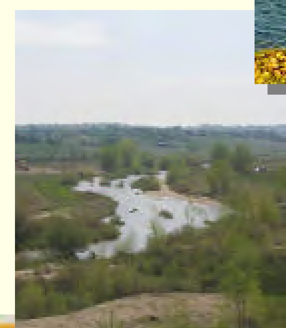
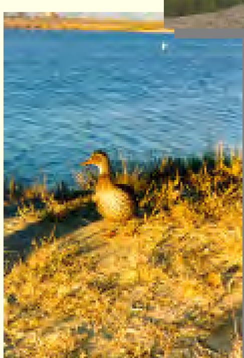
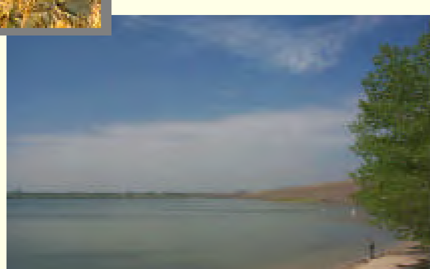
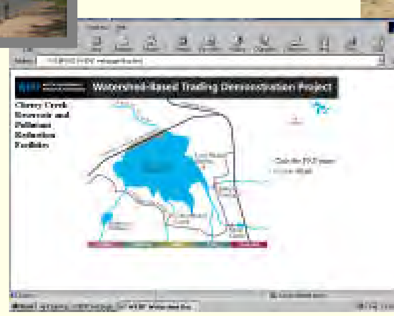
Cherry Creek Watershed
Colorado





Watershed Plan 2000





Cherry Creek Watershed, Colorado
Watershed Plan 2000

Cherry Creek Basin Water Quality Authority Members:

Arapahoe County
Arapahoe County Water and Wastewater Authority
City of Aurora
Cottonwood Water and Sanitation District
Pinery Water & Sanitation District
Douglas County
City of Greenwood Village
Inverness Water and Sanitation District
Meridian Metropolitan District
Parker Water and Sanitation District
Stonegate Metropolitan Water and Sanitation District
Town of Castle Rock
Town of Parker

June 2000

Prepared by:

Cherry Creek Basin Water Quality Authority
c/o R.S. Wells Corp., Suite 102
6399 South Fiddler's Green Circle
Greenwood Village, Colorado 80111-4974

with assistance from

Brown and Caldwell
7535 East Hampden Avenue, Suite 403
Denver, Colorado 80237

Chadwick Ecological Consultants, Inc.
5575 South Sycamore Street, Suite 101
Littleton, Colorado 80120

Dr. John R. Jones
University of Missouri
112 Stevens Hall
Colombia, Missouri 65211

Freshwater Research
3421 Highway 117
Baysville, Ontario
P0B 1A0 Canada

John C. Halepaska and Associates, Inc.
26 West Dry Creek Circle, Suite 640
Littleton, Colorado 80120

McKenna and Cuneo, LLP
370 Seventeenth Street, Suite 4800
Denver, Colorado 80202

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P Urban Growth Boundaries and Service Areas

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Definition of Terms

2000 Watershed Plan	The Cherry Creek Basin Water Quality Management Master Plan presented in this report.
ACCWA	Arapahoe County Water and Wastewater Authority
Algae	Very simple, usually small plants, such as seaweed, that grow in or near water and

	do not have ordinary leaves or roots. Blue-green algae is a poisonous type of plant that grows on the surface of lakes in warm weather.
Authority	Cherry Creek Basin Water Quality Authority
AWT	Advance Wastewater Treatment
Best Management Practices (BMP)	As defined by the Control Regulation, 5 C.C.R. 1002-72 § 72.2(11), and any practices, or a combination of practices, that are effective practicable means (including technological, economic, and institutional considerations) to prevent or control point and nonpoint pollutants at levels compatible with environmental quality goals.
CCSP	Cherry Creek State Park
CDOW	Colorado Department of Wildlife
CDPHE	Colorado Department of Public Health and Environment
COE	U.S. Army Corp of Engineers
Control Regulation	Cherry Creek Control Regulation
Cottonwood WSD	Cottonwood Water and Sanitation District
CPDS	Colorado Permit Discharge System
Direct Discharges	Means the discharge from a wastewater treatment facility directly to a stream segment, either the mainstem of Cherry Creek or its tributaries.
Direct Precipitation Load	Means the annual total phosphorus load from atmospheric deposition and rainfall on Cherry Creek Reservoir.
DRCOG	Denver Regional Council of Governments
Dynamic Model	Means a time-dynamic, mass-balance model that predicts lake-water total-phosphorus concentrations over the year using a weekly time step. The dynamic model was used to develop a July-September relationship between concentrations of total phosphorus and chlorophyll a in the Reservoir.

