sediment load delivered to the reservoir as a direct result of thunderstorms and bed-load transport. Bed-load was estimated at 6.5 million pounds during the summer months. Some of the sedimentation was directly attributable to construction activities. There is a large quantity of sediment passed through the reservoir without deposition. The total pass-through load was not measured.

Sediment and nutrient loading resulting from construction activities within the basin could have affected reservoir quality, but effects from these sources were difficult to quantify. Construction activities tended to affect water quality runoff in thunderstorms with many of these events occurring between monitoring sets. There is limited data available for three of these stormwater runoff events.

Nonpoint source loadings from the watershed were calculated for suspended sediments, ammonia-nitrogen, nitrate-nitrogen and phosphorus. Annual percentage loading to the reservoir was calculated by moving average based on concentrations and averaged monthly flows. Based on these calculations, nonpoint sources annually account for 70 percent (over 100,000 pounds) of the nitrogen and 66 percent (over 21,500 pounds) of the total phosphorus.

RESERVOIR

Reservoir Quality

Seasonal mean water quality data summaries for the reservoir are shown in Tables C1 to C8. There were two principal depth zonation statically defined in the reservoir with an upper photic zone and a lower aphotic zones. In the summer season, there are distinct photic and aphotic zones with differences in most water quality parameters between these zones. The photic zone is also apparent in the spring and winter seasons. The photic zone depth could be estimated by the secchi depth and 1 percent light transmission depth. An ANOVA testing of sites showed no significant difference between stations within the reservoir, but there was a depth effect for selected parameters. Seasonal outflow data are shown in Tables D1 to D4.

The photic zone depth in the spring as measured by the secchi depth was about 1m with a 1 percent light transmission depth ranging from 1m to 4m. Fine-grained sediments entering the reservoir derived from spring snow melts are the primarily constituent limiting light transmission. In the summer growing season, the mean secchi depth was 1.7 m with the 1 percent light transmission depths ranging from 3.5 to 6m. Prior to fall turnover the secchi depth was 1m with the 1 percent light transmission depth at 2.5m. This light limitation was caused by algal biomass in the photic zone. The fall and winter photic zones ranged in depth from 2 to 3m with the 1 percent light transmission from 3.5 to 6m. There was a minor algae bloom which occurred under ice conditions in February and reduced the secchi depth to 1.5m with a 1 percent light transmission depth of 3.5m. The average photic zone depth for the reservoir was 2.5m.

Trend plots of water quality data were made for the photic zone and aphotic zones. Representative trend plots are shown in Figures G1 to G7 for the water quality parameters of specific conductance, pH, alkalinity, suspended sediments, temperature, dissolved oxygen, total nitrogen, total dissolved nitrogen, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, ortho-phosphorus and chlorophyll α. The physical parameters of specific conductance (Figure G1), alkalinity (Figure G2) and suspended sediments (Figure G2) were not related to the reservoir photic or aphotic zones. The pH (Figure G1) and dissolved oxygen (Figure G3) were seasonally variable between the photic and aphotic zones.

The seasonal trend patterns for the nitrogen species (Figures G4 and G5) were generally similar with differences in mean concentrations between the photic and aphotic zones. There were higher concentrations of total nitrogen in the photic zone with significant increases occurring in the fall and winter seasons. The concentrations of nitrate and ammonia-nitrogen showed reverse trends in the summer season with high ammonia concentrations and low nitrate concentrations (Figure G5). There were higher nitrate concentrations in the spring and winter seasons with higher mean values in the photic zone. There was excess nitrogen available for the spring and winter algal blooms.

Total phosphorus and ortho-phosphorus showed similar seasonal trends with significant differences between the photic and aphotic zones (Figure G6). There was significantly more phosphorus in the aphotic zone in the summer growing season. The reactive phosphorus was consumed in algal production in August and September with resultant extensive algal blooms. The algal blooms resulted in depletion of dissolved oxygen in the deeper portion of the reservoir, producing anoxic conditions. These anoxic conditions promoted release of total phosphorus from the reservoir sediments. Peak total phosphorus loading occurred in August. This internal total phosphorus loading can then contribute to the September algal blooms. Internal total phosphorus loading will be an important component of reservoir modeling.

The chlorophyll α concentrations were higher (as expected) in the photic zone, but there was some biomass production occurring in the top of the aphotic zone (Figure G7). The peak biomass production, as evident by chlorophyll α concentrations, occurred in April, the summer season and February.

The residence of water in the reservoir effects algal production by controlling nutrient loading. In the peak spring runoff period the reservoir volume is replaced about five times. By the summer growing season this replacement rate is about monthly. In the fall and winter periods, this replacement rate averages 2 months. The algal blooms in the spring and winter months were small in comparison to the summer blooms. The peak chlorophyll α concentrations were measured in both August and September. The chlorophyll α concentrations are compared with the total nitrogen and phosphorus concentrations (Figure G7). The initial spring biomass production appears to be related to nutrient enrichment from the latter part of the winter season loading. The winter biomass production appears to be related to nutrient enrichment beginning in February from stream loading. The summer biomass production is related to the available nutrients coming into the reservoir during the month of the bloom. A change in the residence time of water storage could dramatically effect algal production.

Temperature and dissolved oxygen concentrations were profiled in the reservoir throughout the year (Figures G8 and G9, respectively). Temperature stratification begins in the reservoir in May and continues through the fall turnover in September. In June, the thermocline were at about 3m and 8m with the lower thermocline showing only a small difference. The thermocline was at 7m from June through August. The water temperature was uniform in the reservoir during the fall turnover in September and remained uniform through December. There was a slight warming of the water column in October. In February under ice conditions, the bottom waters were warmer than the surface waters. The dissolved oxygen profiles show distinct layering in the summer season with oxygen dropping to zero below 4m by late June (Figure G9). This 4m zone of oxygen decline was consistent throughout the year.

There was an ice cover on the reservoir from late December through April. The ice cover was generally typical for the reservoir. However, an early spring warming removed the ice cover earlier than expected with open water in April.

Reservoir water quality data from the U.S. Army Corp of Engineers (1987-1989) from their annual Water Quality Management Program reports also recorded high levels of phenols, metals and suspended sediments. There were also *exceedences of standards* in inflow, reservoir and outflow water for arsenic, copper, lead, iron and manganese. This metal data is in the EPA STORET data base.

The alkalinity in Bear Creek Reservoir ranged from a spring low mean of 55 mg/ℓ to a winter high mean of about 100 mg/ℓ. The summer mean alkalinity was about 64 mg/ℓ, while the fall value averaged 77 mg/ℓ. By relating alkalinity to a harness equivalent (Hem, 1970), the reservoir water is considered *soft* in the summer growing season and moderately hard for the other seasons. The phosphorus concentration required to cause water quality degradation in a waterbody is related to the alkalinity of the waterbody. The combination of reduced phosphorus solution, low alkalinity and the small amount of phosphorus needed to stimulate aquatic plant growth in soft water makes phosphorus control very important and suggests a greater difficulty in recovering these types of waterbodies from nutrient enrichment (King, 1979).

The mean reservoir (entire water column) total phosphorus was 144 mg/ℓ with the growing season and photic zone mean at 111 mg/ℓ and aphotic zone mean of 329 mg/ℓ. The mean chlorophyll α in the photic zone and for the growing season was about 19 mg/ℓ. The mean secchi depth was 1.7m. The maximum chlorophyll α value was 98 mg/ℓ. There was a mean nitrate value for the photic zone of 113 mg/ℓ compared to the aphotic level of 71 mg/ℓ. Fecal coliform ranged from 0 to 20 counts/ 100ml with higher levels of total coliform bacteria.

Reservoir Sedimentation

Extensive erosion occurs in the spring runoff period and in the summer due to runoff from intense thunderstorms (Table 15). This sediment load affects water quality in the streams and reduces aquatic habitat and recreation uses. A portion of this sediment load was carried into and dispersed throughout the reservoir, while a sizeable portion was deposited at the stream mouths in the form of sediment deltas.

A series of sedimentation rates within the reservoir were determined for the growing season period from mid-June to mid-September. Sediment deposition was not uniformly distributed in the reservoir. There was higher deposition rates away from the stream mouths. The highest depositional rate was measured in the central pool with a mean deposition of 9335 g/m^2/growing season. The lowest rate were measured at the inner arm monitoring sites with the Turkey Creek arm having a mean depositional rate of 3257 g/m^2/growing season and the

Bear Creek arm having a mean rate of 5718 g/m^2/growing season. The outer arm monitoring site showed intermediate depositional rates with the mean Turkey Creek arm having a rate of 7607 g/m^2/growing season and the Bear Creek arm having a rate of 7249 g/m^2/growing season.

The higher depositional rates measured toward the middle of the reservoir were probably related to the high flushing rate and fine size class of the particulate matter. Sediments trapped in the outer and central portions of the reservoir were generally fine sands with a high percentage of silt. Sediments in the inner arms were medium to fine sands with a lower percentage of silts.

The sediments carried into the reservoir were analyzed for organic matter content. The central pool sediments averaged 13 percent organic matter. Similar percentages were measured for the inner and outer Bear Creek arm sediments. The percentage of organic matter in sediments from the Turkey Creek arm were significantly higher than those from the Bear Creek side. Average sediment organic content was 22 percent.

The suspended load from streams was related to flows. The inflow suspended matter was calculated by month (Table 15). The peak load occurred in May with about 1.4 million pounds of suspended sediments carried to the reservoir. The fall season showed the lowest loading rates. The suspended load in the reservoir water column was less than the inflow load but showed a direct correlation. The annual load discharged from the reservoir was about 921,000 pounds. There was about 1.7 million pounds of suspended matter deposited in the reservoir.

The mean summer months (mid–June to September) deposition rate, as measured by *sediment fallout*, was 6633 g/m^2. This equates to a total of 6.5 million pounds of sediment for this season. The total particulate load (suspended and bedload) to the reservoir was variable and dependent on inflow volumes and season. The total sediment load discharged into the reservoir for the summer month was 383,573 pounds. There was a significant difference between the suspended load to the reservoir and the estimated *sediment fallout*. This difference can be accounted for by a high rate of sediment re–suspension and deposition of fine sediments introduced as stream bed–load. Bed–load studies conducted in mountainous areas of the west slope of the rockies show very high rates. Bed–load deposition into the reservoir probably accounts for a major portion of *sediment fallout* deposition.

Sediment Delta Formation

Sedimentation deposits are formed at the mouths of both Bear and Turkey creeks. These depositional features are sediment deltas and show typical depositional features of river deltas. A delta is defined as a lobate body consisting of sediment transported to the end of a channel by water current with sub–aerial and sub–aqueous deposition in a standing body of water. The deposition is controlled by sediment particle sizes which can vary from clay–sized particles to boulders, and flow characteristic of the stream. The surface features of a delta are under constant fluctuation as effected sediment load and water velocities. Sediment deltas which show rapid accretion (expansion into the waterbody) are characteristic of watershed with high sedimentation or erosion rates.

The aerial photographs of the reservoir system in 1978 show no delta formation. From 1979 to 1983 there was rapid delta formation at both creek mouths. The Bear Creek delta had expanded about 50m (165 feet) into the reservoir with primary deposition toward the peninsula. There was about 30m (100 feet) of deposition along the stream channel. The Turkey Creek delta showed greater accretion with about 80m (260 feet) deposited into the reservoir in a typical fan shape.

Aerial photographs of the reservoir in 1985, 1987 and 1988 show continued delta accretion. The Bear Creek delta had expanded significantly by 1985 with about 50m of deposition into the reservoir. This deposition altered the channel location, shifting flows southward. The Bear Creek delta had shifting top set beds in 1985. The delta surface showed considerable stabilization by 1988 with extensive vegetation by 1989. The delta back set beds now appear to be stable. The Turkey Creek delta expanded toward the peninsula about 40m by 1985 with subsequent infilling occurring by 1988. The Turkey Creek delta surface has also been extensively vegetated and stabilized.

The Bear Creek delta shows a total linear expansion of about 130m (425 feet), while the Turkey Creek delta shows a total of about 180m (590 feet). This deposition has occurred over a 12 year period and shows that there has been a high sedimentation load from the watershed.

The deltas were surveyed to quantify deposition rates and changes to surface bedding. The delta surface configurations along fixed transects for both Turkey Creek and Bear Creek are shown in Figures 4 and 5, respectively. Both deltas showed spacial changes over the survey period. The channel location across the Bear Creek delta shifted southward with 20m of deposition into the reservoir (Figure 5). This deposition was primarily reworking of the top set beds and did not represent an extensive amount of new bedload. There was some linear expansion of the delta of about 5m. This relates to a annual linear deposition rate of 20m. The Turkey Creek delta showed a similar lateral displacement of sediments as the Bear Creek delta (Figure 4). The Turkey Creek delta showed about 1m of linear expansion into the reservoir. This relates to an annual linear deposition rate of 5m.

The sediment deltas are a strong visual feature of the reservoir. There were a number of Park users who wanted unlimited access to deltas. The City of Lakewood has restricted access to the deltas because of the instability and several accidental drownings in the past. Although delta deposition continues on a regular basis, the top surfaces of the deltas are generally stable.

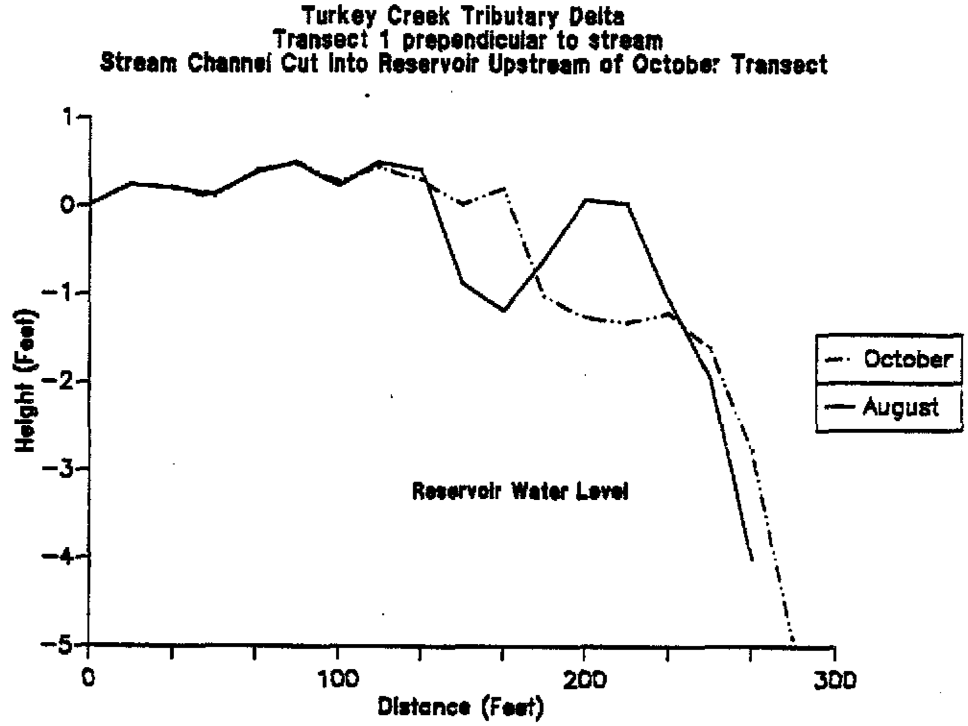
Phytoplankton Community

There were several significant algal blooms which occurred in the reservoir during the monitoring period. These blooms were composed of a number of phytoplanktonic species from the families Cryptophyta, Cyanophyta, Chlorophyta, Chysophyta, Bacillariophyta and Pyrrophyta (Table 16). The composition of species varied throughout the growing season (Table 17).

The functional group distributions of phytoplankton are shown in Table 18. In April, May and June, the dominate genera were Cryptomonas, Navicula and Stephanodiscus. The dominance

Figure 4.

Turkey Creek Tributary Delta



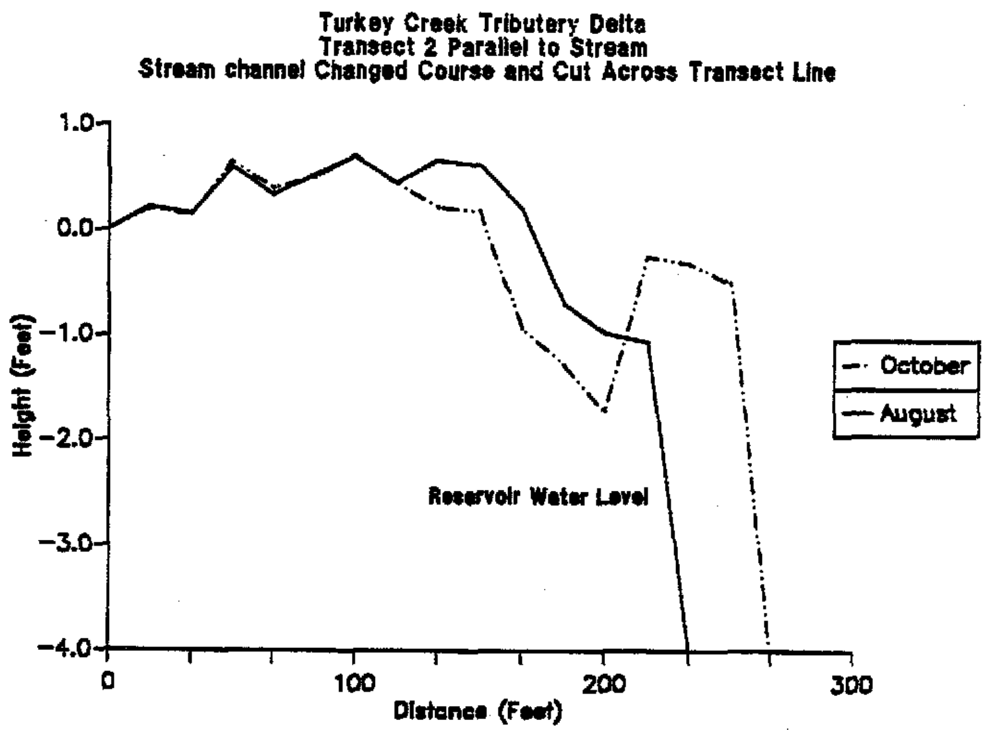
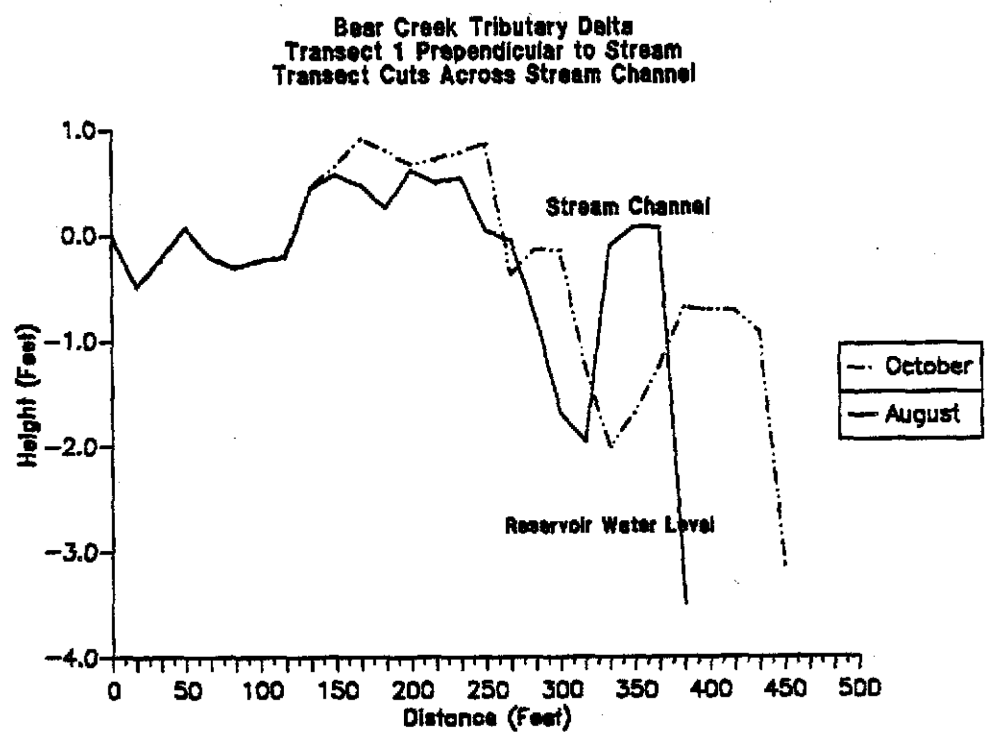


Figure 5.