External Load	Means the sum of annual phosphorus pounds delivered to Cherry Creek Reservoir from load allocations, direct precipitation, wasteload allocations, future allocation pool and reserve pool.
Future Allocation Pool	Means the portion of the external load that may be allocated by the Authority for expansions of existing wastewater treatment plants or new municipal, commercial or industrial dischargers.
Individual Sewage Disposal System (ISDS)	Means treatment of wastewater using septic tanks and leach fields.
Instream Delivery Ratio (IDR)	Is the portion of the phosphorus in waters of the streams and alluvium which is not assimilated based upon a mass-balance equation for the watershed using actual measurements of total phosphorus in surface and subsurface flows. WLA/IDR is the instream delivery ratio for wasteloads based upon wet year conditions, which yield maximum calculated values, plus a 15% margin of safety. These WLA/IDRs are established for specific segments of the watershed, as depicted on Figure 4-3. "LA/IDR" is the instream delivery ratio for loads based upon median precipitation from 1995-1998. The LA/IDRs are established for specific segments of the watershed, as depicted on Figure 4-4.
Inverness or IWSD	Inverness Water and Sanitation District
ISDS	Individual Sewage Disposal System
LA/IDR	Means Load Allocation instream delivery ratio. See instream delivery ratio.
Land Application or Disposal	Means any discharge or pollutant containing waters being applied to land for which no further treatment is intended.
Land Application Return Flow Factor	Means the contribution from the land application site, as depicted on Figure 3-6.
Load Allocation (LA)	Means the annual phosphorus load delivered to Cherry Creek Reservoir from

	surface and subsurface flows comprised primarily of nonpoint sources and municipal stormwaters. The appropriate LA/IDR is applied to these loads from each segment to determine the phosphorus load delivered to Cherry Creek Reservoir.
LPMD	Lincoln Park Metropolitan District, f/k/a Stonegate Center Metropolitan District
Meridian WSD	Meridian Water and Sanitation District
O&M	Operation and Management
OECD	Organization for Economic Cooperation and Development
Parker WSD	Parker Water and Sanitation District
Phase I Baseline Study	Means the water quality collection study initiated in 1994 and continuing to date designed to evaluate surface and ground water quality of the upper Cherry Creek Basin watershed.
Phytoplankton	Minute, free-floating aquatic plants.
Pinery WSD	Pinery Water and Sanitation District
Pollutant Reduction Facilities (PRF)	Are projects that reduce phosphorus loading more than BMPs from nonpoint sources and municipal stormwater
Protozoans	Any of various types of very small, usually single-celled animal which do not have a spine, such as amoebas.
Reserve Pool	Means the portion of the external load that may be allocated by the Authority for temporary or emergency phosphorus allocations. The Reserve Pool provides an additional margin of safety.
Rotifers	Any of various minute multi-cellular aquatic organisms of the phylum Rotifera, having at the anterior end a wheel-like ring of cilia.
RTRM	Relative Thermal Resistance to Mixing
SIC	Standard Industrial Classification
Steady State Model	Means the lake total phosphorus-chlorophyll relationship that uses annual, total phosphorus loads from the watershed to predict in-lake total

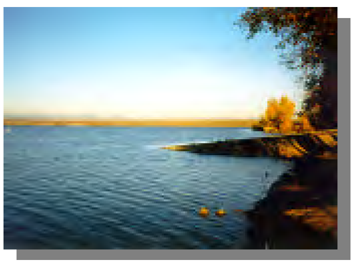
	phosphorus (and therefore, chlorophyll a) concentrations. The steady state model was necessary since weekly watershed loads were not available, necessitating an annual calculation period.
Stream Segment	Means lengths of the Cherry Creek mainstem. Segment 0 is the Reservoir, Segment 1 is from the Reservoir to Franktown/Parker stream flow gage, Segment 2 is from the Franktown/Parker gage to the Castlewood Canyon gage, and Segment 4 is the remainder of the stream.
THMs	Trihalomethanes
Total Maximum Daily Load (TMDL)	Means the total annual phosphorus loads from internal loads and external loads.
Total Phosphorus	Means all forms of phosphorus.
UDFCD	Urban Drainage and Flood Control District
USGS	United States Geological Survey
Wasteload Allocation (WLA)	Means the portion of the external load delivered to the Reservoir from municipal, industrial and commercial wastewater treatment plant discharges and industrial and commercial stormwater discharges. The appropriate WLA/IDR is applied to the total phosphorus from each discharge based on the segment of the discharge to determine the phosphorus load delivered to Cherry Creek Reservoir.
Water Provider	Means a municipal or quasi-municipal entity that provides potable water to users in the Cherry Creek Watershed.
Watershed 2000 Model	Means the hydrologic model used to predict annual total-phosphorus loads from the watershed delivered to the Reservoir. The model is comprised of two components, the water-yield (i.e.: volume of runoff) and the phosphorus-yield parts (i.e.: total phosphorus loads).
WERF	Water Environment Research Foundation
WLA	Wasteload Allocation

WLA/IDR	Means wasteload allocation istream delivery ratio. See instream delivery ratio
WQCC	Water Quality Control Commission
WQCD	Colorado Water Quality Control Division
WQCV	Water Quality Capture Volume
WSD	Water and Sanitation District
WWTF	Wastewater Treatment Facility
WWTP	Wastewater Treatment Plan
Zooplankton	Tiny animals that float passively in the water and are a component of plankton (the passively floating animal and plant life of a body of water). Zooplankton obtain food from the environment (and not by photosynthesis).