Bear Creek Tributary Delta



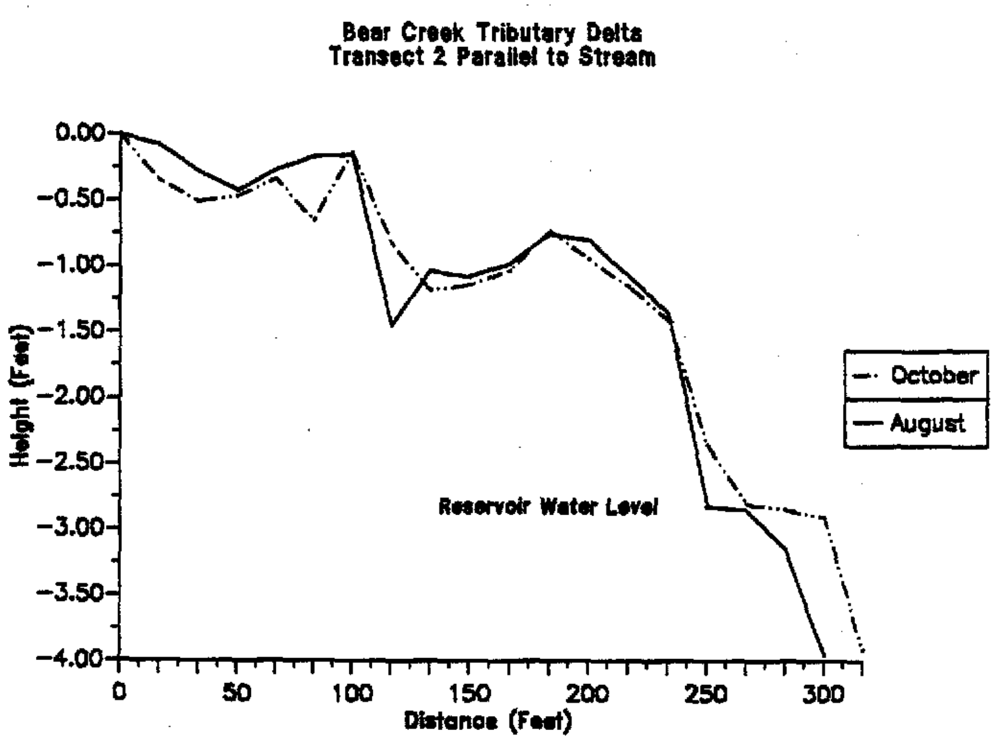


Table 16. Dominent Phytoplankton Genera in Bear Creek Reservoir and Relative Abundance of Major Genera

	Number of Occurrences	Volume	Density	Abundance*
Bacillariophyta_(Diatoms)				
Asterionella	13	1,231,220	1,212	D
Cyclotella	12	33,651	75	S
Fragilaria	9	11,323	44	S
Navicula	19	137,387	49	C
Nitzschia	27	17,639	47	C
Stephanodiscus	27	1,709,830	2,658	D
Synedra	15	80,134	37	C
Cryptophyta_(Small_Floaters)				
Chromulina	5	1,804	174	S
Chryptomonas	93	597,745	391	D
Chrysococcus	7	10,874	417	S
Rhodomonas	33	98,765	935	C
Chlorophyta_(Green_algae)				
Ankyra	28	12,955	286	C
Chlamydomonas	10	421,782	2,383	D
Chlorella	12	1,129	186	S
Pediastrum	14	42,864	687	C
Schroederia	8	21,138	61	S
Cyanophyta_(blue-green_Algae)				
Anabaena	10	246,922	4, 136	D
Aphanizomenon	21	6,907,802	49,093	D
Microcystis	15	4,329,140	46,255	D
Pseudanabaena	15	65,017	18,736	C

*Abundance

D = Dominant (i.e., ranking as the top one or two species in abundance at certain times of the year
C = Common (i.e., top five)
S = Secondary (i.e., reaching significant numbers, but never ranking as top abundant species)

Table 17. Dominant Phytoplankton Genera in Bear Creek Reservoir – Seasonal Frequency

Phytoplankton Genera	Spring Season	Growing Turnover	Fall	Winter
Bacillariophyta (Diatoms)				
Asterionella	38.5*	38.5*	0	23.0
Cyclotella	33.3*	8.4	33.3*	25.0
Fragilaria	55.6*	11.1	11.1	22.2
Navicula	89.5*	0	0	10.5
Nitzschia	63.0*	14.8	11.1	11.1
Stephanodiscus	59.3*	14.8	3.7	22.2
Synedra	33.3*	6.7	26.7	33.3*
Cryptophyta (Small Floaters)				
Chromulina	0	0	60.0*	40.0*
Chryptomonas	28.0	33.4	19.3	19.3
Chrysococcus	85.7*	0	0	14.3
Rhodomonas	27.3	39.4*	18.2	15.1
Chlorophyta (Green Algae)				
Ankyra	10.7	60.7*	17.9	10.7
Chlamydomonas	0	70.0*	10.0	20.0
Chlorella	16.7	16.7	33.3*	33.3*
Pediastrum	0	100.0*	0	0
Schroederia	0	100.0*	0	0
Cyanophyta (Blue-green Algae)				
Anabaena	10.0	70.0*	0	20.0
Aphanizomenon	9.5	66.7*	14.3	9.5
Merisnopedia	33.3	0	33.3	33.3
Microcystis	0	86.7*	13.3	0
Oscillatoria	33.3	0	0	67.7*
Pseudanabaena	6.7	73.3*	13.3	6.7
Synechococcus	0	67.7*	0	33.3

* Indicates genera which are seasonally dominant in each season

Table 18. Frequency of Occurrence of Major Phytoplankton Groups

FUNCTIONAL GROUP	SEASON			
	SPRING	GROWING SEASON	FALL TURNOVER	WINTER
Bacillarophyta (diatoms)	56.6	13.0	10.7	19.7
Cryptophyta (small floaters)	29.7	31.9	19.6	18.8
Chlorophyta (Greens)	8.0	64.0	13.3	14.7
Cyanophyta (Blue-greens)	7.5	70.1	11.9	10.5

of the Navicula and Stephanodiscus genera decreased in July with the disappearance of Navicula species. The dominate genera in July, August, September and October were Aphanizomenon, Microcystis, Cryptomonas and Asterionella. The Aphanizomenon has the appearance of grass clipping and had extensive coverage of the reservoir surface. Aphanizomenon cell counts were measured in excess of 4,000,000 counts/ml during the bloom period. The phytoplankton populations decreased significantly by November with Cryptomonas as the dominate genera. There was a small bloom of Cryptomonas under the ice in February. There was also extensive nutrient loading which occurred at this time.

Aquatic Plant Coverage

The littoral region of the reservoir is the shallower zone between the land and the open waters of the reservoir. This size of the littoral zone was controlled by the reservoir morphology. The littoral zone of the reservoir tends to be narrow. Attached submerged plants (aquatic plants) are found in this littoral zone. Aquatic plants have the potential of high productivity and which can affect other beneficial uses designated for the waterbody, particularly recreational uses (Wetzel, 1983).

The floating-leaved aquatic plants which attach in the littoral zone are usually restricted to water depths from about 0.5 to 3m (10 feet). These plant species have long stems which are easily broken. Large quantities of detached aquatic plants can accumulate along the shoreline where rapid decay occurs. These decaying plants cause odor and visual problems. Park users were concerned about plant accumulations along the shoreline and equated this occurrence with water quality impairment.

Figure 6 depicts the general aquatic plant coverage observed in the reservoir. There was one dominate attached aquatic plant which was a species of Elodea. This is a common species in front range reservoirs. There was a distinct algal mat covering the sediments in the mid to late-summer periods. The matting algal was characteristic of a Schizothrix species.

The aquatic plant coverage which occurred between May and October was generally confined to the upper slopes of the reservoir at depths of less than 2m. The areas of higher coverage were associated with the shallower inflows at the mouths of Bear and Turkey Creeks. Aquatic plant coverages of 80 percentage of the substrate were measured in July and August adjacent to the stream mouths.

There was extensive algal coverage of stream substrata in Bear and Turkey Creeks for the March and April surveys. The algal coverage on substrata in Turkey Creek averaged 60 percent, while Bear Creek was at 45 percent for the same time period. Substrata in the lower portions of the streams approaches 100 percent coverage by late in late summer. The algal components included a filamentous green alga and several types brown diatom encrustations. A blue-green algae species was less common, but still conspicuous.

Zooplankton

Zooplankton composition in the summer was characterized (Table 19). The composition was qualitatively similar at all sites. The reservoir can be considered to be homogeneous in terms of zooplankton composition. Diacycclops thomasi, Skistodiaptomus pallidus and Daphnia

Figure 6.

Aquatic Plant Coverage

Table 19. Zooplankton Species Collected in Bear Creek Reservoir on 22 June 1989

	Central Pool	Bear Creek Arm	Turkey Creek Arm
COPEPODA			
Diacyclops thomasi	x	x	x
Skistodiaptomus pallidus	x	x	x
Aglaodiaptomus clavipes	x	x	x
CLADOCERA			
Daphnia pulex	x	x	x
Chydorus sphaericus	x	x	x
Bosmina sp.		x	x
ROTIFERA			
Keratella quadrata	x	x	x
Polyarthra sp.	x	x	
Euchlanis sp.		x	
Bdelloid sp.			x

pulex are all common and widely distributed in North America. The calanoid copepod, S. pallidus, is widely distributed in the east and great plains states. Although it has not been regarded as common in Colorado, it has shown a relatively dramatic range expansion in the last 40 to 50 years. The other two species are common in other lakes and reservoirs in Colorado. The scarcity of rotifers in the reservoir was surprising but not unique; other Colorado lakes also show this trait.

Hydraulic, Morphometric, Bathymetric Surveys

Reservoirs are distinguished from naturally occurring lakes by several important physical characteristics (Cooke et al., 1986). Reservoirs usually have greater surface area, mean and maximum depth, with shorter residence time and a greater areal water load. The central pool of a reservoir generally behaves more like a natural lake than the inflow area. These considerations can effect the reservoir quality and model predictions. The physical characteristics of the reservoir are shown in Table 5. Additional information was provided in a DRCOG (1987a) technical memoranda on Hydrology Evaluation of Bear Creek and Inflows to Bear Creek Reservoir and Assessment of Reservoir Models.

Water flows into the reservoir from the streams and general flow characteristics were measured using drift drogues. These flow surveys were made to assess reservoir hydraulics and ascertain if flow regimes effected water quality modeling. An area of concern was the possibility of short–circuiting of surface flows across the reservoir. This type of flow regime would keep the reservoir from acting as a mixed system and effect model predictions. The high flushing rates in the reservoir produced measurable water velocities at both the stream mouths and in the central pool for the upper water column. Deeper flow measurements were not conclusive.

There was a characteristic flow regime which was depth related at the stream mouths. Inflowing stream water showed a distinct 2–3m plunge off of the sediment deltas. There was a resultant inward flow of near surface reservoir water into the stream mouths. This produced an eddy complex around the deltas. The plunged inflowing water from both streams flowed toward the central peninsula at a slow rate of about 30m/hour without wind influence.

Current flows within 3m of the surface in both arms of the reservoir showed characteristic large eddy systems with or without wind. Flows in the top 5m of the central pool water column showed a movement toward the outlet structure at rates ranging from 5m/hour (without wind) to 50m/hour (with a prevailing NE wind). Drift drogues deployed at 6 to 8m did not show a distinct flow pattern.

The morphometry of the reservoir modifies the water flow regimes. The central peninsula effects the inflow patterns. This feature in conjunction with the overall shallowness of the reservoir arms creates circular flow patterns or eddy complexes. These circular flows regulate depositional patterns. There is sediment depositional feature across the reservoir edge of the Turkey Creek arm which causes a 2 to 3m water plunge and produces deeper mixing of inflow water.

The hydraulic evaluation of the reservoir shows some short–circuiting of inflows across the surface of the reservoir. Surface flow patterns are significantly effected by the prevailing wind conditions which effected the top 5m of the water column. There are separate flow patterns between the reservoir arms and the central pool. Flow velocities were generally higher in the water column between 1 and 2m.

Water flow data and other hydraulic characteristics of the reservoir suggest that reservoir operations are having an affect on the water quality in the reservoir. The reservoir operations at these time periods are characterized by low release volumes from the eplimnion portion of the reservoir. As a result, the anoxic bottom waters are turned over at a much slower rate compared to surface flows. As a result, the hypolimnion layer of the reservoir is a major portion of the central pool.

The U.S. Army Corps of Engineers is currently assessing the reservoir operations in relation to water quality. There is modeling effort in progress which will evaluate the effect of hypolimnetic withdrawal. Other aspects of reservoir operation under review are related to volume storage and release. There is a potential for reservoir water quality improvement by changing the operation procedures.

The bathymetric contours of the reservoir were mapped by the U.S. Army Corps of Engineers as part of the reservoir construction process (Figure 7). This contouring shows the reservoir before periods of major deposition. There were subsequent surveys made by the U.S. Army Corps of Engineers to monitor erosional changes in adjacent upland areas and infilling of the reservoir. These surveys are shown in Figure 7. There was erosion evident around the reservoir with about of foot of loss over a ten year period. The surveys showed some of the delta formation in cross section. The surveys could not show the magnitude of sediment delta formation. These surveys do not show significant infilling of the reservoir.

A bathymetric survey was made to quantify the existing contours and compare changes to the original contour map. Bathymetric contour changes are shown in Figure 8. There has been some changes in contours, particularly in the reservoir arms (Figure 8). The shoreline has been infilled along the stream inlets with subsequent deposition in the arms of 0.5 to 1.5m. Some areas of the central pool adjacent to the outlet structure are deeper than when the reservoir was constructed. This deepening can be attributed to scouring and/or water weight deformation. There has not been significant infilling in the central pool of the reservoir.

Figure 7.

Bathymetric Transect Changes from 1977 to 1989 From U. S. Army Corps of Engineers Surveys

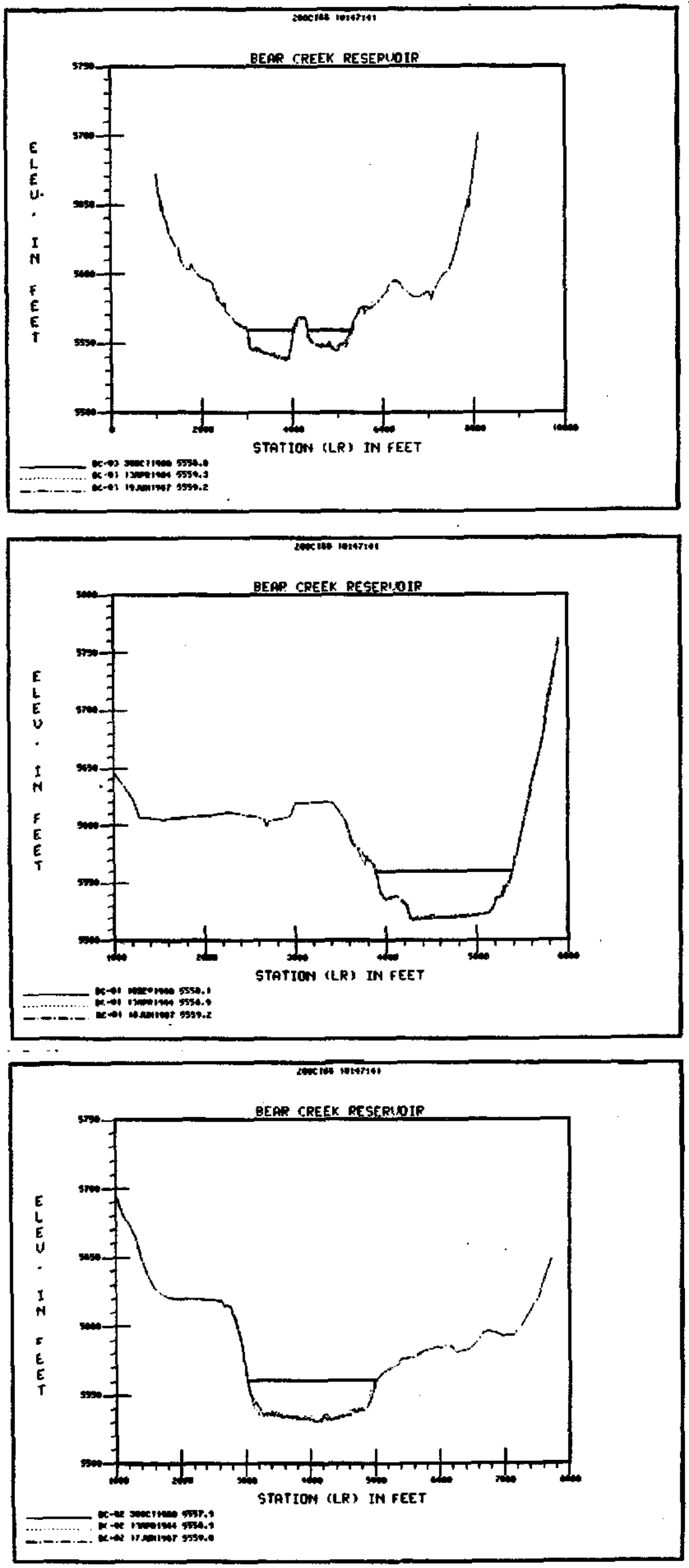


Figure 8.

Bathymetric Contour Changes from 1977 to 1989

V. BIOLOGICAL RESOURCES

SPECIES SURVEYS

Information on the plants and animals found within Bear Creek Park was tabulated from a number of sources and from site surveys. A checklist of common trees, shrubs, herbs, grasses and grass-like plants is shown in Table E1. There are four primary vegetation communities associated with the Park:

- Prairie-like grasslands;
- Cottonwood and willow riparian woodland along the streams;
- Cattail and sedge marshes/wetlands;
- Fields and disturbed area.

These community types are described for an adjacent park area with similar vegetative types in a Bear Creek Park ecological study and habitat enhancement program (City of Lakewood, 1980). These communities and associated flora are typical for the area. There were no rare or unusual species identified at the Park.

A checklist of wildlife associated with the Park and adjacent watershed is shown in Table E2. The checklist includes species identified by Audubon Society members who visited the Park and included lists with surveys. The checklist includes birds, mammals, reptiles, amphibians, fish and invertebrates. The species are generally common along the front range and they are typical of species found at Chatfield Reservoir. There were no rare species found in the Park.

There is a large bird population found at the Park with a large population of seasonal and resident water and shore birds. Canadian geese winter in the Park. A checklist of commonly occurring species is shown in Table E3. There are 23 shore and waterbird species found at the Park. A good population of ring-necked pheasants is associated with grasslands on the southern edge of the Park. The hawk population is stable with a pair of red-tail hawks seen nesting in the Park. Many of the perching birds are associated with the cottonwood-willow community. Bats can be frequently seen at night within the Park. There is a small deer herd which averages about 30 animals frequently seen in the Park. Beaver have attempted to establish along Bear Creek and Turkey Creek. The Park policy has been to discourage beaver from damning the streams or establishing in the Park. In 1988, a pair of coyotes were raising pups at the Park.

There are seven fish species common to the reservoir with three species of sport fish: rainbow trout, smallmouth bass and tiger muskie. The dominant fish in the inlet areas were suckers, fathead minnows and smallmouth bass. The suckers were generally large in these areas with lengths up to 45 cm and 1200 grams. Small sunfish, fathead minnows and smallmouth bass were common along the south shoreline. There were no larger species caught in the sweep of this area.

Smallmouth bass were recovered from the outlet structure area. The smallmouth bass ranged from 30 to 45 cm with the largest specimen massing 1218 grams. There were much larger bass seen, but not recovered.

Trout, tiger muskie and suckers were caught by gill net. Two tiger muskie were gilled with lengths of 79 and 81 cm and masses of 3.4 and 4.0 kilos, respectively. A 46 cm rainbow trout was gilled with a mass of one kilo. This trout was pink fleshed from feeding on crustaceans and can be assumed to have wintered in the reservoir. Several smaller rainbow trout and tiger muskie were released from the net.

The Colorado Division of Wildlife conducted a standard stream survey in Bear Creek during March 1987. Stream segments were sampled at four locations on Bear Creek: at Davidson Lodge below Evergreen; near Swede Gulch on the mainstem of Bear Creek; below Idledale; and below Morrison after the Harriman diversion. A summary of the surveys are shown in Table 20. There were three large fish species found and measured at these sites: rainbow trout; brown trout; and longnose sucker. There were two minnow species found: longnose dace; fathead minnow.

There was a good population of rainbow trout found at the east Swede Gulch station with an estimated total yield of 122 pounds per acre. The rainbow trout population declined substantially downstream with only 4 pounds per acre found at Morrison. The rainbow trout lengths were obtained for five size classes. The size classes in Table 20 were summarized for fish less than 6 inches and fish greater than 6 inches. Trout found below 6 inches are considered to been reproduced within the stream system. There were no fish of this size class stocked in Bear Creek. A large number of fish in this smaller size class is used to define a reproducing fishery. Forty-seven percent of the rainbow trout in Bear Creek were below 6 inches. Therefore, Bear Creek can be considered as a reproducing rainbow trout fishery.

The yield of brown trout was less than rainbow trout with a maximum yield 12 pounds per acre found at the Davidson Lodge. There were only two brown trout sampled with lengths below 6 inches which was 14 percent of the population. The small number of juvenile fish suggests that browns are having only marginal success at reproducing in Bear Creek.

The longnose sucker was found at all stations with a maximum yield of 92 pounds per acre at the Davidson Lodge station. These were large fish with no smaller size classes found in the upper portion of the stream. The largest population of suckers were found near Morrison. There were juvenile suckers found in the lower portions of Bear Creek.