Section 1

Executive Summary

The Cherry Creek Basin Water Quality Authority promotes the protection of water quality in the Cherry Creek watershed for the benefit of the public for recreation, fisheries, drinking water supplies, and other beneficial uses.



The primary objectives of the 2000 Watershed Plan are to…

- *Develop a watershed approach for Reservoir protection*
- *Re-evaluate the phosphorus standard and the chlorophyll a goal*
- *Re-evaluate the Cherry Creek TMDL*
- *Identify projects necessary to achieve objectives*

The Cherry Creek Basin Water Quality Authority (Authority) promotes the protection of water quality in the Cherry Creek watershed for the benefit of the public for recreation, fisheries, drinking water supplies, and other beneficial uses. The Cherry Creek Control Regulation (Control Regulation), adopted by the Water Quality Control Commission (WQCC) in 1985, set forth the basic elements of the total maximum daily load (TMDL) and the Master Plan. The 1985 TMDL determined that the maximum allowable load to the Reservoir was 14,270 pounds of phosphorus per year to meet an in-lake 35 µg/L phosphorus standard and to maintain a 15 µg/L chlorophyll a goal. This TMDL was allocated among point and nonpoint sources in the basin.

Since that time, the Authority has embarked on an aggressive data collection program that includes over 15 years of data and information. This information allows for a re-evaluation of the Upper Cherry Creek Basin watershed (Watershed), the Cherry Creek Reservoir (Reservoir), its in-lake phosphorus standard, chlorophyll a goal, and water quality management strategies.

The Cherry Creek Basin Water Quality Management Master Plan was originally approved in 1985. The update to the original Master Plan in 1989 provided general strategies for water quality improvement for the Reservoir. However, the 1989 Plan did not re-evaluate the technical basis for the original TMDL of 14,270 pounds or the 35 µg/L phosphorus standard, which were based on limited data in the Reservoir. Since 1985, the Authority has conducted extensive water quality monitoring of Cherry Creek, its tributaries, the alluvium, pollutant reduction facilities (PRFs), and the Reservoir. Beginning in 1998, the Authority commenced updates of historic modeling work for the watershed and Reservoir using data collected since the original plan was put in place.

The primary objectives of the Cherry Creek Basin Water Quality Management Master Plan (2000 Watershed Plan) are to:

- Develop a watershed approach for protection of the Reservoir, surface streams, and the alluvial aquifer;
- Re-evaluate the phosphorus standard, the chlorophyll a goal, and the allowable annual loading to the Reservoir based on water quality monitoring and modeling;
- Re-evaluate the Cherry Creek TMDL; and
- Identify and prioritize activities and projects necessary to achieve water quality objectives.

1.1 Introduction and Overview

1.1.1 Geography and Hydrology

The COE leased the Reservoir and surrounding land to the State of Colorado for use as the Cherry Creek State Recreation Area, and it has since received extensive recreational use.

Cherry Creek drains an area of 386 square miles in Arapahoe, Douglas, and El Paso counties. The watershed is comprised of 31 sub-basins, with the Reservoir, including an 880-acre lake, at the terminus. The Reservoir was originally constructed for flood control, and is owned and operated by the U.S. Army Corps of Engineers (COE). The Reservoir and land surrounding it was leased to the State of Colorado for use as the Cherry Creek State Recreation Area in 1957. The 3,915 acre-park almost immediately received extensive recreational use, a pattern that has continued to the present day. Cherry Creek and Cottonwood Creek are the major surface water streams within the basin, each having its own alluvial aquifer. Surface flows in these creeks are intermittent, while tributaries only have visible flow after storm events.

1.1.2 Problem Identification

An in-lake chlorophyll a goal of 15-µg/L as a July to September seasonal mean was determined to be an appropriate target to adequately control Reservoir algae levels in order to protect the beneficial uses, recreation, fisheries, water supply, and agricultural uses.

In 1984, the Commission determined that an in-lake chlorophyll a goal of 15 µg/L as a July to September seasonal mean was an appropriate target to adequately control Reservoir algae levels in order to protect the beneficial uses, recreation, fisheries, water supply, and agricultural uses. As such, the Commission established an in-reservoir total phosphorus standard of 35 µg/L (measured as a July to September seasonal mean) to maintain an average, in-reservoir chlorophyll a goal of 15 µg/L. This total phosphorus value was based on the total phosphorus-chlorophyll relationship published by Jones and Bachmann (1976). Subsequent modeling using assumptions for future conditions resulted in a TMDL of 14,270 pounds of phosphorus per year to protect this standard in the Reservoir.