FISH TISSUE ASSAY

The U.S. Army Corps of Engineers has conducted metal analysis on Bear Creek Reservoir water since 1979 with results summarized in their annual reports as typified by the 1987 report (U.S. Army Corps of Engineers, 1987). These reports do not list actual metal values, but record those metals which exceed EPA ambient water quality criteria and Colorado standards. In 1987, the report lists fish kills, bacterial and viral contamination, low dissolved oxygen, suspended solids, sulfate, temperature and numerous metal exceedances. The metals listed as exceeding state standards included: aluminum, copper, iron, lead,

Table 20. Division of Wildlife Fish Survey Summary for Bear Creek

RAINBOW TROUT

Location	Stream Length (Feet)	Fish Population #/Acre	Total Yield #/Acre	Fish Number <6 Inch	Fish Number >6 Inch
Davidson Lodge	60	240	48	1	5
East Swede Gulch	200	870	122	29	71
Below Idledale	230	197	53	11	15
East Morrison	200	52	4	4	4

BROWN TROUT

Location	Stream Length (Feet)	Fish Population #/Acre	Total Yield #/Acre	Fish Number <6 Inch	Fish Number >6 Inch
Davidson Lodge	60	80	12	0	2
East Swede Gulch	200	26	8	0	3
Below Idledale	230	23	4	2	1
East Morrison	200	70	11	0	8

LONGNOSE SUCKER

Location	Stream Length (Feet)	Fish Population #/Acre	Total Yield #/Acre	Fish Number <6 Inch	Fish Number >6 Inch
Davidson Lodge	60	120	92	0	3
East Swede Gulch	200	174	57	4	16
Below Idledale	230	38	13	1	4
East Morrison	200	313	38	7	30

manganese and phenols. The magnitude of these problems could not be fully evaluated fromthe existing data sets. However, the reports suggest a potential metals problem in Bear Creek Reservoir. Therefore, a screening level survey for the metal mercury was designed for the study. Mercury was selected as the screening metal since a federal action level for toxicity has been established by the U.S. Federal Food and Drug Administration with a standard of 1.0 PPM (wet weight).

Mercury, in the form of methyl-mercury, can increase in a food chain by biomagnification. This process will cause larger predatory fish to have higher mercury concentrations in muscle tissue. There is documentation which shows mercury levels in fish can exceed by several orders of magnitude the levels of mercury found in waterbodies (Friberg and Vostal, 1972; Hartung and Dinman, 1972; McIntyre and Mills, 1978). Accumulation of mercury to sub-lethal or toxic levels in food-chains occurs when the mercury source is persistent and the fish within the exposed water system can not efficiently eliminate it from their systems. Therefore, an evaluation of mercury in edible fish tissue can provide an assessment of a metal problem in the assayed waterbody and the potential for human health problems. Excessive mercury levels in fish can indicate a chronic metal source.

Axial muscle samples were analyzed for total mercury from a selection of fish caught in the reservoir (Table 21). The analysis was done as a screening for bioaccumulation of metals in predatory and filter feeder fish in the reservoir food-chain. The mercury results showed levels which are slightly higher than expected background concentrations (Hartung and Dinman, 1972).

None of the total mercury concentrations in the axial muscle sample exceeded the U.S. Federal Food and Drug Administration action level. There is some bioaccumulation of mercury occurring in larger predatory fish (Table 21). There was a dry weight mean concentration of about 0.5 PPM for the bass, tiger muskie and trout which are top predators. The wet weight was 0.3 ppm or one third of the standard. The sucker is a filter feeder and had a lower mean value of about 0.25 PPM.

An evaluation of environmental metal concentrations in the Bear Creek watershed and at the reservoir should be done to assess the magnitude and extent of metals problems. The analyses should initially focus on stream and reservoir waters, with subsequent verification of metals in fish tissues and reservoir sediments. The evaluation of mercury in wastewater effluent may be useful in identifying if the chronic mercury source is related to point source discharges.

Table 21. Fish Specimens for Tissue Analysis of Mercury

Number	Fish Type	Length (cm)	Mass (grams)	Moisture (%)	Total (ug/kg)	Mercury (PPM) Dry Weight	Mercury (PPM) Wet Weight
1	Smallmouth bass	34.3	680.3	50.7	368	0.37	0.19
2	Smallmouth bass	38.1	871.3	50.0	534	0.53	0.27
3	Smallmouth bass	36.2	741.7	52.3	542	0.54	0.28
4	Smallmouth bass	35.2	634.4	55.9	381	0.38	0.21
5	Smallmouth bass	41.9	218.2	54.8	648	0.65	0.37
6	Sucker	43.2	253.3	52.2	218	0.22	0.11
7	Sucker	44.1	215.9	-	-	-	
8	Sucker	43.8	106.8	48.9	274	0.27	0.13
9	Sucker	15.2	40.2	-	-	-	
10	Sucker	20.3	103.7	-	-	-	
11	Sunfish	10.8	19.5	-	-	-	
12	Tiger muskie	78.8	3400	61.3	559	0.56	0.34
13	Tiger muskie	81.3	4000	48.9	337	0.34	0.21
14	Rainbow trout	45.8	1000	51.9	496	0.50	0.26

The fish submitted for analyses were specimens 1-5, small mouth bass; 6 and 8 white nose sucker; 12 and 13 tiger muskie; and 14 rainbow trout.

VI. TROPHIC STATUS

GENERAL DISCUSSION

The trophic status of a waterbody is a descriptive measure of the natural aging process of the waterbody. The aging process is controlled by a complex interaction of geological, chemical and biological factors. There are three general categories of classification used by lake managers to describe the functional points in the waterbodies aging process.

A waterbody with few available nutrients and low sedimentation is classified oligotrophic. An oligotrophic system promotes little biological growth. As nutrient loading increases and larger biological communities establish, the waterbody is defined as mesotrophic. A mesotrophic system exhibits high diversity and few water quality problems. As nutrient levels increase and more sediment infilling occurs, resulting in extensive biological growth, the waterbody is defined as eutrophic. A eutrophic waterbody can experience water quality problems in relation to human activities. Man–induced perturbations can accelerate the aging process and cause waterbodies to become eutrophic in short time periods compared with natural changes.

There are a number of trophic status classification systems which have devised to assist in lake or reservoir management. These systems provide a descriptive framework for assessing the effectiveness of management techniques. The classification is also used to define a goal for a waterbody undergoing a restoration program.

The process of eutrophication results from enrichment of a natural or man–made waterbody from nutrients which affect lakes by increasing algal growth and rooted aquatic plants to excessive levels. This eutrophication causes excessive plant production, reduced oxygen levels, changes in fish population, and distribution and taste/odor problems in drinking water supplies. The nutrients essential to plant growth are transported to the waterbody from a number of sources and by many pathways with subsequent internal recycling.

The eutrophication process also includes excessive erosion in the watershed which causes siltation in the lake or reservoir. Nutrients and organic matter are associated with and bound to the sediments transported to the waterbody. Sedimentation can also reduce available surface area, impair aesthetic values and provide rooting substrata for aquatic plants.

Although productivity responses to changes from nutrient loadings is understood and generally predictable, resultant changes in phytoplankton community structure are not as well understood (Carpenter, 1988). The phytoplankton community and change in composition is an important facet of a waterbodies trophic status (Klemer and Konopha, 1989). There are complex interactions from multiple pathways which change the community structure in a stressed system. The temporal and spacial heterogeneity of the community can be substantially effected by biogeochemical cycles.

There are two general types of theories (Klemer and Konopha, 1989) used to explain control mechanisms for phytoplankton communities:

1. The *bottom–up* theories which emphasis nutrient loading, hydrology or physical effects;

and

2. The *top-down* theories which emphasis biological processes and foodweb interactions such as predation and grazing.

The resource-based competition theory is an example of a *bottom-up* theory. According to this theory, phytoplankton composition is controlled by nutrient supply ratios moderated by the algae themselves through a complex matrix of links among species populations and individual nutrient pools (Carpenter, 1989). A *top-down* control process would use zooplankton to moderate phytoplankton community structure.

Both general theory types have been explored in the literature to explain community dynamics in stressed ecosystems (Carpenter, 1989). Since many of the studies which assess only one theory type fail to explain the observed community structure over time, it appears that both of these theory types can operate in a given waterbody within the same time-frame. These theory types should be viewed as components of an integrated process.

Mixing has been shown to be an effective management technique for destroying chemical gradients (nitrogen, phosphorus, etc.), preventing surface blooms and eliminating anoxia in the hypolimnion. Based on analysis of phytoplankton, zooplankton and hydrological data shown previously in this report, the use of a top-down biomanipulation is not likely to be an effective management strategy (Carpenter, 1989).

There may also be a phytoplankton size limitation which effects population densities. This non-nutrient constraint may be an important controlling mechanism for algal biomass (Agusti et al., 1990). In bloom periods, the algal community was dominated by large blue-green species which were near the maximal achievable cell densities and showed the greatest biomass accumulation. This tendency toward dominance of large algae species as non-nutrient constraints become more important in regulating biomass is consistent with many studies relating biomass and cell size (Agusti et al., 1990).

Although aquatic plant productivity is high in the littoral zone, aquatic plant production is not as significant as phytoplankton production. Aquatic plants have a greater effect on the aesthetic characteristic of the reservoir. Aquatic plant control does not appear to be a needed management option for the reservoir.

An often identified major objective of a reservoir management program is to restrict nutrient quantities and sediment loads reaching the waterbody (Vittomark, 1979). Nutrient reduction is generally focused on biologically available nutrients at a time when they contribute to undesirable algal or aquatic plant growth. The restoration approaches are then designed to accomplish one or more of the following:

- Reduce external nutrient loading
- Accelerate nutrient outflow from the system
- Disrupt internal nutrient cycling

- Channel nutrients to biological production
- Reduce external sediment and organic matter loading
- Modify the ecosystem balance in the waterbody

RESERVOIR

The trophic status of Bear Creek Reservoir was assessed by several trophic indices. These various indices compared specific water quality parameters to determine relationships. Although many trophic indices were evaluated only the probability distribution curve method was included in this report.

One means to evaluate the trophic status is by assessing nutrient limitations in the waterbody. The ratio of nitrogen to phosphorus species has been used to determine the limiting nutrient. The ratio of total soluble inorganic nitrogen to ortho-phosphorus is shown in Figure G10. The headwaters were phosphorus limited throughout most of the year with distinct limitation in the summer season. The inflows to the reservoir were phosphorus limited only in August. The reservoir was weakly phosphorus limited in April and December with distinct limitation occurring in August and February. The outflow from the reservoir was phosphorus limited only in December.

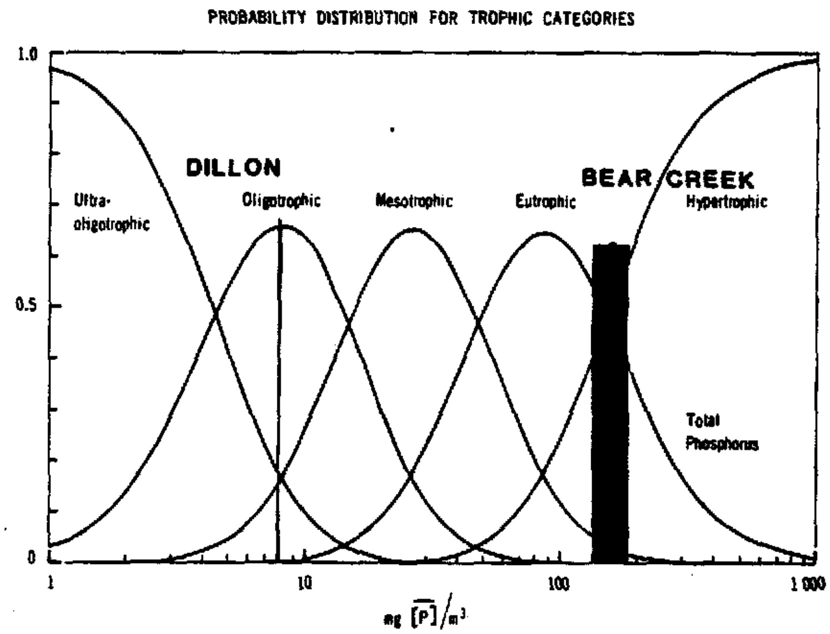
Probability distribution curves for trophic categories were developed which define the time response probability of being in one of five trophic categories (OECD, 1982). These probability curves have been used to define the trophic status of other reservoirs in Colorado, including Cherry Creek, Chatfield and Dillon. The trophic categories include ultraoligotrophic, oligotrophic, mesotrophic, eutrophic and hypertrophic. The water quality parameters used to make the trophic determinations are average reservoir total phosphorus, average and peak chlorophyll α concentrations, and average yearly Secchi disc transparency. The average chlorophyll α and phosphorus concentrations are shown in Figure 9. The maximum chlorophyll α and Secchi transparency are shown in Figure 10.

Based on the average reservoir phosphorus concentrations, the reservoir has a 6 percent probability of being mesotrophic and a 94 percent chance of being either eutrophic or hypertrophic. Similar trends are shown for the other trophic indicators (Figures 9 and 10). The reservoir is primarily eutrophic with common periods of being hypertrophic. The reservoir can be expected to become primarily hypertrophic without control programs. In order to give the reservoir a 50 percent probability of being mesotrophic, the average reservoir phosphorus concentration would need to be reduced to about 45 ug/l (Figure 9).

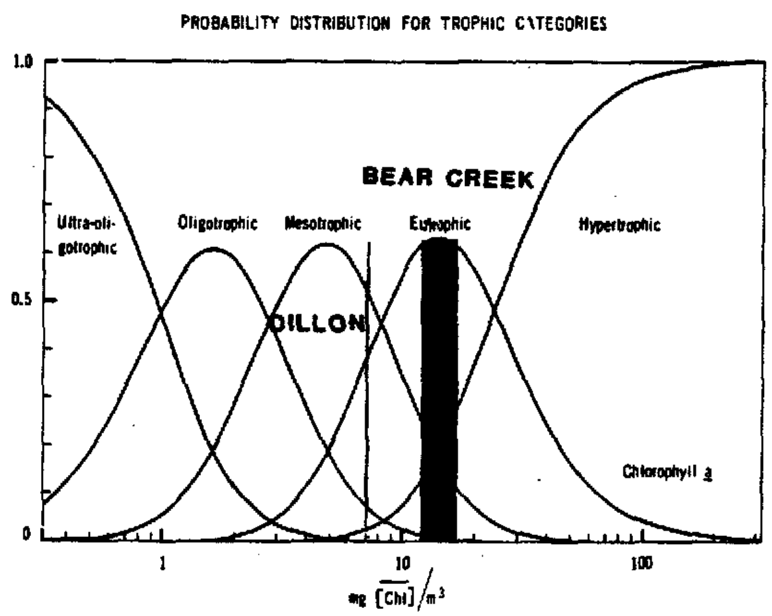
Research by Klemer and Konopha (1989) shows buoyancy regulation can account for biomass distribution and the dominance of specific blue-green algal species. This buoyancy control is influenced by nutrient loading. Waters enriched by nitrogen, phosphorus and inorganic carbon permit significantly more effective buoyancy regulation and more intense bloom formation than un-enriched waters. An important mechanism in Bear Creek Reservoir which could effect phytoplankton structure is external nutrient loading. This *bottom-up* control, coupled with foodweb interactions results in the dominance of blue-green species.

Figure 9.

Trophic status of Bear Creek Reservoir



Average Phosphorus
0% Oligotropic
6% Mesotropic
59% Eutrophic
35% Hypertropic

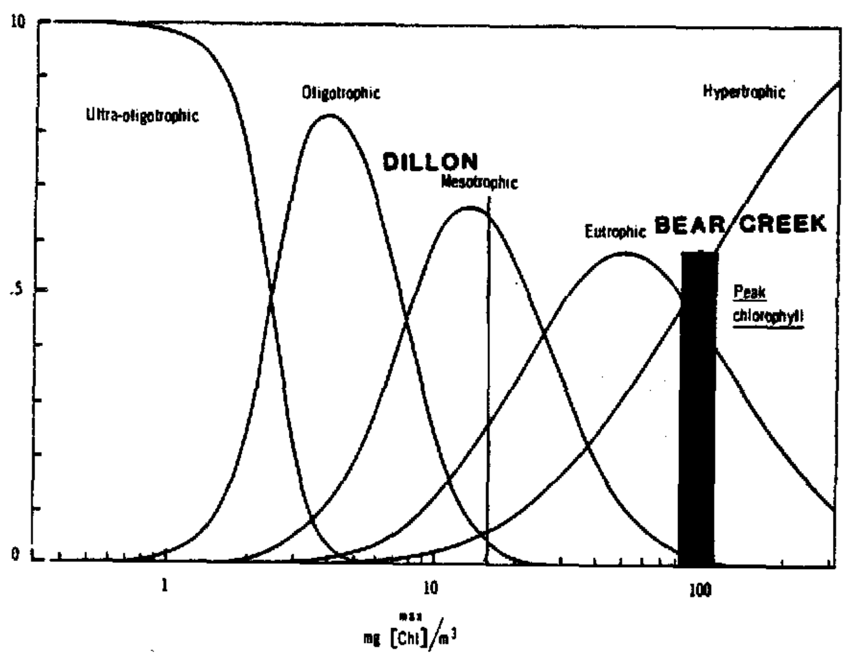


Average Chlorophyll a
1% Oligotropic
18% Mesotropic
61% Eutrophic
20% Hypertropic

Figure 10.

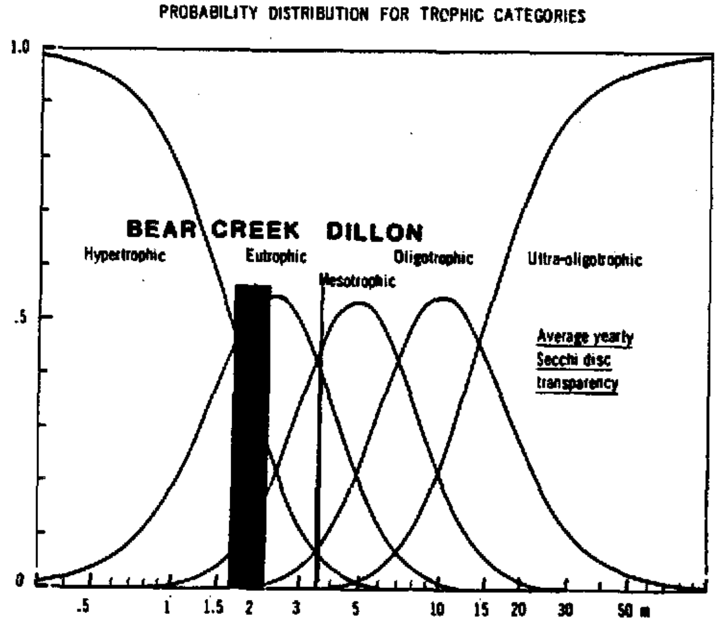
Trophic status of Bear Creek Reservoir

PROBABILITY DISTRIBUTION FOR TROPHIC CATEGORIES



Maximum Chlorophyll a
0% Oligotropic
1% Mesotropic
45% Eutrophic
54% Hypertropic

PROBABILITY DISTRIBUTION FOR TROPHIC CATEGORIES



Summer/Fall Secchi
1% Oligotropic
11% Mesotropic
52% Eutrophic
37% Hypertropic

Water quality and biological data have shown Bear Creek Reservoir has an existing trophicstatus which ranges from eutrophic to hypertrophic (Figures 9 and 10). This type of trophic status shows the reservoir to be use impaired as defined by the WQCC. There is a potential that the reservoir is not meeting its beneficial uses.

A general approach to changing the trophic status of waterbodies in Colorado is to regulate the total phosphorus input into the system by setting a numeric limit in the reservoir or lake. This numeric limit is then applied to wastewater discharge permits and adopted in nonpoint source control regulations which are designed to reduce total phosphorus loading and subsequently alter the tropic status to a mesotrophic category.

These specific numeric total phosphorus concentration standards have been established at Cherry Creek Reservoir, Chatfield Reservoir and Dillon Reservoir with the primary use of assigning numeric total phosphorus allocations. However, it must be understood that the establishment of a specific numeric total phosphorus standard for a waterbody and subsequent development of associated wasteload allocations may create a framework for basin management which has limited application from a technical prospective. This may not be the most effective approach to basin management for nutrient sources.

VII. RESERVOIR MODELING

MODELING OVERVIEW

A water quality model provides a tool for lake managers to predict future changes in a waterbody based on actual measured data. Developing nutrient-water or sediment-water budgets for a waterbody provides a measure of the annual, seasonal or other time-frame input and output of these constituents. Water quality models can be powerful management tools for assessing specific budgets over a variety of time periods and for a variety of projected load conditions.

Trophic modeling studies in reservoirs can be used in predicting changes to water quality benefits as a result of management programs in the watershed. There have been numerous modeling studies done for eutrophic waterbodies which could be applied to Bear Creek Reservoir. These various models are reviewed by Cooke et al. (1986), Jones and Bachmann (1976), Jones and Lee (1982), Moore (1987), OECD (1982), Reckhow and Chapra (1983a), Wetzel (1983) and others. In Colorado, there have been several reservoir studies which modified existing models to fit measured water quality trends (eg. DRCOG, 1984a; DRCOG, 1984B; Lewis et al., 1984; Hortman et al., 1980).