The previous TMDL and seasonal in-lake standard of 35 µg/L were based on only one year of data collected in 1982. With historical perspective and data from the subsequent years, it is clear that 1982 was a comparatively dry year, with very low inflows to the Reservoir and no outflows from the Reservoir. Moreover, the 1982 modeling contained several assumptions regarding the physical attributes and functioning of the Reservoir, which were based on a limited database and are now considered incorrect. As such, the total phosphorus standard of 35 µg/L (seasonal mean) was not related to the chlorophyll a goal of 15 µg/L for this Reservoir. These previous incorrect assumptions were discovered through monitoring and evaluation of the models.

Presented in the 2000 Watershed Plan is the scientific basis to modify the total phosphorus standard for the Reservoir.

Presented in the 2000 Watershed Plan is the scientific basis to modify the total phosphorus standard for the Reservoir. Data collection and modeling indicated that the Reservoir concentration of total phosphorus varied depending on annual volume of inflow. Accordingly, the Authority recommends changing the total phosphorus standard, from 35 µg/L to a hydrologic based standard of 60 µg/L. This flow-based standard better correlates with the 15 µg/L chlorophyll a goal and baseline average inflow volumes of 8,568 acre-feet/year.

Data collection and modeling indicated that the Reservoir concentration of total phosphorus varied depending on annual volume of inflow.

The Authority has developed an index of the predicted total phosphorus for inflow volumes greater than 8,578 acre-feet per year. The following index of predicted total phosphorus to inflow volumes was presented in the Control Regulations and predicts total phosphorus levels at inflows greater than 8,578 acre-feet per year, as shown in Table 1-1.

Table 1-1. Predicted Total Phosphorus for Inflow Volumes Greater than 8,578 acre-feet/ year

Inflows (acre-feet)	Predicted Total Phosphorus (ug/L)
10,000	65
12,000	71
14,000	77
16,000	83
18,000	88
20,000	94
22,000	99
24,000	103

The new TMDL reduces the maximum loads to 11,944 pounds of phosphorus annually.

The corrected seasonal phosphorus standard of 60-µg/L dictates that new allowable loads for the Reservoir be determined. The new TMDL reduces the maximum loads to 11,944 pounds of phosphorus annually predicated upon modeling that predicts inflows of 15,470 acre-feet per year.

1.1.3 Expert Panel Review

Beginning in 1997, the Authority conducted studies to reanalyze the phosphorus and chlorophyll a relationships in the reservoir and to analyze historical phosphorus loads. Concerns regarding the results of these reviews were raised by the City of Greenwood Village, a member of the Authority. To resolve these concerns, an Expert Panel of renowned limnologists and scientists was convened in November 1998 to discuss and propose further steps in the development of water quality goals for the Reservoir. The Expert Panel arrived at the following conclusions (see Appendix A for complete report).

- Both internal and external loads of phosphorus contribute to lake water quality. While there is net internal loading in summer, it is felt that lake water quality is controlled more by external loads.
- Nitrogen can be limiting algal growth at times, but the Authority should continue to manage the basin to reduce external phosphorus loads.
- The Authority should begin using a dynamic model (i.e., a mass balance model with resolution of a week) and should collect monitoring data to support such a model.

- Total phosphorus/chlorophyll relationships used to determine the current standard do not accurately reflect the lake's response.
- The current in-lake phosphorus standard of 35-µg/L, which translates into a 14,270-pound load is clearly inaccurate; moreover, it is inaccurate to believe that the Authority can achieve an in-lake phosphorous standard of 35 µg/L.
- The chlorophyll a goal of 15 µg/L (as a July-September seasonal mean) is a supportable goal.

According to the Expert Panel, "the dynamic model is considered to adequately represent lake total phosphorus during the spring-summer period and provides a semi-mechanistic explanation for the sediment-water P exchange operating in the lake."

As the result of the Expert Panel recommendations, additional data were collected from the Reservoir and a new in-lake model was prepared by Freshwater Research based on a work plan approved by the Expert Panel. The Freshwater Research findings (see Appendix K) were subsequently reviewed by the Expert Panel, who concluded:

"*… The dynamic model is considered to adequately represent lake total phosphorus during the spring-summer period and provides a semi-mechanistic explanation for the sediment-water phosphorus exchange operating in the lake. Based on rates from the dynamic model, predictions using the steady state model are considered valid to evaluate management scenarios. However, the dynamic model should be calibrated and verified on an annual basis when winter lake data become available.*"

1.2 Current Conditions

1.2.1 Land Uses and Population Trends

Development commenced nearest the Reservoir in Arapahoe County, and progressed upstream to Douglas County, the nation's fastest growing county.

Development commenced nearest the Reservoir in Arapahoe County and City of Aurora, and progressed upstream to the Parker area in Douglas County, the nation's fastest growing county. Recently, development pressures in the middle 1/3 of the watershed have come from the Castle Rock area. Whereas residential uses continue to be the largest land use (other than undeveloped uses, including open space, parks, floodplains, and agriculture), commercial/office uses are also prominent.