Generally, nutrient sources are the focus of reservoir or lake management programs. In an ideal lake system, water quality relationships and interactions of the chemistry, biology, limnology, meteorology, and hydrodynamics are known and they can be described by mathematical relationships. In the real world, these interactions provide too many variables over a usually limited observation time to actually develop a complex (sometimes called *mechanistic*) model.

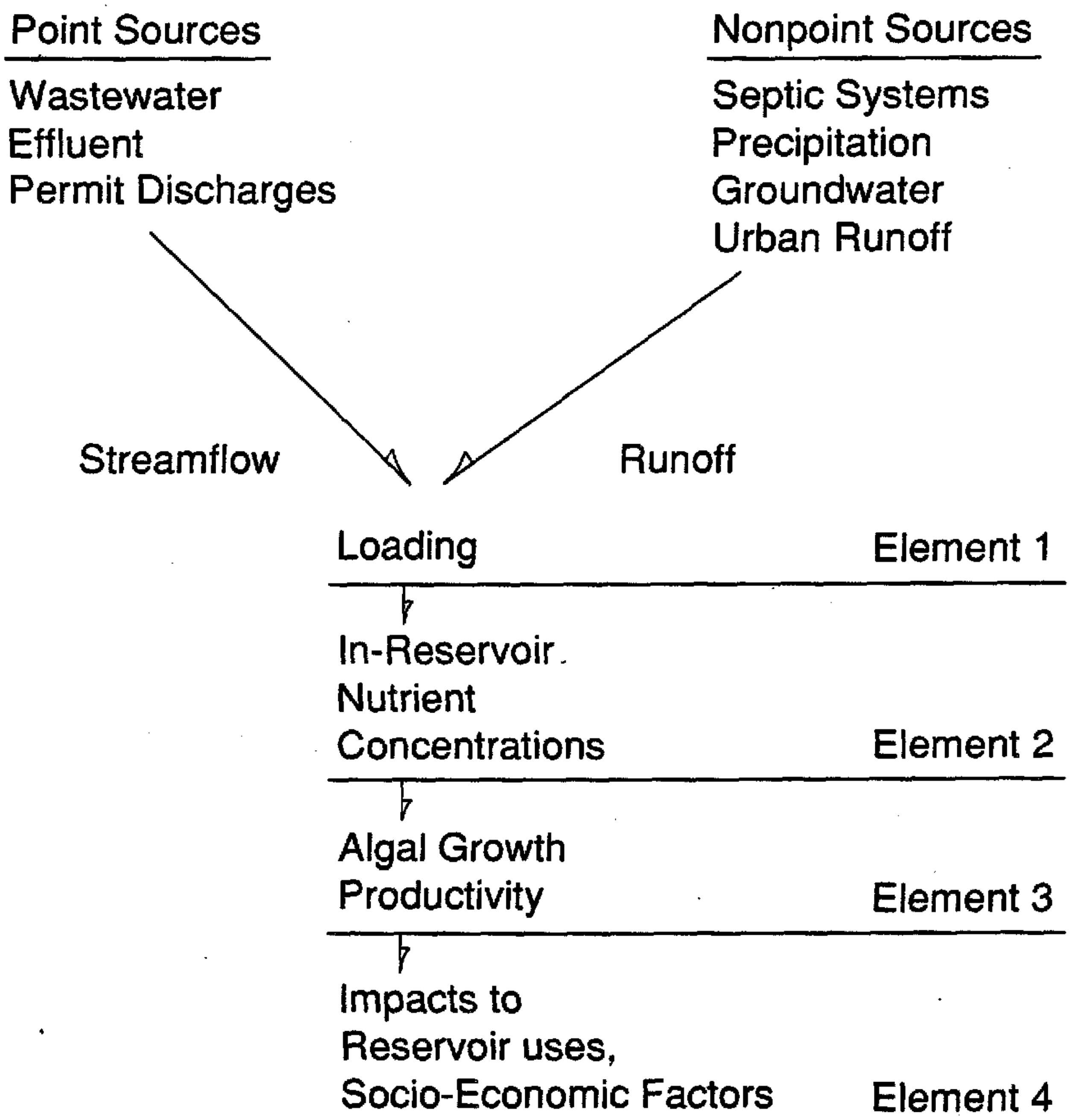
There are many examples in the literature of simple water quality models having been applied to reservoir systems and successfully predicting water quality changes based on limited actual data (Reckhow and Chapra, 1983a). This approach has been used in many cases and has been applied to several front range reservoirs to establish specific total phosphorus water quality standards (DRCOG 1984a; 1984b).

Reservoir systems are affected by a complex set of relationships. This complexity causes uncertainties with predicting trophic water quality parameters. A fundamental process for lake management is a determination of the likely causal relationships among the waterbody and associated watershed (Reckhow, 1979).

Lake or reservoir system relationships can be divided into several elements in an attempt to explain, or *model* significant factors which modify the trophic status of a waterbody. A generalized schematic of four elements which can be related to Bear Creek Reservoir to progressively explain trophic system relationships is shown in Figure 11. The approach shown in Figure 11 has been widely accepted by lake managers as a basis for establishing water quality management programs in lakes or reservoirs and the associated watersheds (Wetzel, 1983).

Figure 11.

Lake Relationships Used in Modeling



As discussed in the watershed section, point and nonpoint sources of nutrients result in a mass loading (expressed as pounds per year) of a specific pollutant to the system and is depicted as element 1 (Figure 11). Since total phosphorus is the nutrient of concern in Bear Creek Reservoir, the discussion will focus on phosphorus relationships with trophic parameters.

A generally accepted principle applied to phosphorus loading, is that no significant increase or decrease in the amount of phosphorus (conservative loading) reaches a reservoir from the source as a result of stream transport (Garman et al., 1986; Moore, 1987). There is the potential for some of point and nonpoint sources of phosphorus to be reduced prior to reaching the reservoir through plant uptake and soil infiltration within the stream bed. There is also a potential for diversions which result in a net reduction of source phosphorus load. However, it is generally accepted by lake managers that what enters the stream system is available as phosphorus loading to the reservoir.

Element II in Figure 11 is used to explain the relationship of total phosphorus loading from watershed point and nonpoint sources to the total phosphorus mass balance within the reservoir water column. There have been numerous phosphorus models proposed in the literature that attempt to explain this Element 2 relationship (Cooke et al., 1986; Dillon, 1975; Garman et al., 1986; Jones and Lee, 1982; Moore, 1987; OCED, 1982; Reckhow and Chapra, 1983a and 1983b).

Several of the popular models, which have been used in Colorado, are the Vollenweider, Canfield–Bachmann, and Dillon–Rigler models (Reckhow and Chapra, 1983a). These models are simple and they are based on the following assumptions:

1. The waterbody is phosphorus limited or can be made limited;

2. The waterbody behaves as a long–term completely mixed system;

3. Reservoir volume remains a constant;

4. The influx of phosphorus is constant, losses occur through deposition and outflow, and net internal loss is proportional to phosphorus concentration in the reservoir.

By their nature, the above assumptions introduce a certain level of uncertainty when applying models to explain Element 2 relationships. There are periods when a waterbody can be phosphorus limited, nitrogen limited or co–nutrient limited within an annual cycle. Most waterbody, particularly those with eutrophic status, experience periods of stratification and, therefore, they are not always completed mixed. Precipitation events and operations of a waterbody can result in a fluctuating volume, which is particularly event in reservoirs used for agricultural or water supply. There can also be large seasonal variability in the influx and fate of the phosphorus within a reservoir system.

Nevertheless, the simple phosphorus models have been successfully used, and in some cases have been quite accurate in predicting the waterbody total phosphorus concentrations from calculated mass phosphorus loadings of point and nonpoint sources. Therefore, the uncertainty in the model of Element 2 is dependent upon the reservoir system. This uncertainty decreases as the number of years of data is increased and the data base becomes more reliable for refining the total phosphorus modeling.

The algal growth relationships as depicted in Element 3 (Figure 11) represents a step in the trophic modeling process which is a source of uncertainty. The link between total phosphorus concentration and algae growth in a phosphorus limited system is undisputed: more phosphorus results in more algae (Wetzel, 1983). However, there is wide variance among relationship models which attempt to quantify total phosphorus with the resultant algal productivity. Algal growth is quantified by the concentration of Chlorophyll α . Most of these models then relate total phosphorus concentration to the concentration of chlorophyll α .

The uncertainties of defining exact rate responses are due to variations in sampling periods and techniques, analytical procedures, zooplankton grazing, light limitation, types of algae and supplies of other nutrients which effect chlorophyll α production. Most of the relationships reported in the literature also are based on seasonal total phosphorus and chlorophyll α observations (eg. Canfield and Bachmann, 1980; Chapra and Tarapchak, 1976). There are very few published relationships which link the in-lake phosphorus concentration to an instantaneous or peak chlorophyll α concentration (eg. Prairie et al., 1989).

The Cherry Creek Reservoir clean lake study provides an example of the uncertainty in modeling Element 3 relationships (DRCOG, 1984b). The model used for this reservoir study was the Jones-Bachmann relationship which correlates seasonal total phosphorus and chlorophyll as shown in Figure 12. The relationship has not been satisfactory with respect to predicting chlorophyll on a year to year basis in Cherry Creek Reservoir (Cherry Creek Water Quality Authority, 1986–1989). Similar results have been demonstrated for Chatfield Reservoir (Chatfield Basin Water Quality Association, 1986–1989; Woodward-Clyde, 1990).

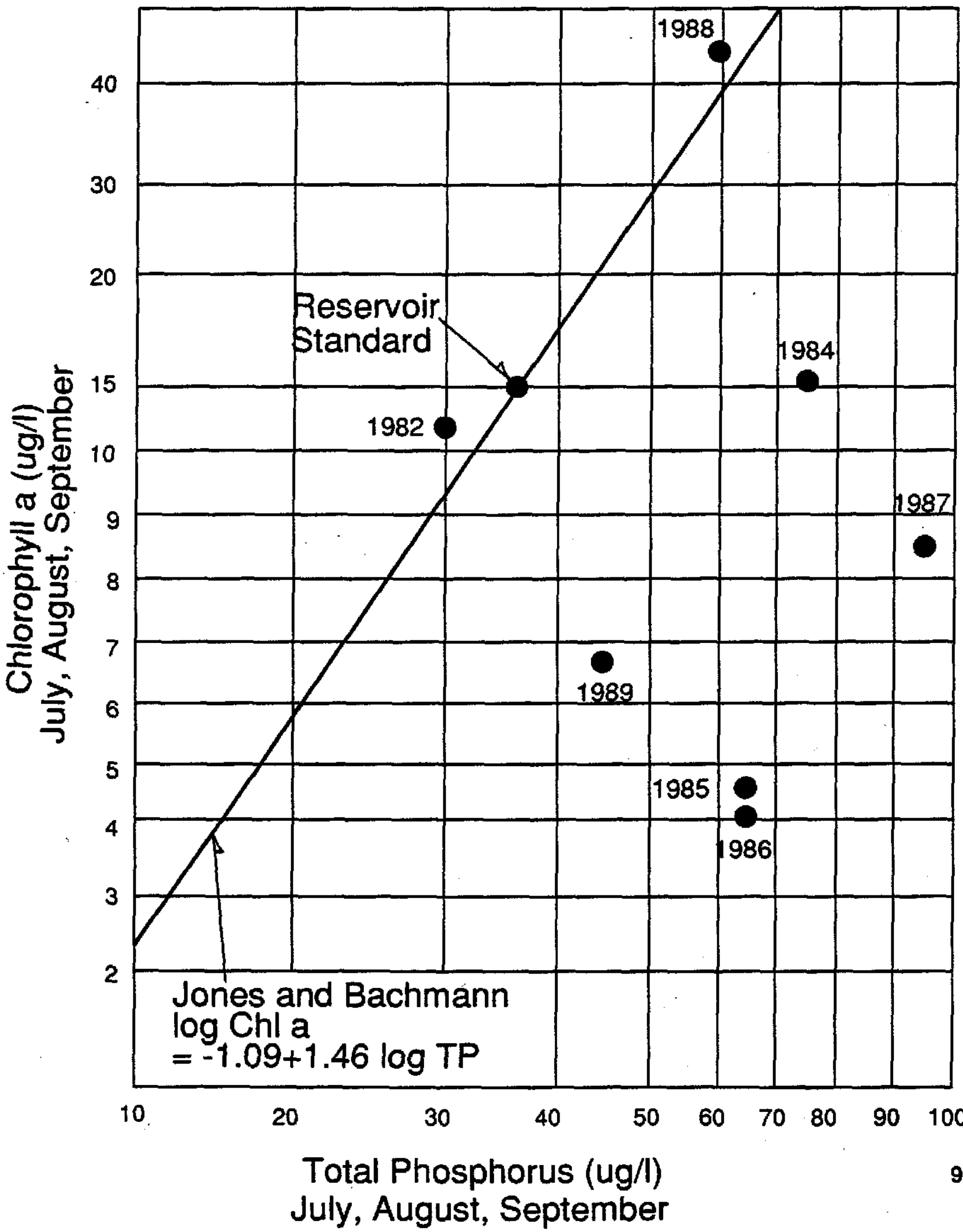
The link between algae growth and impacts to reservoir uses is depicted in Element 4 (Figure 11). This element is the most significant of the four elements when considering lake management. Most lakes have multiple beneficial uses: drinking water supply, aquatic life, recreation and agricultural supply. There is a degree of uncertainty when attempting to establish a relationship between algal growth and recreation uses.

A primary reason for this uncertainty is the difference in what people view as acceptable water quality impacts and the actual measured degradation to a waterbody. Opinions of people using reservoirs for recreation are subjective. A wide range of acceptability has been recorded in the literature and is based on a number of factors including reservoir type, location, climate, economic factors, and others (eg. WQCD, 1982). The user population opinions on acceptable water quality relationships are summarized in the public and user survey section of this report.

There are numerous issues and concerns which must be evaluated when establishing specific numerical chlorophyll α and total phosphorus concentrations, particularly when attempting to explain links of point and nonpoint source nutrient inputs to lake impacts. The combination of uncertainties in Elements 1–4 can restrict the use of single numeric values as a sensible management approach for lake management. A range of values may be more appropriate from a management approach.

Figure 12.

Jones and Bachmann Relationship for Cherry Creek Reservoir



RESERVOIR MODEL

Bear Creek Reservoir has been identified as a eutrophic reservoir due to an input of sediments, nutrients and organic matter, as well as internal loading of phosphorus when the reservoir is anoxic, at rates which exceed the reservoirs assimilative or discharge capacities. The high nutrient loading to the reservoir results in periodic algal blooms and general degradation of water quality. The nutrients of concern are nitrogen and phosphorus. The reservoir generally shows co-limitation between phosphorus and nitrogen. Nitrogen is difficult to control with basin management strategies and it is generally practical to target nitrogen for control of algal productivity. The management strategy then must focus on phosphorus which can be better controlled.

The water quality monitoring program for the reservoir was conducted from March 1988 through March 1989. Very limited reservoir data exist prior to this sampling period. Water quality relationship models for Bear Creek Reservoir are primarily based on the limited water quality monitoring performed as part of the clean lakes study with some model verification based on data collected by the WQCD (1988). Model relationships are discussed for Elements 1–4 shown in Figure 11.

Annual total phosphorus loadings to Bear Creek Reservoir from various sources was presented in the reservoir quality section and is shown in Tables 22 and 23. Total phosphorus models are usually developed to evaluate annual phosphorus loadings to a given waterbody. However, these annual models are generally developed for waterbodies with long detention times, measured in one or more years.

Bear Creek Reservoir has short detention times with the entire reservoir volume being replaced in the range of less than 1 week in the spring runoff period to 2.3 months in the winter period. If there is surface pass through during any of these periods, then the actual detention times for the epilimnion would be less. However, for modeling purposes the detention times are based on replacement of the entire waterbody. An annual approach to phosphorus modeling is not appropriate because of these variable and short detention times. The detention times are more consistent for seasonal periods. In the summer growing season, the detention times are generally constant as a result of reservoir operations and regulation of inflow water by the agricultural diversions.

A seasonal approach was used to investigate the phosphorus and algal relationships in Bear Creek Reservoir. A summer growing season was defined as the time period between mid-June and mid-September. This summer season was selected for model evaluation for the following reasons:

1. It represents a period of maximum chlorophyll α production;

2. It was the period of nuisance algal blooms;

3. It was a period of high recreational use at the Park;

4. It begins at the end of the high spring inflows and extends to the fall reservoir turnover;

5. The inflow/outflow volumes and detention time was generally constant;

6. Internal loading of phosphorus occurs as a result of anoxic conditions.

A schematic of the Bear Creek Reservoir System showing the assumptions used in the development of total phosphorus loadings to the reservoir is shown in Figure 13. A major factor affecting loading in Element 1 was, in 1988, approximately 45 percent of the total hydraulic flow in Bear Creek was diverted away from the reservoir via Harriman Ditch during the mid–June through mid–September period. The average annual diversion is about 30 percent [see the water rights section for more details on water diversion].

The out–come of storage changes in Bear Creek Reservoir could not be taken into account in modeling studies at this time. The water quality models can be applied to projected changes in storage volume, once this information is determined by the water court. Therefore, an important assumption made in this study was no change in the pool volume would occur in the near future. Any increase in the permanent pool volume would effect the water quality and a re–assessment of water quality data and modeling would be required for reservoir management.

As a result, a significant portion of the total phosphorus loading from the Evergreen, West Jefferson County, Kittredge, and Genesee Wastewater Treatment Facilities, as well as, a portion of the nonpoint source load was diverted away from the Reservoir during the summer growing season. The entire wastewater point sources from the Morrison and Willowbrook Facilities were assumed to reach the Reservoir. The ortho–phosphorus point source loading obtained for each wastewater treatment facility was based on measured sewage flow rates and effluent total phosphorus concentrations monitored in 1988 and 1989. This effluent monitoring was coordinated with the clean lakes monitoring. The summer season total phosphorus loading calculated for each wastewater treatment facilities in the Bear Creek Basin are shown in Table 22.

Based upon the water quality monitoring performed in 1988, it was determined that approximately 3,280 pounds of total phosphorus entered the reservoir from all sources during the mid–June through mid–September summer growing season. The difference between this total phosphorus loading and the calculated total point source loading of 2,300 pounds is 980 pounds which was assumed to be the nonpoint source contribution of total phosphorus loading to the reservoir during the summer season.

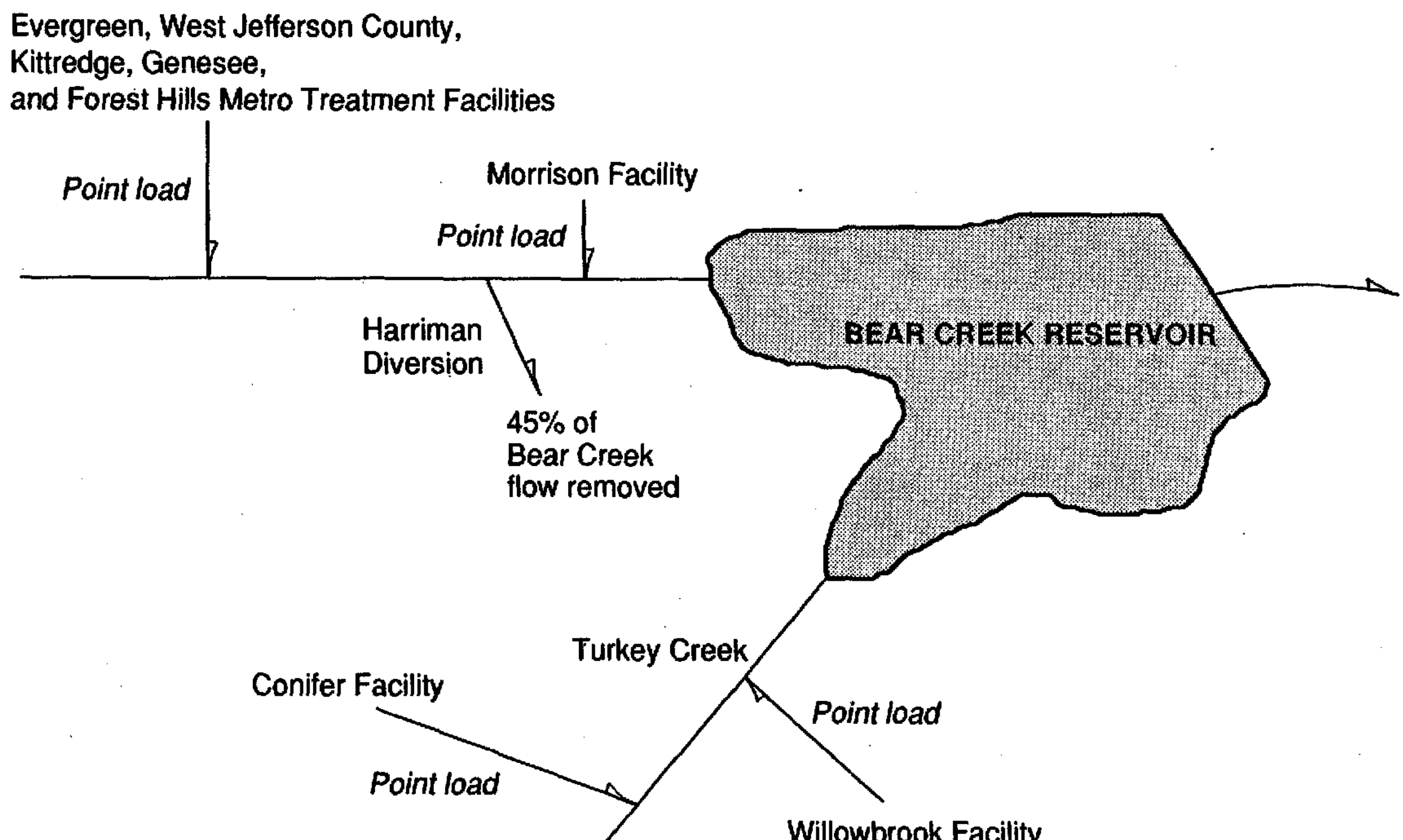
Several of the simple empirical phosphorus models reported in the literature were applied to the data obtained from Bear Creek Reservoir during the 1988 monitoring season (Cooke et al., 1986; Dillon and Rigler, 1974; Jones and Bachmann, 1976; Reckhow and Chapra, 1983a and 1983b). Of the models tested, the Dillon and Rigler (1974) total phosphorus model provided the best fit between the predicted and measured photic zone phosphorus on a monthly and seasonal basis. The modified Dillon–Rigler model (1974) as shown in Cooke, et.al. (1986) and proposed for use with Bear Creek Reservoir is as follows:

Table 22. Total Phosphorus (TP) Point Sources and Loading for the Summer Season

FACILITY	TP LOADING TO CREEKS (lbs/season)	PERCENT TO RESERVOIR* (%)	TP TO RESERVOIR (lbs/season)
Evergreen	1310	55	720
West Jefferson County	1130	55	620
Kittridge	240	55	130
Genesee	350	55	190
Forest Hills Metro	20	55	10
Morrison	130	100	130
Willowbrook	480	100	480
Conifer	20	100	20
TOTAL POINT SOURCE	3680	62	2300

* A percentage of the total phosphorus load was assumed to be diverted by the Harriman Ditch, which averaged (time-weighted) 45 percent diversion for the summer season.

Figure 13.
Assumptions used for Bear Creek Reservoir System



PR = [L*(1-R)]/[Z*pf]

where;

PR = in-reservoir phosphorus concentration, mg P/m^3

L = areal loading of total phosphorus, mg/m^2/month for the lake surface

R = phosphorus retention coefficient, where

R = TP(in)-TP(out)/TP(in)

Z = mean depth (m), [based on reservoir volume and surface area]

pf = flushing rate, per month, where

pf= Q/V with,

Q = monthly water outflow, m^3/month

V = lake volume, m^3

The monthly total phosphorus concentrations in the reservoir were tabulated by photic zone, aphotic zone and for a composite water column. The phosphorus retention coefficient accounts for monthly internal loading of phosphorus. The total phosphorus values predicted by the model were compared with the reservoir measured values. The monthly comparisons are shown in Table 23.

There were significant differences in photic zone and aphotic zone phosphorus concentrations for the months of February, July, August and September. In February, the photic zone total phosphorus concentration was significantly higher than the aphotic zone concentration. In the three summer months, the aphotic zone total phosphorus concentration was significantly greater than concentrations in the photic zone. The high aphotic zone concentrations were a result of a net loss of total phosphorus from sediments into the water column (internal loading). The total phosphorus sedimentation rate for September is negative showing that a net increase in the in-reservoir total phosphorus concentration was a result of total phosphorus release from the sediments.

As shown in Table 23, the Dillon-Rigler model does not predict in-reservoir phosphorus concentrations when the reservoir does not act as a complete mixed system, as defined by the differences in the photic and aphotic total phosphorus concentrations. The model does predict the in-reservoir phosphorus concentration for months when the reservoir acts as a complete mix system.

T-tests were performed on the predicted total phosphorus concentrations and those measured concentrations for photic, aphotic, and composite zones. The t-tests showed a correlation between photic zone concentrations and predicted values. The major months of deviation between predicted and measured values occurred during months when the reservoir was not completely mixed.

The Dillon-Rigler model was used to compare predicted and observed total phosphorus concentrations by seasons as shown in Table 24. The predicted total phosphorus concentrations showed good fit with photic zone measured total phosphorus concentrations. The Dillon-Rigler Model values for the summer season are as follows:

Table 23. Bear Creek Reservoir Model Data for Phosphorus (TP) by Month

	INFLOW (AC-FT) (Q)	STORAGE (AC-FT) (V)	OUTFLOW (AC-FT)	FLUSH RATE (pf)	TP INFLOW (mg/m3)	TP OUTFLOW (mg/m3)	TP SED. RATE (R) (conc)	TP SED. RATE (R) (mass)	LOADING (mg/m2) (L)	TP RESERVOIR PHOTIC (mg/m3)	TP RESERVOIR APHOTIC (mg/m3)	TP RESERVOIR COMPOSIT (mg/m3)	TP PREDICTED (mg/m3) (Pr) (conc)	TP PREDICTED (mg/m3) (Pr) (mass)
Jan.	1342	1987	1375	0.69	469	180	0.62	0.61	1742	-	-	-	172	177
Feb.	1467	1983	1514	0.76	511	332	0.35	0.33	2075	256	135	219	318	330
Mar.	2419	1987	2614	1.31	402	275	0.32	0.26	2692	-	-	-	250	274
Apr.	6854	2064	6451	3.13	143	108	0.24	0.26	2613	115	115	115	114	111
May	13184	2069	10778	5.21	106	101	0.05	0.22	3869	99	104	101	127	104
June	6587	2016	7578	3.76	96	81	0.16	0.03	1751	74	120	88	71	81
July	2849	1971	2150	1.09	158	150	0.05	0.28	1246	89	332	164	195	148
Aug.	2186	2026	2408	1.19	161	114	0.29	0.22	974	118	462	224	105	115
Sept.	1226	1963	1356	0.69	146	165	-0.13	-0.25	496	173	233	191	146	162
Oct.	1034	1978	861	0.44	322	115	0.64	0.70	114	119	115		137	113
Nov.	1259	1971	1206	0.61	346	118	0.66	0.67	113	113	113		121	118
Dec.	1420	1968	1368	0.70	361	107	0.70	0.71	1419	108	109	108	110	104
Monthly	3486	2000	3305	1.65	268	154	0.43	0.46	1759	126	184	154		
Year	41,827	2000	39,659	19.8					31,033				154	

Note:

1) Mean reservoir depth 5.55 M.
2) Annual reservoir flush rate is 19.8 times per year, 18.4 days.

Table 24. Bear Creek Reservoir Predicted Phosphorus (TP) Model Data for Seasons

Season	TP Loading (mg/m3) (L)	TP Sediment Rate (R)	Flush Rate (Pf)	TP Reservoir Photic (mg/m2)	TP Reservoir Aphotic (mg/m3) (Pr)	TP Reservoir Composite (mg/m3)	Predicted TP (mg/m3)
Spring	2778	0.17	4.03	96	102	98	103
Summer	1117	0.11	1.68	111	329	178	118
Fall	1182	0.69	0.58	111	113	112	115
Winter	2170	0.40	0.92	256	135	219	255

- Average phosphorus retention coefficient (R) = 0.11
- Mean depth (Z) = 5.55m
- Mean flushing rate (pf) = 4.53
- In-reservoir phosphorus concentration (PR) = L [1 - 0.11] / 5.55(4.53)
- PR = 0.035(L)

A constant reservoir surface area of 110 acres was used in the Dillon-Rigler modeling. The predicted total phosphorus concentrations for the summer season based on the measured total phosphorus loading of 3,280 pounds resulted in a predicted seasonal phosphorus concentration of 118 ug/l. This compared to an observed total phosphorus concentration of 111 ug/l for this same period.

TRANSPARENCY MODEL

There are several equations which have been developed to describe the relationship of phosphorus to transparency as measured by Secchi depth. A transparency relationship model as developed by Carlson (1977) was modified to reflect relationships in the reservoir:

$\ln(SD) = 5.451 - 0.98\,[\ln(TP)]$
where, TP = mean summer photic zone total phosphorus
SD = mean summer Secchi depth

This equation was used to predict Secchi transparency for seasons. The seasonal relationship data based on the above equation compared with the mean measured values are shown below:

SEASON	SECCHI DEPTH (M) MEASURED	PREDICTED
SPRING	0.8	2.4
SUMMER	2.1	2.3
FALL	2.0	1.9
WINTER	1.6	1.1

The predicted Secchi depths are similar to measured mean data for the summer, fall and winter seasons. The mean spring Secchi depth was much less than the predicted value. This difference was due to the introduction of suspended sediments associated with spring runoff. Therefore, the relationship between phosphorus and Secchi depth in the spring season is obscured by other factors. The application of a transparency model in reservoir management will be in assessing light availability for algal productivity. The phytoplankton community structure and diversity is effected by the depth of light penetration. The low summer Secchi readings are indicative of a eutrophic waterbody.

UNIFYING NUTRIENT–CHLOROPHYLL RELATIONSHIP MODEL

Previous studies of the relationship between phosphorus, nitrogen and chlorophyll α have shown a linkage (eg. Canfield and Bachmann, 1980; Chapra and Tracpchak, 1976; Dillon and Rigler, 1974; Dillon, 1975; Hoyer and Jones, 1983; Jones and Bachmann, 1976; Reckhow and Chapra, 1983a). The use of these relationships has been applied in management of eutrophic waterbodies (OECD, 1982). However, there is enough variance in the regression equations within and among waterbodies to warrant caution in using an empirical model which only defines generalized relationships. This variance is caused by residual uncertainties in a number of physical, chemical and biological factors.

Phosphorus–chlorophyll α relationships are typically unreliable once total phosphorus concentrations exceed 100 mg/m^3 which suggests phosphorus addition beyond the 100 mg/m^3 limit do not enhance algal biomass productivity (Agusti et al., 1990). This observation may account for some of the uncertainty in applying phosphorus–chlorophyll α models to highly eutrophic systems, such as Bear Creek Reservoir.

An upper phosphorus limiting value was investigated by Smith (1982), who explained this limitation by showing nitrogen becomes limiting at high phosphorus concentrations. An alternate hypothesis is that nutrient conditions ameliorate, where increased light attenuation caused by algal production reduces light availability to a point where increased nutrient loading has no effect on algal biomass (Agusti et al., 1990). This light limitation hypothesis has been proposed to explain nutrient limitation in Cherry Creek Reservoir (Camp Dresser and McKee,Inc., 1990).

These potential phosphorus limiting conditions could occur in the reservoir. Therefore, an alternate phosphorus–chlorophyll α model was investigated which could assess phosphorus and chlorophyll α relationships in the reservoir. Prairie et al. (1989) evaluated the nutrient chlorophyll α relationships in many lakes and reservoirs to assess if variation in the total nitrogen to total phosphorus (TN:TP) ratio could be used to explain differences in slope and intercept of phosphorus chlorophyll α equations. The focus of the assessment was restricted to eplimnetic waters. The findings of the Prairie et al. study are as follows:

1. The TN:TP ratio affects the slope, correlation coefficient of phosphorus–chlorophyll α and nitrogen–chlorophyll α relationships;

2. TN and TP correlate equally well with chlorophyll α over the whole TN:TP range;

3. Lakes with low TN:TP ratios have a tight coupling between phytoplankton biomass and phosphorus;

4. Use of chlorophyll α –phosphorus equations should be restricted to waterbodies with similar TN:TP ratios.

The chlorophyll α – phosphorus relationships in Bear Creek Reservoir were evaluated by the TN:TP ratio model as described by Praire et al. (1989). Additionally, the ratio of total insoluble nitrogen (TSIN) to ortho–phosphorus (PO_4) was also assessed by the TN:TP ratio model. The relationship between the slope and intercept coefficients of the chlorophyll α –phosphorus and chlorophyll α –nitrogen equations and the TN:TP ratios were plotted (Figure 14) as shown in Praire et al. (1989). An *asymptote* of TP is reached at about 100–125 mg/m^3 where the chlorophyll α concentration appears to reach a maximum with further increases in phosphorus concentration not resulting in higher chlorophyll α concentrations (Figure 14).

The TN:TP ratios and mean values for nitrogen, phosphorus and chlorophyll α used in the unifying nutrient–chlorophyll α model are shown below:

SEASON	RATIO TN:TP	RATIO TSIN: PO_4	NITROGEN PHOTIC (mg/ℓ)	NITROGEN APHOTIC (mg/ℓ)	PHOSPHORUS PHOTIC (mg/ℓ)	PHOSPHORUS APHOTIC (mg/ℓ)	CHLOROPHYLL PHOTIC (ug/l)	CHLOROPHYLL APHOTIC (ug/l)
SPRING	8	6	0.771	0.900	0.096	0.102	10.3	6.8
SUMMER	9	4	0.919	0.893	0.111	0.329	19.2	2.3
FALL	17	5	1.841	1.559	0.111	0.113	9.5	7.2
WINTER	7	7	1.719	2.081	0.256	0.135	16.7	0.6

The summer season values for the photic zone were compared to the slope and intercepts in Figure 14. This information was used to develop summer chlorophyll α – phosphorus model equations. Comparisons can also be made for other seasonal data as necessary for reservoir management.

A comparison was made between TN:TP and TSIN:PO_4 ratios. The TSIN:PO_4 relationships show a good correlation for measured reservoir data. This TSIN:PO_4 ratio model may provide a better estimate of chlorophyll α –phosphorus relationships. However, there is much less literature information relating ortho–phosphorus and algal biomass. Most of the phosphorus released in wastewater effluent is in the ortho form. The stream data shows ortho–phosphorus is the major form of phosphorus reaching the reservoir in the summer season.

The recommended chlorophyll α – phosphorus and chlorophyll α – nitrogen equations for use in management of Bear Creek Reservoir in the summer season are:

1. Phosphorus $LOG10\ (CHL\ \alpha) = 0.15 + 0.55\ [LOG10\ (TP)]$
2. Nitrogen $LOG10\ (CHL\ \alpha) = -0.10 + 0.46\ [LOG10\ (TN)]$

These equations are based on existing TN:TP ratios. A change in the ratio could require new equations based on the new slope and intercept from Figure 14. However, the initial model assessment would be made for the existing ratio which could actually underestimate in–reservoir chlorophyll. A new predicted TP:TN ratio would be used to adjust predicted chlorophyll.

A plot of the mean chlorophyll α to total phosphorus can be generated from the TP equation for various projected mean chlorophyll α concentrations which could occur in the reservoir

Figure 14.

Slope and intercept curves for TP and TN for Chlorophyll Relationship Model.

The lines are LOWESS fitted curves to regression coefficients produced by the moving window algorithm. (Prarie et al., 1989).

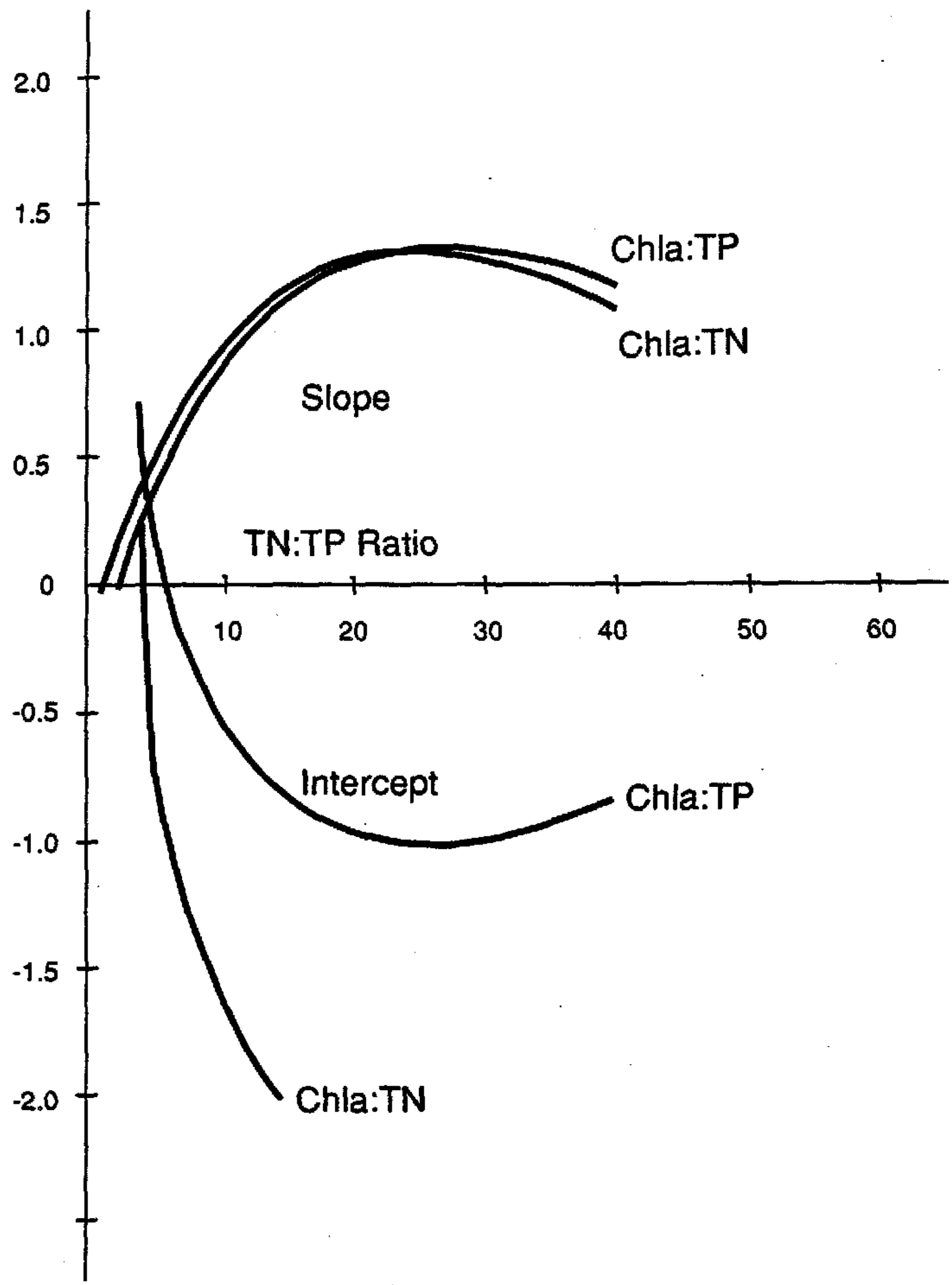
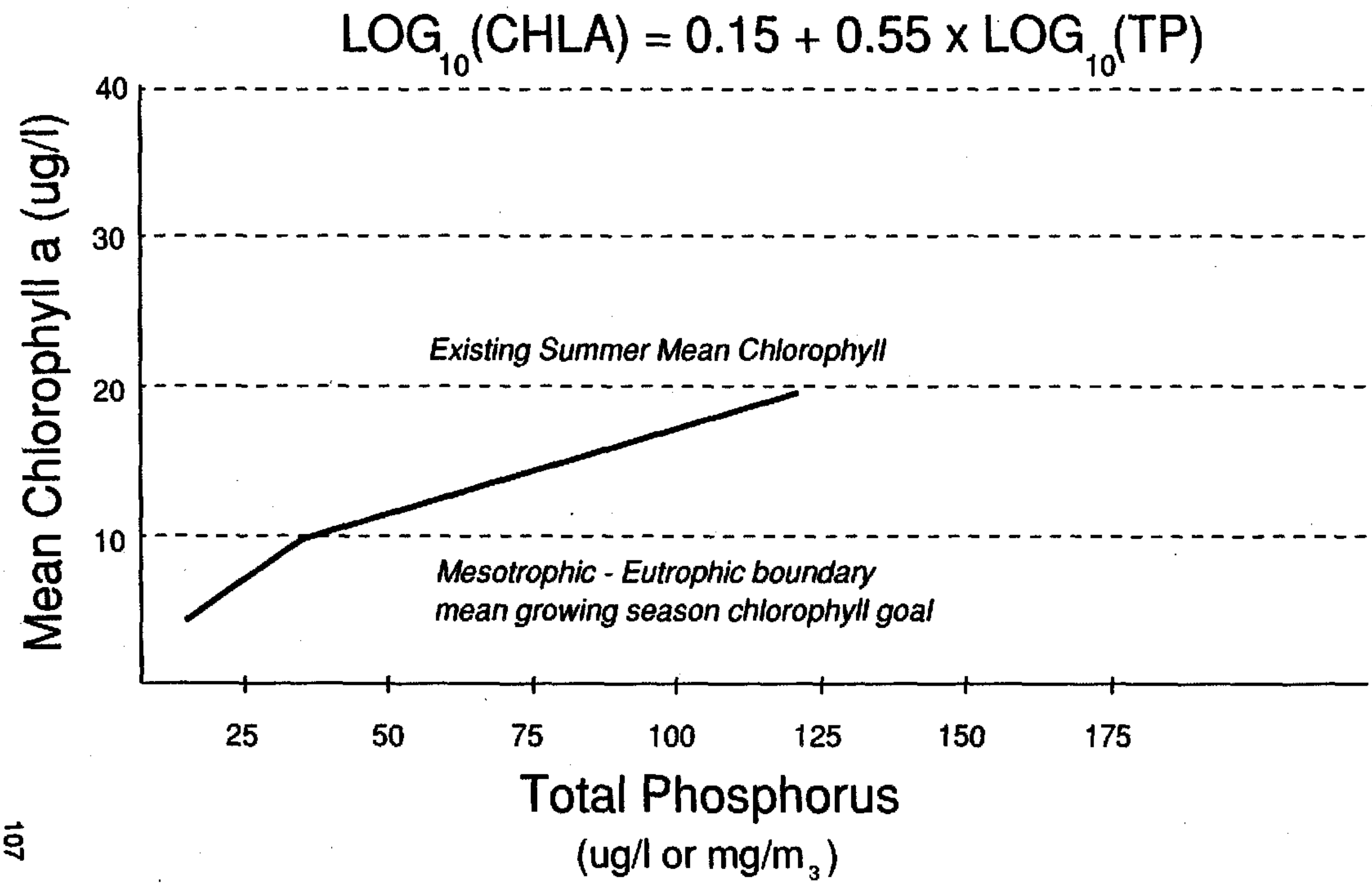


Figure 15.