1.2.2 Municipal Water Sources

Municipal water sources come from the alluvial and deep, non-tributary aquifers, and surface water supplies imported to the watershed.

Pumping by principal entities has a direct positive bearing on lake water quality.

Municipal water sources in the Cherry Creek Basin come from the alluvial and deep, non-tributary aquifers as well as surface water supplies imported to the watershed. There are five principal municipal water supply entities in the upper Cherry Creek Basin that utilize Cherry Creek alluvial aquifer wells. These entities, Arapahoe County Water and Wastewater Authority (ACWWA), City of Aurora, Cottonwood Water and Sanitation District (Cottonwood WSD), Parker Water and Sanitation District (Parker WSD), and the Pinery Water and Sanitation District (Pinery WSD), have pumped an average of over 5,400 acre-feet annually, which has a direct positive bearing on lake water quality.

1.2.3 Wastewater Treatment Facilities

Wastewater treatment plants (WWTP) provide for a very high level of phosphorus removal and treatment using either secondary treatment followed by land application, or advanced wastewater treatment (AWT)

WWTPs provide for a very high level of phosphorus removal and treatment.

followed by land application or direct discharge. The NPDES permits require dischargers to monitor and quantify the concentration and total pounds of phosphorus discharged, regardless of disposal method. These records show that phosphorus loads have diminished at each discharge point from 1997 to 1998.

1.2.4 Watershed Monitoring

The water quality data indicate that phosphorus concentrations are relatively constant throughout the Cherry Creek mainstem and the underlying alluvial aquifer.

The Authority monitors Cherry Creek streams to evaluate nutrient loading to the Reservoir. Monitoring of surface and groundwater quality for the Cherry Creek mainstem, as described in Appendix B, began in August 1994 and has continued to date. While there is a wide range of water quality constituents being monitored, the study has focused primarily on nutrients (i.e., nitrogen and phosphorus species) as it relates to their potential to impact the Reservoir.

The water quality data collected to date indicate that phosphorus concentrations are relatively constant throughout the Cherry Creek mainstem and the underlying alluvial aquifer, ranging between 150 µg/L and 250 µg/L. There are no discernible changes in concentrations at monitoring locations down-gradient of direct discharges that would imply that effluent has impacted phosphorus loads to the creek or Reservoir. Phosphorus concentration and flow data at Castlewood Canyon can be used as background, and compared to concentration and flow data at the Reservoir.

The principal variability in phosphorus loading throughout the mainstem and to the Reservoir is related to the volume of flow.

The water pumped from the alluvial aquifer by the municipal water entities is replaced by AWT plant effluent, 4 to 10 times lower in phosphorus concentrations than the water removed.

The principal variability in phosphorus loading throughout the mainstem and to the Reservoir is related to the volume of flow. Even at higher flows during spring runoff, phosphorus concentrations do not increase above background levels. The consistent phosphorus concentrations throughout the water can be attributed, in part, to the removal of phosphorus by municipal water users. The alluvial water that is pumped from the Cherry Creek alluvial aquifer by the municipal water entities is replaced by AWT plant effluent, which is 4 to 10 times lower in phosphorus concentrations than the water removed. This removal mechanism is minimizing changes in phosphorus concentrations that may be resulting from nonpoint and stormwater sources in the study reach.

Average distribution of loads into the Reservoir...

Cherry Creek and its alluvium = 73%

Cottonwood Creek = 14%

Direct precipitation = 11%

Since 1992, on an annual basis, total phosphorus loads into the Reservoir have ranged from 4,764 pounds to 20,199 pounds, with an eight-year average of 9,502 pounds. On average, Cherry Creek and its alluvium are responsible for 73 percent of the total loads, with approximately 14 percent from Cottonwood Creek, 11 percent from direct precipitation, and 2 percent from Shop Creek. For the period 1995 through 1997, cumulative annual phosphorus loads at Castlewood Canyon and upstream of the reservoir were generally declining. The principal cause of the reduction in phosphorus loads appears to be related to lower flows, while total phosphorus concentrations remained relatively consistent throughout this 3-year period. Conversely, in 1998 and 1999 phosphorus loads greatly increased, principally related to much higher flows in Cherry Creek, while

13-years of Authority monitoring have shown the July-September seasonal means of phosphorus to be well above the old phosphorus standard.

The high flows and higher loads in 1998 and 1999 represent the first years that loads had exceeded the TMDL of 14,270 pounds.

Planktivorous fish may also be influencing nutrient dynamics in the Reservoir through their predation on zooplankton.

total phosphorus concentrations remained consistent with values reported during the low flow years of 1995 to 1997.

1.2.5 Reservoir Quality

Based on data collected by the Authority since 1987, water quality and aquatic biological conditions in the Reservoir were assessed. The following observations support the need to update the Master Plan, TMDL, and Control Regulation.