Chlorophyll - Phosphorus Summer Season Relationship in Bear Creek Reservoir



with a corresponding mean summer chlorophyll α concentration of 19 ug/l.

As an example of the relationship between chlorophyll α – phosphorus with the TP equation, if total phosphorus is reduced to a mean summer value of 50 mg/ℓ, it would result in a new mean summer chlorophyll α concentration of about 12 ug/l. The TP model shows it would require an 80 percent reduction in total phosphorus to obtain a 50 percent reduction in mean chlorophyll α concentrations.

NUISANCE ALGAL BLOOM FREQUENCY MODEL

Although phosphorus controls are often implemented in management programs for eutrophic waterbodies, the actual control is directed at biomass production. The excessive biomass production in eutrophic systems is a major cause of continued degradation. Controlling nutrient sources has been shown to be a sound method for indirectly reducing productivity of the system (Garman et al. 1986). Chlorophyll α has been used to measure algal biomass and assess the success of a management program. There have been many studies which have related chlorophyll α to water quality aspects that impact water uses, including transparency, hypolimnetic oxygen depletion, fish production, taste-odor episodes, blue-green toxicity and trihalomethane (Walker, 1985).

In considering total phosphorus, the lake has a 35 percent probability of being hypertrophic. It is assumed that the relatively high flushing rate of the reservoir is removing nutrients and algae from the reservoir's eplimnion layer as shown by the outflow data sets. If the reservoir flushing rate is reduced and nutrient loadings remain constant, then the potential for further eutrophication problems related to algal productivity will substantially increase.

The measured mean summer phosphorus concentration of 111 ug/l had the potential of producing very high chlorophyll levels. Several phosphorus/chlorophyll models were used to test the relationship in the reservoir. These models predicted a range of average growing season chlorophyll α values between 50 and 80 ug/l (eg. Carlson, 1977). However, the observed average chlorophyll α concentration during the summer period was 19 ug/l.

As a comparison, the total phosphorus water quality standards in Chatfield and Cherry Creek Reservoir were established with corresponding chlorophyll α concentration goals of 17 and 15 ug/l, respectively, for the summer (July – September) growing season (DRCOG 1984a and 1984b). These reservoirs have substantially lower summer phosphorus values compared with Bear Creek Reservoir. This suggests a potential for higher chlorophyll α concentrations in Bear Creek Reservoir with the existing total phosphorus loading. The detention time of the reservoir appears to have an important role in algal production.

There was a large temporal variability in chlorophyll α data within the summer growing season for the photic zone of Bear Creek Reservoir. The summer photic zone chlorophyll α in the reservoir was 19 ug/l while the geometric mean was about 11 ug/l. The mean chlorophyll α data is skewed by high peak bloom values which produces a bimodal data distribution. Higher chlorophyll α values of about 100 ug/l were measured during the summer. However, the chlorophyll α response is usually assessed from mean concentrations.

The use of mean chlorophyll α data in modeling and assessing conditions in waterbodies have certain advantages (Walker, 1985):

1. Estimates of means from a given monitoring program have lower variance;

2. Mean values can be related to watershed conditions using nutrient budgets; and

3. Mean values have been used in many waterbody assessments, classifications and management programs.

There is a natural temporal variability in chlorophyll α concentrations within a given waterbody for a given season (OPEC, 1982). This variability is not always reflected by a mean value, as demonstrated by the Bear Creek data. The development of management programs based solely on mean concentrations or trophic state indices must be applied with caution by decision makers (Bachmann and Jones, 1976; Carlson, 1977; Chapra and Tarapchak, 1976; Walker, 1985).

The peak chlorophyll α periods were associated with nuisance algal blooms which were regarded as use impairment by the public and Park users. The reservoir quality was otherwise considered as good. Peak chlorophyll α concentrations were observed in February, April, and a five week period in August through September. The late summer peak chlorophyll α occurred during the time of maximum recreational use. Therefore, an important aspect of reservoir management should be directed at reducing the frequency of nuisance algal blooms.

The paper by Walker (1985) develops a conceptual framework for relating mean chlorophyll α values to indices of use impairment. The method developed by Walker (1985) employs statistical frequency distributions which account for temporal variability in chlorophyll α on use impairment. This approach is based on the concept that water use impacts are more directly related to instantaneous chlorophyll α concentrations than annual or season mean values.

Nuisance values have been described for chlorophyll α ranges based on literature data (Walker, 1985) and user survey information:

CHLOROPHYLL α (ug/l)	NUISANCE CONDITIONS	USER RESPONSE
0–10	NO PROBLEM	GOOD
10–20	ALGAL SCUM EVIDENT	AVERAGE
20–30	NUISANCE CONDITIONS	POOR
>30	SEVERE NUISANCE PROBLEMS	USE IMPAIRED

There is general agreement in the literature that mean chlorophyll α values exceeding 20 ug/l are indicative of a use-impaired waterbody. The boundary between mesotrophic and eutrophic states , based on chlorophyll α, ranges from 9 to 15 ug/l (OCED, 1982; Cooke et al., 1986; Reckhow and Chapra, 1983a; 1983b). A target mean chlorophyll α value of 10 ug/l has been proposed as defining the limit for a good water system which does not need major restoration.

Walker (1985) presents a set of algorithms for describing chlorophyll α frequency distributions. The algorithms were solved using summer photic zone data. The probability of chlorophyll α samples exceeding specific criteria levels (FZ20, FZ30, FZ40 and FZ50) in the reservoir by seasons and photic zone are shown in Table 25. In the summer season, the chlorophyll α would exceed 20 ug/l 29 percent of the time. This higher percentage exceedance of the 20 ug/l level also occurs in the winter period. Table 25 provides a measure of nuisance frequency for various management options. The objective of this model in relation to reservoir management is to reduce the probability of values exceeding a specific chlorophyll α level.

Two target options (FZ20 and FZ40) were selected for reservoir evaluation. These options were plotted against mean chlorophyll α and percent exceedance (Figure 16). The existing conditions for the summer are graphed with bold lines (Chl α = 19 ug/l; percent exceedance = 29). The lower limit of 10 ug/l chlorophyll α relates to percent exceedance of 14 percent at the 20 ug/l option and 5 percent at the 40 ug/l option. Even when the reservoir trophic status is balanced at the mesotrophic/eutrophic boundary, there will be nuisance algal blooms in the summer and winter periods.

However, the frequency of blooms is near to a value that Park users would not perceive a problem. Therefore, the range of reduction in nuisance frequency for reservoir management will be between 30 to 14 percent for a 20 ug/l option and 11 to 5 percent for a 40 ug/l option.

A reduction in nuisance bloom frequency can be an effective management tool, since reduced frequency can be related to a corresponding nutrient reduction in the watershed. Reducing nuisance bloom frequency will cause a lower predicted mean chlorophyll α for a given season (ie., summer). A mean chlorophyll α value can be imputed into the TP:CHL equation previously presented in the nutrient-chlorophyll α section. Once a new TP value is predicted, then the TN:TP ratio changes which requires a new TP:CHL equation. The adjusted CHL can then be calculated to project anticipated a mean summer chlorophyll with reduced phosphorus loading. The predicted TP value, based on the proposed chlorophyll α goal, can then be applied to the modified Dillon-Rigler model. The result from this equation is an estimated loading reduction for phosphorus for the specified season.

The reduction in phosphorus from the watershed can then be evaluated by source until a total percent reduction is achieved. It is the objective of the management program to develop the reduction criteria for point and nonpoint sources.

Three examples of this modeling process are presented below for summer conditions:

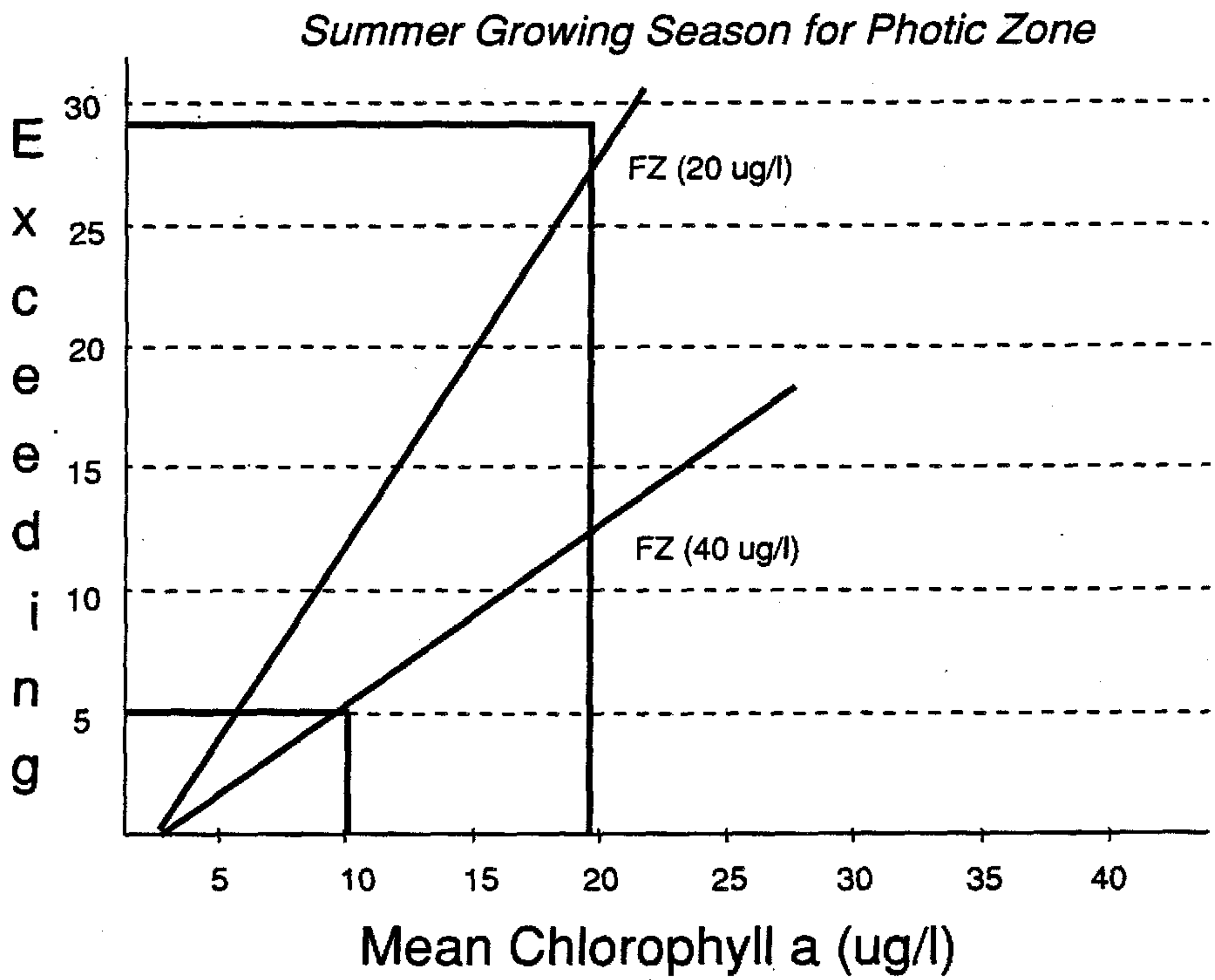
A. <u>Reducing nuisance bloom frequency from 30 to 20 percent probability</u>

1. Mean predicted chlorophyll α = 14 ug/ℓ (initial) and adjusted to 15.6 ug/ℓ after defining new TN:TP ratio
2. Mean predicted TP = 65 ug/ℓ
3. Projected reservoir loading TP = 652 mg/m^2
4. Existing summer loading TP = 1117 mg/m^2
5. Requires 42 percent reduction in phosphorus loading

Table 25. Probability of Chlorophyll α Exceeding Criteria Levels in the Reservoir.

Season	Chlorophyll α Criteria (μg/ liter)	Percent Time in Exceedance of Criteria
Spring (April – Mid–June)	20	11.8
	30	6.4
	40	3.9
	50	2.5
Summer (Mid–June – Sept)	20	28.6
	30	17.1
	40	11.0
	50	7.5
Fall (Oct – Dec)	20	8.2
	30	2.2
	40	0.7
	50	0.2
Winter (Jan – March)	20	31.8
	30	22.5
	40	17.0
	50	13.3

Figure 16.
Percent Bloom Frequency for Summer Season



B. Reducing nuisance bloom frequency from 30 to 17.5 percent probability

1. Mean predicted chlorophyll α = 12 ug/ℓ (initial and adjusted to 15.0 ug/ℓ after defining new TN:TP ratio
2. Mean predicted TP = 49 ug/ℓ
3. Projected reservoir loading TP = 490 mg/m^2
4. Existing summer loading TP = 1117 mg/m^2
5. Requires 56 percent reduction in phosphorus loading

C. Reducing nuisance bloom frequency from 30 to 14 percent probability

1. Mean predicted chlorophyll α = 10 ug/ℓ (initial and adjusted to 10 ug/ℓ after defining new TN:TP ratio
2. Mean predicted TP = 35 ug/ℓ
3. Projected reservoir loading TP = 350 mg/m^2
4. Existing summer loading TP = 1117 mg/m^2
5. Requires 70 percent reduction in phosphorus loading

Example C represents a maximum nuisance bloom frequency reduction which might be considered in reservoir management, based on the models used in this assessment. Example C would balance the reservoir between a mesotrophic and eutrophic status.

VIII. GOALS AND OBJECTIVES

From a regulatory viewpoint and as identified by the WQCC and WQCD, standards have been and will continue to be an important method for water quality control. The determination of a standard value for any body of water is a difficult task. There are a few water quality characteristics which make Bear Creek Reservoir unique in relation to water quality control and management.

The type of goal used for two reservoirs in the metropolitan region in past studies has been the setting of a phosphorus standard (DRCOG 1984a; 1984b). The purpose of the phosphorus standard was to control the biomass production in the reservoirs. Phosphorus standards developed for Cherry Creek Reservoir, Chatfield Reservoir and Dillon lake were related to this algal biomass production as measured by chlorophyll α. This biomass production was impacting beneficial uses.

The phosphorus standards applied to both Cherry Creek and Chatfield Reservoirs has been an issue of concern to local water quality planning and management associations. These standards were developed from limited data, although they may still represent the best management tool for these waterbodies.

There were five options considered by the Task Force in establishing a goal for Bear Creek Reservoir:

1. Keep the reservoir at status quo;
2. Set an in-reservoir phosphorus standard which could be translated into permit limits;
3. Develop a reservoir management program to change the trophic status in the reservoir;
4. Development of a watershed management program to reduce phosphorus loading;
5. Develop a joint watershed and reservoir management program to change trophic status and phosphorus loading.

The existing water quality data shows Bear Creek Reservoir to have use impairment. Keeping the reservoir at status quo was determined by the Task Force not to be a preferred option and improvement to water quality would be necessary for both the watershed and reservoir. The public surveys showed a desire by Park users for improved recreational opportunities at the Park and within the reservoir.

A standard could be established as a goal with a time schedule developed to evaluate progress in meeting the standard. A goal standard could be reviewed every three years through the triennial review process of the WQCC. The value for the goal standard could be estimated from water quality modeling data.

There are many management methods shown in the literature for watersheds and reservoirs which can be used to define a reservoir goal. These management methods can be applied separately to either the watershed or reservoir and still result in water quality improvement. Applying these methods in a comprehensive watershed/reservoir management program could provide maximum benefits and enhance water quality improvements.

The water quality data and modeling show a need to reduce phosphorus loading in the watershed from both point and nonpoint sources; reduce in-reservoir phosphorus loading; reduce the extent and anoxic conditions of the hypolimnion and reduce sediment loading to the reservoir.

There are a number of management strategies which could be used to change the trophic status or reduce the frequency of algal blooms. The reservoir trophic status is currently balanced between being hypertrophic and eutrophic. In the summer growing season, there are several significant algal bloom periods which affect the reservoir quality. The geometric mean chlorophyll α concentrations are similar to other waterbodies in the region, but the peak values are much higher.

Phosphorus loading can be assigned from bloom frequency reductions. Reducing bloom frequency, as related to mean chlorophyll α values, can be used to predict mean phosphorus concentrations and subsequent load reduction requirements. A model relationship has been devised for chlorophyll α concentrations and in-reservoir phosphorus concentrations.

A generalized trophic system is shown in Figure 17 which relates to water quality, use attainment and required management programs. Bear Creek Reservoir is hypertrophic with low water quality, use limitations and could require a restoration management program. Cherry Creek and Chatfield Reservoirs were characterized as slightly eutrophic, medium-low water quality, meeting uses with some uses threatened and requiring some restoration with a management program (DRCOG 1984a; 1984b). Dillon Reservoir is a mesotrophic system threatened by phosphorus loading which requires a management program (Lewis et al., 1988). It is not realistic to change the trophic status of Bear Creek Reservoir to the same level as Dillon Reservoir because of differences in hydrologic conditions. However, it is possible to change the status in Bear Creek Reservoir to be consistent with other front range systems (Figure 17).

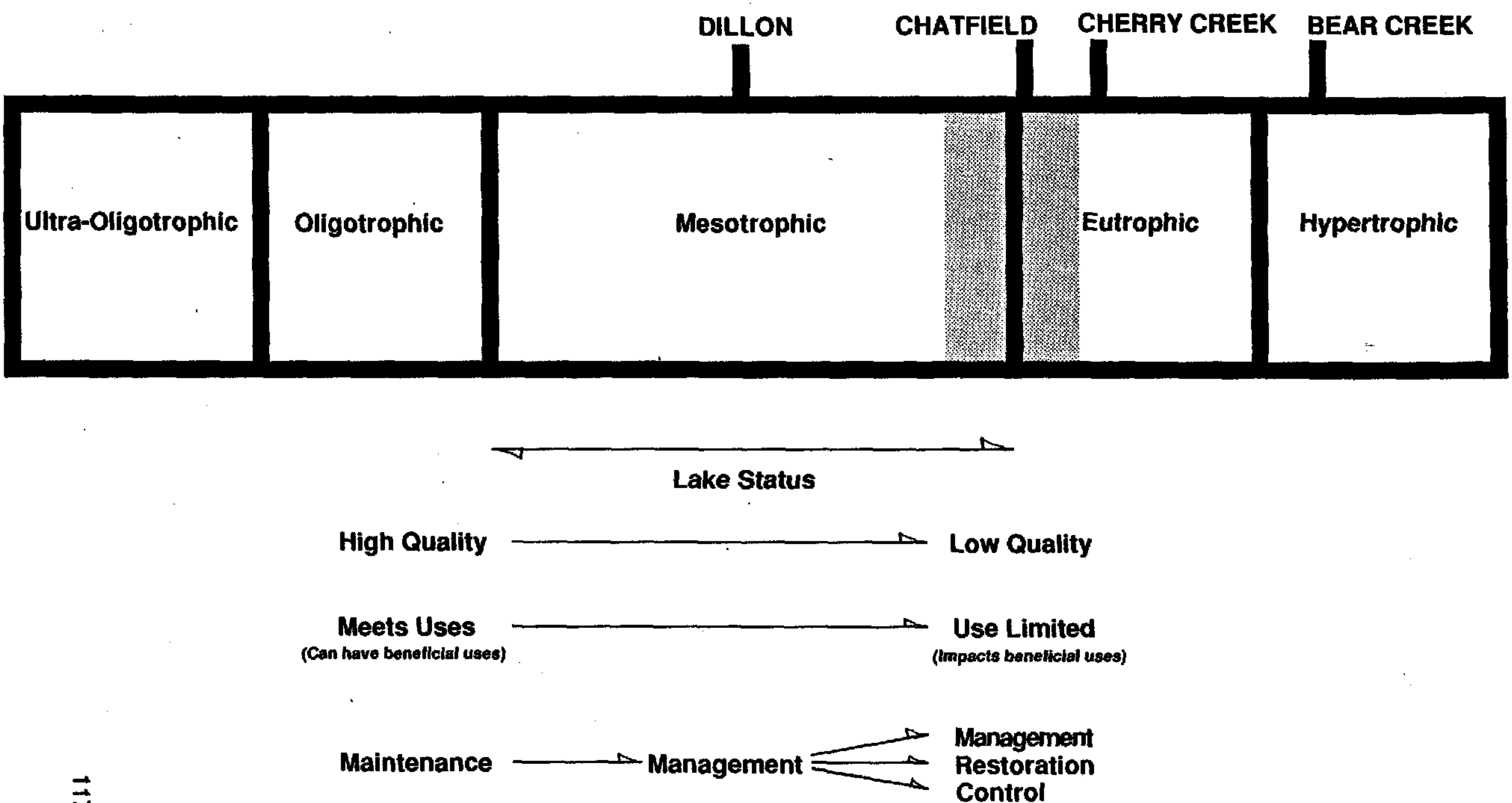
A potential goal for the reservoir is to reduce the probability that the reservoir is hypertrophic/eutrophic as defined by algal bloom frequency. The reduction of nuisance blooms exceeding 20 ug/l in the summer growing season by fifty percent would change the reservoir trophic status and balance the system between mesotrophic and eutrophic, as depicted by the shaded zone in Figure 17. If this strategy were used, then this goal should be defined as a staged process which might require 10 years for full implementation.

The four water quality models developed for Bear Creek Reservoir could be useful management tools for a water quality program directed toward a nuisance bloom control goal. Management strategies for this type of program could then systematically result in phosphorus load reduction as related to nuisance bloom frequency. A management plan could allocate phosphorus reduction levels to a combination of point and nonpoint sources within the watershed and in-reservoir loading.

Figure 17.

Reservoir Management Relationships

The shaded area represents the goal for Bear Creek Reservoir



IX. MANAGEMENT ALTERNATIVES

ASSUMPTIONS

Water quality management alternatives have been selected for consideration in Bear Creek reservoir and the associated watershed. These management strategies represent a series of structural and nonstructural control practices which are based on water quality characteristics and problems identified in the watershed and reservoir. These alternatives do not constitute a management program and they are recommended only as the most feasible solutions which could be used to improve water quality.

The following assumptions were made by the Task Force in the study to assist in selecting the management alternatives:

1. The water quality in the reservoir should be improved and not left at existing conditions. The degree of improvement should be defined in a future management program.

2. The phosphorus loading to the reservoir will need to be reduced from both point and nonpoint sources.

3. Reservoir management strategies should focus on improving the reservoir fishery and enhanced recreational potential, along with habitat in Bear Creek Park.

4. The City of Lakewood will continue to be responsible for Bear Creek Park management and implementation of phase II recreational facilities as defined in the Park master plan.

5. Septic system and erosional control strategies in the watershed should be reviewed by Jefferson County and the Jefferson County Health Department. Abetter septic system enforcement system should be considered.

6. Structural watershed control strategies might use a combination of physical and biological treatments for water quality improvement.

7. Water quality monitoring in both the watershed and reservoir will be funded by management agencies and special grants.

8. A separate management report from this Clean Lakes Study should be developed to define the watershed and reservoir programs and should use information from this Clean Lakes Report.

RESERVOIR ALTERNATIVE MATRIX

There are two major areas of management which could be used for in-reservoir treatment and maintenance. These include structural control strategies and non-structural or policy related control strategies. There are a large number of structural control options which could be used to improve reservoir water quality. However, many of these options were not effective management procedures as defined by existing literature for the types of water quality problems which exist in Bear Creek Reservoir (eg., Cooke et al., 1986).

The nonstructural options are related primarily to the management of the reservoir by the City of Lakewood and the U.S. Army Corps of Engineers. The City of Lakewood is responsible for Park management, while the Corps of Engineers operates the reservoir structures, regulates outflow as decreed by the Colorado State Engineers office and maintains shoreline.

Some water quality improvement could result from reduced erosional sources within the Park and stabilizing portions of the reservoir shoreline near the stream mouths. The policy direction for management of Bear Creek Park should be defined by the City of Lakewood as part of their park use plan.

The set of reservoir structural alternatives are shown in Table 26. These alternatives were related to water quality trends, water quality standards (decreasing phosphorus loading), and improvement of beneficial uses for recreation, aquatic life and other uses. A total cost estimate was made for each of these control alternatives. Capital cost estimates were made in three groups: low, ranging up to $250,000; medium, ranging from $250,000 to $1,000,000; and high, over $1,000,000.

The major alternatives selected from all available alternatives by the Task Force for consideration in the future management program were structural controls designed to reduce nutrient impacts, aerate the water column and decrease sedimentation:

1. Hypolimnetic aeration (with maintenance of natural stratification patterns)

2. Hypolimnetic withdrawal (as related to reservoir operation)

3. Phosphorus precipitation and inactivation

4. Nutrient diversion

5. Sediment delta stabilization and sediment trapping

The cost estimates showed most structural controls were moderate in relation to capital costs. Nutrient diversions were a very high cost item, since they effect watershed water rights and discharges from wastewater treatment facilities. There are no feasible alternatives from either an engineering or economic perspective to divert wastewater flows from the reservoir. The water rights have allocated this water for other uses and they have defined the hydrologic flow regimes.

Phosphorus precipitation and inactivation are reservoir treatment processes which reduce internal nutrient loading. Phosphorus is generally the target nutrient which is either removed from the water column (phosphorus precipitation) or kept from releasing out of the bottom sediments (phosphorus inactivation). These treatment processes have been successfully used as a lake management tools (Cooke, et al., 1986). There is some internal loading of phosphorus in the reservoir which could be reduced through an inactivation treatment process.

Table 26. Reservoir Water Quality Alternative Matrix

	Water Quality Trends		WQ Standards	Improve Beneficial Uses			
	Reduce Eut.	Reverse Meso.	Decrease Phos.	Rec.	Fish	Other Uses	TOTAL COST
STRUCTURAL							
Reservoir Operation	L	L	L	L	L	L	LOW
Sediment Load Reduction/Delta Stabilization	M	L	M	M	M	M	MOD
Hypolimnetic Withdrawal	M	L	M	M	M	M	MOD
Phosphorus Inactivation/Precipitation	M	M	L	L	L	L	MOD
Hypolimnetic Aeration	M	M	M	M	M	M	MOD
Nutrient Diversion-Watershed Management	H	H	H	H	M	M	HIGH
NONSTRUCTURAL							
Park Management/Park Policy	L	L	L	M	M	M	MOD
RESERVOIR-PHOSPHORUS STANDARD	H	H	H	M	M	M	HIGH

H - High Efficiency
M - Medium Efficiency
L - Low Efficiency

CAPITAL COST
L - < 250,000
M - 250,000 - 1,000,000
H - > 1,000,000

However, this treatment type is costly, can potentially introduce a toxic substance into thewaterbody and may not be an effective long-range management strategy, if the cause of the phosphorus loading is not controlled.

Hypolimnetic withdrawal is a low cost management technique which could potentially improve water quality. The principal purpose of this technique is control the depth of water withdrawal from the waterbody, so that nutrient-rich bottom water instead of nutrient-poor surface water is discharged from the waterbody (Cooke, et al., 1986). The technique will result in lower hypolimnion detention time and reduce the chance for anaerobic conditions to develop, which lessens the availability of nutrients to the epilimnion from entrainment. The technique can result in improved fishery habitat. The U.S. Army Corps of Engineers is investigating hypolimnetic withdrawal as an operational technique for the reservoir.

There is a substantial amount of suspended and bedload sedimentation reaching the reservoir from the watershed. The sediment deltas have shown extensive accretion into the reservoir and reduced the reservoir volume. Stabilization of the existing deltas can be achieved by maintaining the riparian vegetation and reducing the water velocity during storm runoff periods. Sediment trapping by using in-stream check structures with maintenance sediment removal could improve reservoir quality. The in-stream structure would also serve as erosion control devices. These structures can be made from natural materials for relatively low costs. A sediment removal program would be more costly and would require a characterization of the sediments and associated constituents for disposal purposes.

A potentially useful in-reservoir alternative selected by the Task Force was hypolimnetic aeration. This management technique would serve to control three water quality problems associated with the reservoir: low oxygen content in the hypolimnion, reduced fish habitat and internal phosphorus and nitrogen loading from bottom sediments. Hypolimnetic aeration will raise the oxygen content of the hypolimnion without destratifying the water column or warming the hypolimnion. The aeration process results in increased habitat and food-supply for cold-water fish species. The establishment of aerobic conditions at the sediment-water interface should reduce the internal loading of phosphorus and other constituents.

There are a number hypolimnetic aerators available which have been designed for a wide variety of waterbodies (Cooke, et al., 1986). The hydraulics and morphology of Bear Creek Reservoir would make hypolimnetic aeration a feasible management technique.

The City of Lakewood is currently reviewing the Park use master plan. The operation and maintenance of the Park is a management oriented control strategy which should result in some improvement to recreational opportunities and water quality enhancement.

The final alternative left in the matrix table was a reservoir phosphorus standard. Phosphorus standards have been applied to other reservoirs in the region as a means of improving water quality. A standard gives the WQCD a method to regulate wastewater effluent quality. However, the standard setting process has been difficult and the numeric limits used for other reservoirs may not be the most representative values for water quality protection. A standard is the least preferred alternative.

WATERSHED ALTERNATIVE MATRIX

There are a large number control strategies which could be applied to the entire basin. The watershed quality alternative matrix defines a set of these options for three major areas: Structural, nonstructural and wastewater facilities (Table 27). The matrix table has the same factorial relationships as developed for the reservoir. The cost estimates also use the same range as the reservoir alternatives.

There are five structural alternatives which could be used in a future watershed management program: two types of erosion control (tributary and in-stream); septic system discharges; stormwater management in urbanized areas; and use of wetlands for nutrient control. Stormwater management is estimated to be the most costly program to initiate and maintain. Wetland and in-stream erosion control are moderately expensive but potentially effective control strategies. Since tributary erosion control is a low cost strategy, it could be the first type of strategy applied to the watershed.

One component of a potential in-stream management program could be directed toward habitat improvements. There is a stream bank erosion problem in the watershed related to natural topography, recreational activities and construction projects. A stream bank protection program could be initiated in conjunction with other management projects.

A biological based BMP could be used to reduce point source nutrients and nonpoint sediments within the same process scheme. In-stream biological based BMPs (i.e., wetlands) could be used as part of either a nonpoint or point source control strategy. Manufactured wetlands could be used to *treat* stream flows. These wetlands could be constructed either in-channel or off-channel with a wide variety of configurations.

In-channel wetlands have the potential to be flooded during spring runoff and in periods of intense thunderstorm activity. An off-channel feature has a better chance to maintain integrity in flood periods. The wetland configurations could be designed to make maximum use of natural topography. This would generally be a long narrow structure. An off-channel structure would need to return flows back to the stream in such a manner not to disrupt water rights. The in-stream wetland would require a flood protection system, while the off-channel wetland will require flow regulation devises to move flows into and out of the wetland.

The two nonstructural alternatives are related to improving the erosion control and septic system regulations. These are initially low cost items, but over time they can be very costly. Major issues are enforcement of septic and other regulations and the manpower required to maintain these regulatory programs.

The primary point source control available is at the existing wastewater treatment facilities. Some degree of tertiary treatment for phosphorus will be needed for improvement of basin water quality. This tertiary treatment will be very costly with a five to ten year time frame needed for full implementation. The potential program is discussed in the Point Source Control Strategy Chapter.

Table 27. Watershed Water Quality Alternative Matrix

	Water Quality Trends		WQ Standards	Improve Beneficial Uses			TOTAL COST
	Reduce Eut.	Reverse Meso.	Decrease Phos.	Rec.	Fish	Other Uses	
STRUCTURAL							
Tributary Erosion Control	M	L	L	L	L	L	LOW
Septic Buffer Zones/Future Development	M	M	M	M	L	L	LOW
In-Stream Erosion Control	M	L	L	L	M	M	MOD
Stormwater Management-Urban Development	M	L	M	M	L	L	HIGH
Wetlands	H	M	H	H	M	M	MOD
NONSTRUCTURAL							
Erosion Regulation/Enforcement	M	M	M	L	M	M	LOW
Septic Regulation/Enforcement	M	M	M	L	M	M	LOW
WASTEWATER FACILITIES							
Phosphorus Removal/Equal Treatment	H	M	H	M	M	M	HIGH

H - High Efficiency
M - Medium Efficiency
L - Low Efficiency

CAPITAL COST
L - < 250,000
M - 250,000 - 1,000,000
H - > 1,000,000

WASTEWATER FACILITY SYSTEM

The existing system of major wastewater treatment facilities, which include Evergreen, West Jefferson County, Kittridge, Genesee, Forest Hills Metro, Morrison, Willowbrook, Jefferson County Schools and Conifer, will be needed for wastewater service in the future. The El Rancho wastewater treatment facility was combined with the Kittridge facility and details of the merger are provided in a separate section. The Forest Hill Metropolitan District was not previously shown in the Clean Water Plan. A subsequent section discusses this facility with a recommendation that this facility be recognized in the Clean Water Plan (DRCOG, 1989).

The smaller wastewater treatment systems for Brookforest, Davidson Lodge and Tiny Town require further evaluation on the continued need for these systems. The cost of tertiary treatment may not make it feasible to continue operating these facilities.

There is a facility study in progress which is evaluating the need for a wastewater treatment facility for the Aspen Park area. This area has been recognized as having urban densities and some type of wastewater treatment facility would be recommended to replace the individual septic systems. A similar study will be needed for the Indian Hills area and the Town of Idledale.

At all of the major wastewater treatment facility sites, there is sufficient space available for expansion to accommodate expanded treatment processes. The West Jefferson County facility has been proposed as the first facility to upgrade for phosphorus removal. The facility is investigating the use a biological process. The effectiveness of the facility will be monitored by the other wastewater service providers.

Service area data sheets were developed for all major wastewater treatment facilities. These data sheets provide information on sizing, staging, facility type, construction schedules, water quality issues and population, employment and wastewater projections(Appendix A). This information is included in the Clean Water Plan (DRCOG, 1989).

MONITORING PROGRAM

A comprehensive ongoing characterization of the watershed and reservoir is essential to analyze potential strategies discussed in the final Bear Creek Reservoir Clean Lake Study. Water quality trend data will be valuable in developing and modifying future reservoir or watershed management programs. This trend data will be obtained through a 1990/1991 monitoring program of the watershed and reservoir. The monitoring program will be administered by DRCOG at the direction of the Bear Creek Basin Management Plan Committee. The results of the data set will be analyzed and summarized by a report to be approved by the Committee.

The watershed and reservoir data collection program as outlined below is designed to provide a good characterization of water quality and biological trends. Quality assurance procedures will be included with the sampling program and submitted as part of the data summary.

Watershed

The watershed monitoring program is designed to characterize water quality in the two major tributaries to the Bear Creek Reservoir: Bear Creek and Turkey Creek. The watershed sampling program will duplicate sampling procedures and analyses methods used in the Bear Creek Reservoir Clean Lakes Study. A similar quality assurance program used on the Bear Creek Reservoir Clean Lake Study will be applied to the monitoring program.

The watershed will characterized by measuring selected water quality parameters in-stream waters and Bear Creek Reservoir at the lower extent of the basin. The upper portions of the watershed have been characterized as part of the Bear Creek Reservoir Clean Lake Study, which provides a background data set. Periodic sampling at other selected sites in the Basin for selected water quality parameters may be required in future monitoring programs. This additional water quality monitoring will be determined from the ongoing water quality data sets and would require an amendment to the monitoring program. The ongoing sampling program has been simplified to focus on inputs and outputs from Bear Creek Reservoir.

The watershed sampling stations can provide data which could be used verify reservoir models as presented in the Bear Creek Reservoir Clean Lakes Study and define water quality trends in the watershed. The watershed sampling will be done at three stations in the lower portion of Bear Creek Basin:

- Turkey Creek at the Bear Creek Park Maintenance Yard;
- Bear Creek at the western bridge area;
- Below the reservoir in lower Bear Creek.

There will be 16 samples taken per year with biweekly samples in June, July, August and September, and monthly for other months. Selected physical, chemical and biological components will be sampled as shown in the following list:

PHYSICAL

Instantaneous flow
[Turkey Creek station will need flow measurement, USGS gaging station will be used on Bear Creek and U.S. Army Corps of Engineers reservoir outflow data will be used for the lower Bear Creek Station]
Dissolved Oxygen
Specific Conductance
Total Suspended Solids
Temperature
pH

CHEMICAL

Ortho-phosphorus
Total Phosphorus
Nitrate-Nitrogen
Ammonia-Nitrogen

BIOLOGICAL

Fecal Coliform Bacteria

Reservoir

The reservoir sampling program is designed to provide a necessary data set to make statistical water quality trend assessments and verify the effectiveness of control and alternative management programs. The reservoir sampling program will duplicate sampling procedures and analyses methods used in the Bear Creek Reservoir Clean Lakes Study. A similar quality assurance program used on the Bear Creek Reservoir Clean Lake Study will be applied to the monitoring program.

The reservoir will be monitored at a single station located in the central pool. The data collected in the Bear Creek Reservoir Clean Lakes Study showed there was no statistical difference between stations. However, there was a depth difference for selected parameters which could require depth sampling. Temperature, dissolved oxygen and specific conductance will be profiled at 1m intervals from surface to bottom which should result in nine or ten measurements per sampling set.

The depth sampling will be reduced to three vertical stations for the remaining physical and chemical parameters. The biological characterizations of phytoplankton will be confined to near surface waters within the photic zone of the reservoir [top 3.5m of the water column]. The algal sampling will include genera characterization and a count of numerical density of major genera. A single zooplankton characterization will be made in the growing season. A vertical tow of the reservoir water column will be made to characterize zooplankton genera. The sampling depths for the chemical and physical parameters at the reservoir station are as follows:

- Surface at –0.5m,
- Mid–water column at –5.0m;
- Bottom at +0.5m (about 10m).

The City of Lakewood will provide a boat and operator for the reservoir monitoring program. Coordination for boat usage will be made with the Department of Recreation and Bear Creek Reservoir Park personnel. Boat usage is not included as an expense in the monitoring program.

There will be 16 reservoir samples taken per year with biweekly sampling in June, July, August and September, and monthly for other months. There may be some sample periods in the winter which cannot be sampled due to poor ice conditions. If a winter monitoring set can not be taken due to unsafe conditions, then the monitoring set will be added at a later time period to the annual monitoring program which will result in a total of 16 monitoring sets at the end of the monitoring period.

The following list of physical, chemical and biological parameters will be done at the reservoir monitoring station:

PHYSICAL

Temperature (vertical profile at 1m intervals)
Specific Conductance (vertical profile at 1m intervals)
Dissolved Oxygen (vertical profile at 1m intervals)
Total Suspended Solids
Secchi Transparency

CHEMICAL

Ortho-phosphorus
Total Phosphorus
Nitrate-Nitrogen
Chlorophyll α

BIOLOGICAL

Fecal Coliform Bacteria
Algal genera characterization (photic zone)
Algal Density (photic zone)
Zooplankton genera characterization (vertical tow – *one time sample*)

In addition to routine monitoring, there are some special short-term studies which could be done to provide more specific data for specific parameters (ie. mercury, zinc, arsenic). Since there is a potential for biomagnification of specific metals in fish and other metals have been recorded above standards, limited heavy metal samples should be taken at effluent discharges and in both Turkey and Bear Creeks. These samples could be taken at high and low flow periods. Some additional special studies could include: development of a predictive model relating phosphorus and land-use; a synoptic evaluation of internal phosphorus loading in the reservoir during a summer no-oxygen period; determination of a nitrification rate for Bear and Turkey Creeks; and measuring the diel variations in temperature and pH for ammonia-nitrogen evaluations.

X. POINT SOURCE CONTROL PROGRAM

A potential point source management strategy could focus on control measures at wastewater treatment facilities. Nutrient control measures could be directed at tertiary treatment of wastewater flows for phosphorus. A phosphorus effluent limit has not been established for existing or future facilities.

There are several general approaches which could be used to control phosphorus effluent limits and reduce phosphorus loading to the reservoir:

1. Setting a numeric limit for each wastewater facility through an allocation process which could result in different permit limits between facilities;

2. Setting the same numeric limit for all wastewater facilities;

3. Developing a management and a tertiary phosphorus process control regulation.

The recommendation from the wastewater service providers is to develop a management program which follows the third approach of a process control strategy. This type of strategy allows more options for the type of tertiary control which could be implemented at any given wastewater treatment facility. The details of this type of process should be developed in the management program.

The preference of wastewater service providers is to develop a management process which could be used by the WQCD for permit compliance. This management oriented permit process has not been used in Colorado. A control program for wastewater treatment levels would need to be presented to the WQCC for adoption.

Tertiary treatment can be achieved through chemical or biological processes. Chemical processes have been extensively used in phosphorus reduction with a good engineering basis available for general application to existing facilities. Chemical treatment can achieve phosphorus reduction in effluent to values of less than 1 mg/ℓ phosphorus. Although biological treatment has also been widely used, there is less information available on general application. Biological treatment generally reduces phosphorus to a range of 1 to 2 mg/ℓ.

Chemical processes to reduce effluent phosphorus can be costly, dependent on the level of treatment required. Biological processes can be adapted to existing facilities for lower costs. The wastewater service providers recommend testing biological control processes for effectiveness at the West Jefferson County Facility. If biological process prove to be effective and economic, then general use could be applied to the other wastewater facilities.