- Over the 13 years of Authority monitoring, July-September seasonal means of phosphorus have ranged from 39 µg/L in 1989 to 96 µg/L in 1997, with a long-term average value of 66 µg/L, well above the old phosphorus standard.
- Average July-September chlorophyll-a content has ranged from 5.6 µg/L in 1989 to 31.8 µg/L in 1999, with a long-term average value of 16.9 µg/L, slightly higher than the chlorophyll a goal.
- Season mean Secchi depth (transparency) has averaged approximately 1 meter over the period of record with a slight increase in Secchi depth being observed since 1987 (i.e., greater clarity in recent years).
- Cumulative effects of high flows resulted in the higher loads in the past two years, 1998 and 1999, representing the first years that loads had exceeded the TMDL of 14,270 pounds.

Sampling of aquatic biota and nutrients in reservoir and tributary streams demonstrated that water transparency varied throughout the year, with lowest values corresponding to periods of high phytoplankton density. Water temperature data suggest that the Reservoir experiences periods of complete mixing interspersed with short periods of minimal thermal stratification during the summer. Data on fecal coliforms and *E. coli* indicated that pathogenic bacteria in the main body of the reservoir probably meet water quality standards for swimming and body contact recreation.

Blue-green algae were consistently the most abundant algal group in the Reservoir. Zooplankton populations (which serve as grazers of algae) were comprised primarily of protozoans and rotifers during much of the summer. During late summer, periods of low zooplankton densities often correlated to periods when, phytoplankton densities and chlorophyll a concentrations were generally high. The fish community in the Reservoir has historically been dominated by gizzard shad, an effective zooplanktivore. Such planktivorous fish may also be influencing nutrient dynamics in the Reservoir through their predation on zooplankton.

1.3 Growth in the Watershed

1.3.1 Population Projections

The Denver Regional Council of Governments (DRCOG) projected population for the Cherry Creek Basin in its 1998 Clean Water Plan Update. The projections were based on 1990 census data, updated through planning processes such as traffic analysis zones, number of homes, and land use. DRCOG estimates 2020 population projections by the year 2020 increasing to 62,534. (DRCOG, 1998).

1.3.2 Municipal Water Sources

Future alluvial pumping can have an effect on Reservoir water quality.

Municipal water requirements in the Cherry Creek Basin will likely result in increased pumping from alluvial and deep non-tributary aquifers. Currently, municipal pumping from alluvial aquifers ranges from a low of about 3,500 to over 7,500 acre-feet annually, with an average around 5,200 acre-feet. Some projections have estimated total future pumping at over 10,000 acre-feet annually.

Pumping from the alluvium directly affects inflow volume (and phosphorus loads) delivered to the Reservoir, both of which can have an effect on Reservoir water quality. Future alluvial pumping is also an alternative PRF that will be investigated further by the Authority (see Section 5.2.2.2.5).

1.3.3 Wastewater Treatment Projections

Growth in the watershed will require expansion of existing wastewater treatment facilities (WWTFs) and additional facilities or consolidation of existing facilities for development outside current service areas. Current water providers have projected their discharges, which have been used to estimate future phosphorus loads. New developments and WWTP expansions may apply to the Authority for a wasteload allocation (WLA) via the future WLA pool of 1,411 pounds. Load projections to the Reservoir require phosphorus concentrations of 0.05 mg/L for direct dischargers. In-stream delivery ratios and land application zones affect computation of loads to the Reservoir. The total phosphorus available for WLA to the Reservoir by the year 2020 from current and future point source discharges is estimated at 2,280 pounds.

1.3.4 Nonpoint and Stormwater Load Projections

Runoff volumes are projected to increase 57% by the year 2020.

Without benefits of BMPs and PRFs, phosphorus loads from stormwater are projected to increase 46% by the year 2020.

Empirical data and water quality models have been applied to the Cherry Creek Reservoir Basin to help provide a scientific basis for the Master Plan Update. Specifically, the models provide a characterization of storm runoff volumes and phosphorus loads to Cherry Creek and the Cherry Creek Reservoir resulting from point and nonpoint sources for two development conditions - current (2000) and future (2020). Runoff volumes are projected to increase from an average of 7,285 acre-feet/year to 11,435 acre-feet/year, an increase of 57 percent by the year 2020. Without benefits of best management practices (BMP) and PRFs, phosphorus loads from stormwater are projected to increase from an average of 5,432 pounds to 7,909 pounds, an increase of 46 percent by the year 2020. These projections are based on no increases in alluvial pumping by water providers, and are considered conservative estimates.