Other basin water quality studies in the region have recommended tertiary treatment levels which can only be achieved through land application or chemical treatment. Wastewater facilities in the Cherry Creek Basin are required to meet 0.05 mg/ℓ phosphorus limits, while Chatfield Basin requires a 0.2 mg/ℓ effluent limit.

A general policy used in the metropolitan region is to have equal treatment removal at all wastewater treatment facilities. It is recognized that low level phosphorus removal can be expensive for small treatment facilities, however some degree of control might be required. The currently intention is to have the major facilities commit to some type of control process, while the small facilities may have a different control process.

The use of in-stream BMPs to reduce nutrient loads would help augment facility nutrient removal. Although control of point sources will reduce nutrient loading which can reach the reservoir, nonpoint control strategies will also be needed to improve reservoir quality.

XI. NONPOINT SOURCE CONTROL PROGRAM

CONTROL STRATEGIES

Nonpoint source control strategies should be an integral component of the overall watershed management program. This program could be directed at prevention of nonpoint source problems with a restoration and protection portion designed to reduce existing problems. Nonpoint source controls should focus on erosion and sedimentation.

Nonpoint source pollution has been identified as a major contributor to reservoir degradation on an annual basis. About 50 percent of the annual phosphorus and almost all of the suspended sediments are from nonpoint sources. In the summer season, point source contribute about 70 percent of the phosphorus load with the remaining 30 percent from nonpoint sources. In the spring runoff period, nonpoint source loading of phosphorus is about 65 percent of the total load.

There is a substantial quantity of suspended sediment and bedload delivered to reservoir on an annual basis. The sediment delta formations at the mouths of Bear and Turkey Creek typify this sedimentation process. Erosion in the watershed is attributable to both natural and man-induced conditions. A certain amount of natural erosion is anticipated in a mountainous terrain. The problem arises from excessive erosion related to construction, agricultural and urban activities. Erosion control practices are required to reduce the excessive sedimentation.

There is a connection between public activities, land use practices and water quality. The general public does not perceive this connection. An awareness of the magnitude and extent of the nonpoint source problem and solutions needs to be communicated to the citizens at a local level. The nonpoint source program needs to develop a mechanism which can increase the public awareness level.

There are seven primary areas which should be assessed as part of a nonpoint management program:

1. Determining potential solutions to existing nonpoint source problems; including preferred best management practices (BMPs); developing a long-range milestone schedule for implementation of BMPs.

2. Increasing public awareness of nonpoint source pollution potential, prevention, restoration and involvement in watershed management; develop an education program; make provisions for public review of program progress and success.

3. Determine the economic forces and incentives; establish economic priorities; develop cost alternatives; assess local and state funding sources - who pays; determining responsible agencies.

4. Evaluate existing and proposed regulatory programs and assess relationship to program.

5. Determine the type and quantity of additional technical or water quality monitoring information is necessary and required for future programs; defining the water quality objectives to be achieved; estimating the loading reduction to be achieved.

6. Assess if formal agreements need to be made to ensure inter- and intra-jurisdictional cooperation.

7. Define the trade-offs between point source and nonpoint source control measures.

A future management program should initially focus of public awareness and testing potential BMPs. A potential BMP demonstration project on wetland technology has been proposed by DRCOG which could reduce stream nonpoint source loading to the reservoir. The outcome of this demonstration project might be useful in the development of future nonpoint source management programs by appropriate management agencies.

Septic system failure is suspected to be a significant nonpoint source contributor of phosphorus. This septic pollutant source could be about 50 to 75 percent of the total nonpoint source load to the reservoir. A public awareness program on septic system effects on water quality could be useful for Basin residents. This program could be established by Jefferson County and the Jefferson County Health Department. Part of this process is a reevaluation of the existing individual disposal system regulation.

IMPLEMENTATION

A phased nonpoint source program could substantially reduce phosphorus and sediment loads to the reservoir over a 10 year period. An integral component of the management strategy should be continuous water quality monitoring within the watershed and at the reservoir. There are four primary approaches which should be considered in a nonpoint source program:

1. Implementation of BMPs at sources which are designed to reduce or eliminate constituents of concern before they reach a surface waterbody. An example of source control which could reduce the phosphorus load from septic systems is the reduction in home use of high phosphorus detergents. Another focus of this source control strategy could be to reduce erosion loadings from small tributaries or gulches which discharge into Bear and Turkey Creeks. A future monitoring program could designate problem gulches which need control structures. A stormwater management program for the urbanized areas could be used as part of a source control strategy.

2. Minimizing watershed disturbances which can effect water quality in receiving waters. This could include innovative land use planning and regulated controls of disturbances to minimize or mitigate effects. This would be a responsibility of the County and communities at a local level.

3. Maintenance of riparian vegetation or stream buffer zones and in-stream erosion control can reduce the potential for water quality degradation. There is a certain amount of stream bank erosion along both streams which could be eliminated by application of BMPs. Additionally, stream flow velocities can be reduced by adding in-

stream structures designed to lessen erosion effects. These structures also serve as habitat improvement for fish and other wildlife.

4. Collection and treatment of water sources and streams to alter the water quality. These treatment types could vary from passive to active systems which utilize a variety of physical, chemical or biological processes. From an economic viewpoint, there is a preference to use passive biological processes. The use of manufactured wetlands or similar biological processes can provide water quality benefits and provide new wildlife habitat.

The implementation of a nonpoint source program might require a joint effort from such agencies as the wastewater service providers, Jefferson County and the City of Lakewood. A general milestone schedule which could be implemented for nonpoint source control is as follows:

- A wetland demonstration project started in 1991 and completed by 1994;
- An evaluation of the individual sewage disposal regulation from 1990 to 1992 with data collection to quantify the problem;
- An evaluation of the erosion control regulation in 1990 to 1991 with an adopted regulation by 1993;
- Stream bank and riparian zone maintenance program initiated by 1995;
- A comprehensive nonpoint source management program implemented by 1995.

XII. SEPTIC SYSTEMS CONTROL PROGRAM

Single family lots are the major type of urban development currently found in the Bear Creek Basin. These lots are classified as large with an average size of 5 acres. This type of urban development is and anticipated to continue through the year 2010 (DRCOG, 1989). There are a number of areas within the Basin which have low-density urban development (a type of cluster building) and are not on centralized sewage systems (eg. Indian Hills, Idledale). The large lot single family developments have a tendency to occur along drainage courses in the alluvial valleys.

These single family or low-density developments rely on individual disposal systems. These disposal systems are used to treat domestic, commercial and industrial wastewaters. These systems use septic tanks and engineered leach fields to treat wastewater effluent. Septic systems can and do provide a viable means of wastewater treatment and disposal in the Basin where sewage collection systems are not feasible from either an engineering or economic perspective (Kaplan, 1988).

The problems with septic systems in the mountainous regions of Jefferson County have been recognized since the early 1970's. Septic system effluents have contaminated the potable groundwater wells in the Indian Hills area. Jefferson County has placed a moratorium on construction of new septic systems in the area of Indian Hills. This study measured elevated phosphorus in areas of low-density development. The Jefferson County Health Department has recorded common septic system failure throughout the Basin.

The processed wastewater from septic systems filters into the saturated groundwater zone and then migrates into adjacent gulches and streams. Since much of the Basin has soils poorly suited for leach fields, there is a potential for a significant water quality problem related to septic systems. If the septic tank and leach field system is not functioning according to design, then septic systems pollutants can reach the streams with little or no filtering.

A number of the low-density urban developments in the Basin could be changed from the existing septic systems to a centralized sewage treatment process. This change will be important from a water quality perspective. Many of these low-density developments are suspected contributors of significant quantities of phosphorus into the watershed which causes eutrophication of the reservoir.

The process of converting most of these low-density urban areas to a centralized system could be difficult. There are engineering and economic constraints effecting the development of centralized sewage systems. In most cases, the economics are a bigger factor than engineering issues. Many of the smaller low-density developments do not have the financial means to support a centralized system.

There is a comprehensive wastewater facility plan in progress for the Aspen Park area which will evaluate the feasibility of adding centralized sewage treatment to the area. This facility plan is evaluating several treatment plant options and economic alternatives. The Aspen Park community is assessing the feasibility of becoming a water and wastewater special district.

This type of planning effort would be required for the other low-density areas before initiating centralized services.

Septic system wastewater flows could account for 75 percent of the nonpoint source contribution of phosphorus. There is insufficient data available on the performance of system systems in Bear Creek Basin to accurately estimate the actual total nutrient contribution from these systems. However, the problem is significant and warrants action.

There are two processes and a Task Force recommendation which could be considered for initiating a septic system control program in Bear Creek Basin.

1. Jefferson County, Jefferson County Health Department and the Jefferson County Mountain Water Quality Association could form an action group to in begin a septic system control plan.

2. Jefferson County and the Jefferson County Health Department could evaluate the current Jefferson County Individual Sewage Disposal System Regulation (July, 1986) and make changes designed to improve enforcement, inspection, siting and maintenance.

3. All future septic systems built in Bear Creek Basin should not contribute pollutants to any gulch, stream or other waterbody. Those existing systems which are currently contributing pollutants should be upgraded when economically or technically feasible.

XIII. REFERENCES

Agusti, S., C.M. Durate and D.E. Canfield, Jr. 1990. Phytoplankton abundance in Florida lakes: evidence for frequent lack of nutrient limitation. Limnol. Oceanogr. 35:181–183.

APHA. 1985. Standard methods for the examination of water and wastewater, 16th edition. APHA–AWWA–WPCF, Amer Public Works Assoc., Washington, D.C. 1268p.

Bachmann, R.W. and J.R. Jones. 1976. Is nutrient removal worthwhile? Water and Wastes Engineering. 2:14,8p.

Bendschneider, K. and R.J. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11:87–96.

Brown, L. C. and T. O. Barnwell, Jr. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E–UNCAS: Documentation and User Model. Environmental Research Lab., Office of Res. and Dev., U.S. Envir. Protection Agency. EPA/600/3–87/007:189 p.

Camp Dresser and Mckee, Inc. 1990. Evaluation of in–reservoir control options. Prepared in association with the Riverside Technology, Inc. for the Cherry Creek Water Quality Authority. CDM, Inc., Denver.

Canfield, D.E.,Jr. and R.W. Bachmann. 1980. Prediction of total phosphorus concentrations, chlorophyll α and secchi depths in natural and artificial lakes. Can. J. Fish. Aquatic Sci. 38:414–423.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361–368.

Carpenter, S.R. (ed). 1988. Complex interactions in lake communities. Springer–verlag, New York. 283p.

CDH. 1990. Classifications and numeric standards South Platte River Basin. Colorado Department of health, Water Quality Control Commission, 3.8.0 (5 CCR 1002–8).

Chapra, S.C. and S.J. Tarapchak. 1976. A chlorophyll α model and its relationship to phosphorus loading plots for lakes. Water Resources Res. 12:1260–1264.

Chatfield Basin Water Quality Association. 1986–1989. Annual Water Quality Monitoring Data for Chatfield Basin. Annual Data Summaries, Data on file at DRCOG, Denver.

Cherry Creek Water Quality Authority. 1986–1989. Annual water Quality Monitoring Reports. Reports Presented to the Water Quality Control Commission, Data on File at DRCOG, Denver.

City of Lakewood. 1980. Bear Creek Park ecological study and habitat enhancement program. Engineering-Science, Denver.

Cooke, C.D., E.B. Welch, S.A. Peterson and P.R. Newroth. 1986. Lake and reservoir restoration. Butterworth, Boston. 392p.

Cornett, J.R. and F.H. Rigler, 1980. Areal hypolimnetic oxygen deficit: an empirical test of the model. Limnol. Oceanogr. 25:672-679.

Dillon, P.J. and F.H. Rigler. 1974. The phosphorus-chlorophyll α relationships in lakes. Limnol Oceanogr. 19:767-773.

Dillon, P.J. 1975. The phosphorus budget of Cameron Lake Ontario: the importance of flushing rates to the degree of eutrophy of lakes. Limnol. Oceanogr. 20:28-39.

DRCOG. 1983. Denver Urban Runoff Program. Technical Report, Denver Regional Council of Governments, Denver. 156 p.

DRCOG. 1984a. Chatfield Reservoir clean lakes study. Denver Regional Council of Governments, Denver. 155p.

DRCOG. 1984b. Cherry Creek Reservoir clean lakes study. Denver Regional Council of Governments, Denver. 165p.

DRCOG. 1986. Planning Scenario Development. Technical Memorandum 1.1, Bear Creek Management Study, Denver Regional Council of Governments, Denver.

DRCOG. 1987a. Hydrology evaluation of Bear Creek and inflows to Bear Creek Reservoir. Technical Memorandum 1.2.1, Bear Creek Management Study, Denver Regional Council of Governments, Denver.

DRCOG. 1987b. Water quality problem identification/sampling results. Technical Memorandum 1.2.2, Bear Creek Management Study, Denver Regional Council of Governments, Denver.

DRCOG. 1987c. Assessment of reservoir models. Technical Memorandum 1.2.2, Bear Creek Management Study, Denver Regional Council of Governments, Denver.

DRCOG. 1988. Chatfield Basin Water Quality Study. Denver Regional Council of Governments, Denver. 104p.

DRCOG. 1989. Clean Water Plan, Volume II. Denver Regional Council of Governments, Denver. 133 p.

DRCOG. 1990a. The Status of QUAL2e Modeling in the Denver Region. Denver Regional Council of Governments, Denver. 13 p.

DRCOG. 1990b. Public and Users Survey, Bear Creek Lakes Study. Technical memorandum, Denver Regional Council of Governments, April 13, 1990

Friberg, L. and J. Vostal (eds). 1972. Mercury in the environment: an epidemiological and toxicology appraisal. CRC Press, The Chemical Rubber Comp., Cleveland. 215p.

Garman, G. D., G.B. Good and L.M. Hinsman. 1986. Phosphorus: a summary of information regarding lake water quality. Div. Water Pollut. Control, Ill. Environ. Protect. Agency, Springfield. 67p.

Gerhart, P.Z. and G.E. Likens. 1975. Enrichment experiments for determining nutrient limitation: four methods compared. Limnol Oceanogr. 20:649-653.

Golerman, H.L. and R.S. Clymo. 1969. Methods for chemical analysis of fresh waters. Blackwell Scientific Publications, Oxford. 172p.

Gore, J.A. 1985. The restoration of rivers and streams: theories and experience. Butterworth, Boston. 280p.

Hartung, R. and B.D. Dinman (eds). 1972. Environmental mercury contamination. Ann Arbor Science Publishers, Inc., Michigan. 249p.

Hem, J.D. 1970. Study and interpretation of the chemical characteristic of natural water. Geol. Survey Water-supply paper 1473:363.

Hofstra, W.E. and D.C. Hall. 1975. Geologic control of supply and quality of water in the mountainous part of Jefferson County, Colorado. Colorado Geol. Survey, Depart. Natural Resources, Bull. 36:51.

Hortman, H.K., G. F. Lee and R.A. Jones. 1980. Eutrophication-related water quality in Dillon reservoir. Proc. Environ. Enging. Conf., New York.

Hoyer, M.V. and J.R. Jones. 1983. Factors affecting the relation between phosphorus and chlorophyll α in midwestern reservoirs. Can. J. Fish. Aquatic Sci. 40(2):192-199.

Jones, J.R. and R.W. Bachmann. 1976. Prediction of phosphorus and chlorophyll α in lakes. J. Water Pollut. Contr. Fed. 48:2176-2182.

Jones, R.A. and G.F. Lee. 1982. Recent advances in assessing impact of phosphorus loads on eutrophic-related water quality. Water Res. 16:503-515.

Kaplan, O.B. 1988. Septic systems handbook. Lewis, Michigan. 290p.

King, D.L. 1979. Lake measurements. In-Lake Restoration. Proc. Natl. Conf., August 22-24, Minnesota, EPA-440/5-79-001.

Klemer, A. R. and A.E. Konopha. 1989. Causes and consequences of blue-green algal (Cyanobacterial) blooms. Lake Res. Manage. 5(1):9–19.

Levine, S.N. and D.W. Schindler. 1980. Radiochemical analysis of orthophosphate concentration and seasonal changes in the flux of orthophosphate to seston in Canadian Shield Lakes. Can. J. Fish. Aquatic Sci. 37:479–487.

Lewis, W.M., Jr., J.F. Saunders, D.W. Crumpocker, Sr. and C.M. Brendecke. 1988. Eutrophication and land use, Lake Dillon, Colorado. Springer-verlag, New York. 202p.

Marker, A.F.H., E.A. Nusch, H. Rai and B. Riemann. 1980. The measurement of photosynethetic pigments in freshwaters and standardization of methods: conclusions and recommendations. Arch. Hydrobiol. 14:91–106.

Moore, M.L. 1987. NALMS management guide for lakes and reservoirs. North American Lake Management Society, Washington, D.C. 42p.

Moore, J.W. 1989. Balancing the needs of water use. Springer-verlag, New York. 267p.

McIntyre, A.D. and C.F. Mills, 1978. Ecological toxicology research: effects of heavy metal and organohalogen compounds. Plenum Press, New York. 323p.

Murphy, J. and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27:31–36.

OECD. 1982. Eutrophication of Waters: Monitoring, assessment and control. Organization for Economic Cooperation and Development, Paris. 154p.

Prairie, Y.T., C.M. Durate and J. Kalff. 1989. Unifying nutrient-chlorophyll α relationships in lakes. Can J. Fish. Aquatic Sci. 46:1176–1182.

Reckhow, K. H. 1979. Quantitative techniques for the assessment of lake quality. U.S. Environmental Protection Agency. EPA-4440/5-79-015.

Reckhow, K.H. and S.C. Chapra. 1983a. Engineering Approaches for lake management, Volume 1: Data analysis and empirical modeling. Butterworth, Boston. 340p.

Reckhow, K.H. and S.C. Chapra. 1983b. Engineering Approaches for lake management. Volume 2: Mechanistic modeling. Butterworth, Boston. 492p.

Rigler, F.H. 1968. Further observations inconsistent with the hypothesis that the molybdenum blue method measures orthophosphate in lake water. Limnol Oceanogr. 13:7–13.

SAS Institute. 1982. SAS users guide: basics. SAS Institute Inc., North Carolina. 921p.

Sheldon, R.W. 1972. Size separations of marine seston by membrane and glassfiber filters. Limnol. Oceanogr. 17:494–498.

Solorzano, L. and J. Sharp. 1980a. Determination of total dissolved phosphorus and particulate phosphorus in natural waters. Limnol. Oceanogr. 25:754–758.

Solorzano, L. and J. Sharp. 1980b. Determination of total dissolved nitrogen in natural waters. Limnol. Oceanogr. 25:751–754.

Smith, V.H. 1982. The nitrogen and phosphorus dependence of algal biomass in lakes: an empirical and theoretical analysis. Limnol. Oceanogr. 27:1101–1112.

U.S. Army Corps of Engineers. 1976–1987. Sediment Surveys. Water Quality Management Program, Missouri River Division Lake Projects. Omaha District. Survey data was available for 1976, 1977, 1980, 1984 and 1987.

U.S. Army Corps of Engineers. 1987–1989. Annual report. Water Quality Management Program, Missouri River Division Lake Projects. Omaha District.

U.S. EPA. 1979. Lake Restoration. Proceedings of a National Conference, August 22–24, 1978, Minn., Minnesota. U.S. Environmental Protection Agency. EPA–440/5–79–001.

U.S. EPA. 1981. Interim method for sampling and analysis of priority pollutants in sediment and fish tissue. U.S. Environmental Protection Agency. EPA–600/4–81–055.

USGS. 1989. Water resources data, Colorado water–year 1989, Volume 1 Missouri River Basin, Arkansas River Basin and Rio Grande Basin. U.S. Geol. Sur. Water–data Rpt. CO–89–1.

Uttormark, P.D. 1979. General concepts of lake degradation and lake restoration. In–Lake Restoration. Proc. Natl. Conf., August 22–24, Minnesota, EPA–440/5–79–001.

Uttormark, P,D. 1974. Estimating nutrient loadings of lakes from nonpoint sources. EPA–660/3–74–020. Prepared for the Off. Res. Monitoring, U.S. Environ. Prot. Agency, Washington, D.C.

Walker, W.M, Jr. 1985. Statistical bases for mean chlorophyll α criteria. In: Water quality criteria and standards, Lake and Reservoir Management – Practical Applications. Proceeding of the Fourth Annual Conference and International Symposium, North American Lake Management Society.

Wetzel, R. G. 1983. Limnology. Saunders College Publishers, Philadelphia. 767p.

Wood, E.D., F.A.J. Armstrong and F.A. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrate. J. Mar. Biol. Assoc., UK 47:23–31.

WQCD. 1985. FY 1985 Annual Report Colorado Water Quality Control Division. Colorado Department of Health, Water Quality Control Division, Denver. 29 p.

WQCD. 1986-1989. Annual Report(s) Colorado Water Quality Control Division. Colorado Department of Health, Water Quality Control Division, Denver. 30 p.

WQCD. 1988. Task 1: Assessment of Bear Creek Water Quality. Misc. Report, Colorado Department of Health, Water Quality Control Division, Denver.

WQCD. 1989a. Colorado Nonpoint Assessment Report. Water Quality Control Division, Denver. 189p.

WQCD. 1989b. Colorado Nonpoint Source Management Program. Water Quality Control Division, Denver. 93p.