1.3.5 Proposed Cherry Creek TMDL

The total annual loads of phosphorus to the Reservoir are predicated upon modeling that predicts that future loads (at 15,470 acre feet per year inflows to the Reservoir) will result in an in-lake seasonal mean total phosphorus of 60 µg/L, needed to maintain the seasonal mean chlorophyll a goal of 15 µg/L, on average (see text below). The Cherry Creek TMDL of 11,944 pounds is distributed between internal sources and external sources. The Cherry Creek Total Phosphorus Load = Internal Load + External Load (Load Allocation + Direct Precipitation + Wasteload Allocations + Reserve Pool + Trading Pool). The TMDL (see Figure 1-1) incorporates an implicit margin of safety because numerous conservative assumptions were utilized for projections and modeling. Estimates were made to determine effects of increased pumping, the 15 percent explicit margin on wasteload allocation instream delivery ratios (WLA/IDR), greater than 50th percentile difference, and BMP implementation. Based on these estimates, margins of safety provide a buffer of at least 15percent on estimated loads delivered to the Reservoir.

The Cherry Creek Total Phosphorus Load =

Internal Load +

External Load +

Direct Precipitation +

Wasteload Allocations +

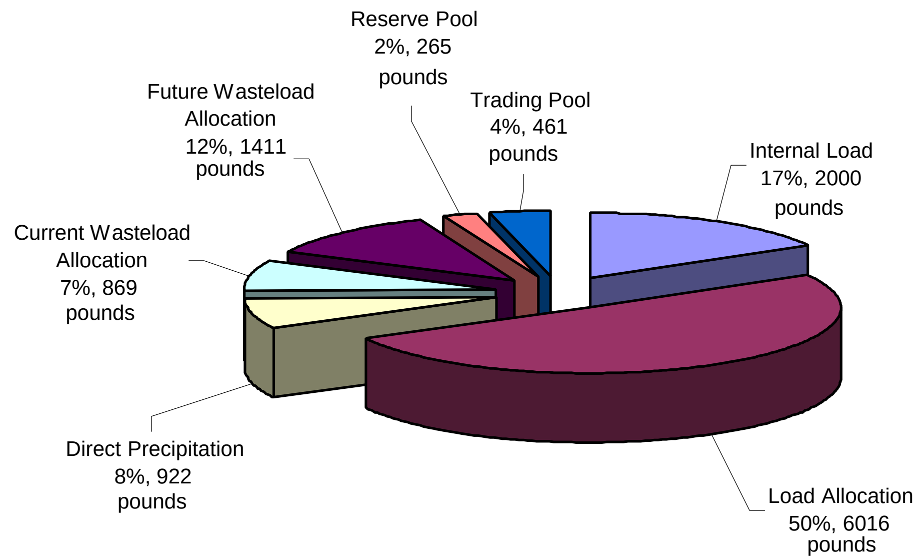
Reserve Pool +

Trading Pool).

The TMDL is comprised of the following:

- A load allocation of pounds 6,016 (50 percent), which is primarily stormwater runoff, but also includes background and individual sewage disposal systems (ISDS).
- Direct precipitation of 922 pounds (8 percent), which is greater than the average measurements made since 1987.
- Current WLA of 869 pounds (7 percent) from the seven current WWTFs for a 2010 projection. The amount is based on effluent concentration of 0.05 mg/L for direct discharges and 0.20 mg/L for land applied effluent.
- Future WLA of 1,411 pounds (12 percent), also based on effluent concentration of 0.05 mg/L for direct discharges and 0.20 mg/L for land applied effluent.
- Reserve pool of 265 pounds (2 percent) may be allocated by the Authority for temporary or emergency conditions.
- Trading pool of 461 pounds (4 percent), which may be awarded by the Authority to dischargers pursuant to the Trading Program.
- Internal Reservoir loads of 2,000 pounds (17 percent), which represents a 50 percent reduction from above average conditions.

Figure 1-1. The Cherry Creek TMDL



1.4 Future Conditions in the Reservoir

1.4.1 Proposed In-Lake Phosphorus Standards and Chlorophyll a Goal

Various in-lake models have been used in the past to predict the relationship between chlorophyll a and phosphorus. Future conditions in the Reservoir, however, are predicted based on a new dynamic model of the reservoir relationships.

Based on data and modeling for the Reservoir, a total phosphorus standard of 60-µg/L in the upper 5 meters of the Reservoir is measured as a July through September seasonal mean.

The goal of 15 µg/L chlorophyll a as a July-September mean value is recommended to be maintained. Based on 40 years of empirical data on chlorophyll a and phosphorus for the Reservoir, the Dynamic Model, and modeling of future scenarios using a steady-state, annual load model, a total phosphorus standard of 60 µg/L in the upper 5 meters of the Reservoir is measured as a July through September seasonal mean. In-lake phosphorus and phosphorus loadings to the Reservoir are strongly dependent on streamflow volume. Compliance with the seasonal total phosphorus standard would be determined annually based upon achieving a seasonal mean of 60 µg/L total phosphorus or less for all years with flows less than 8,578 acre-feet per year (using baseline conditions), and indexed for inflows that are higher than this value, as shown on Table 1-1. For years with inflows exceeding 8,578 acre-feet per year, compliance would be determined based upon the deviation of measured seasonal mean total phosphorus from predicted total phosphorus in the index. It is understood that for those high flow years that as total phosphorus increases beyond 60 µg/L that chlorophyll will likely exceed the goal of 15 µg/L.

1.4.2 In-Lake Model and Phosphorus Projections

Using input from the Dynamic Model reviewed by the Expert Panel, a steady state model was applied to long-term hydrological conditions for the years of normal Reservoir operation from 1960 to 1999. Given the variable hydrological and loading conditions, medians, 25th and 75th percentile values were reported to characterize these long-term baseline conditions (see Scenario 1 in Table 4-4). These calculations also allow the percentage of time below which the proposed seasonal mean total phosphorus of 60 µg/L) is achieved (63percent for baseline conditions). A number of scenarios were run under long-term baseline conditions predicting changes in seasonal mean total phosphorus because of external and internal load reduction.

Four additional scenarios were modeled according to future (year 2020) development and phosphorus load control strategies projections. Lowest July-September total phosphorus averages are predicted in scenarios where both external and internal phosphorus sources are addressed. The Authority recommended adopting a TMDL based on the modeling for "Future Scenario 8," a scenario which incorporates future flow increases, but small increases in external phosphorus loads. The external phosphorus load increases are assumed reduced through implementation of BMPs for stormwater drainage, construction of PRFs removing approximately 1,557 pounds of phosphorus, and maintaining alluvial pumping at current levels. A 50percent reduction of internal loads through in-lake management was also incorporated in Scenario 8.

The City of Greenwood Village and the Authority developed a more aggressive BMP implementation and total phosphorus control scenario, the "Best Efforts Scenario," to remove a total of 2,730 pounds of phosphorus annually.

With these internal and external loading controls, the model predicted 71 percent compliance with the seasonal mean 60 µg/L total phosphorus standard (an increase over the 63percent during baseline conditions). However, the City of Greenwood Village requested that the Authority consider whether additional external load controls were feasible to improve water quality compliance. Collectively, the City of Greenwood Village along with the Authority developed a more aggressive BMP implementation and total phosphorus control scenario to remove a total of 2,730 pounds of phosphorus annually ("Best Efforts Scenario"). Under this Best Efforts Scenario, additional modeling indicates that the seasonal mean 60 µg/L in-lake total phosphorus standard should be more consistently attained, even with variable inflows. Further, it predicts resulting seasonal mean chlorophyll a levels should be within the goal of 15 µg/L on a more consistent basis. The Best Efforts Scenario is contained in the Control Regulation revisions being approved and is more fully detailed in the Watershed Plan.

1.5 Implementing the Best Efforts Plan

The Authority has already commenced implementing aspects of the Best Efforts Plan and has reasonable assurance of full implementation. The stormwater quality regulations have been adopted by the Authority and two

The Authority has already commenced implementing aspects of the Best Efforts Plan and has reasonable assurance of full implementation.

land use jurisdictions; the Authority will provide support to its other members to assure their adoption of the stormwater quality regulations. The discharge permits for existing dischargers mandate the phosphorus concentrations and annual loadings, so permits will be modified, as necessary to reflect new limits. The Best Efforts Plan has identified and prioritized watershed projects based upon phosphorus removals. The Authority intends to use its funds and seek grants and loans and cost sharing from other agencies to construct the PRFs and implement in-lake management. Because of implementation activities already commenced and the specificity of the Best Efforts Plan, there is reasonable assurance it can and will be implemented.

Components of the Best Efforts Plan include...

- *Adoption of stormwater quality regulations by all Authority members*
- *Implementation of PRFs*
- *Control of point-source discharges*
- *Implementation of in-lake management techniques*
- *An operation and maintenance plan to insure PRFs*

The Authority has adopted a long-range plan to manage stormwater and nonpoint sources in the watershed, with the common goal of reducing phosphorus (and other pollutants) loads delivered to the stream system and reservoir. Components of the plan include:

1. Adoption by all Authority members of stormwater quality regulations to implement, monitor, and enforce on-site BMPs that control stormwater pollution during and after construction. BMPs are required to address impacts from residential, commercial and industrial (which includes sand and gravel operations) development. Brief descriptions of the BMPs are provided in Section 5.2.1.3 with more detailed information in Appendix L. Regulations also identify additional requirements to protect stream preservation and groundwater areas.

2. Implementation of facilities that provide protection beyond BMPs are referred to as PRFs. Presented in Section 5 is a summary of the recommended PRF facilities to meet the TMDL goal. With implementation of all PRFs, external loads to the reservoir (i.e., not including in-lake management), would be reduced by 2,730 pounds per year. Load reductions take into account load-allocation, in-stream delivery ratios. The present worth cost is estimated at $7,428,000 and an annual cost of $619,800, which includes capital, capital replacement, and operations/maintenance. These are estimated costs to the Authority, based on assumed cost-sharing formulas. Total present-worth costs are estimated to be almost $16,000,000.

3. Control of point-source discharges by incorporating the phosphorus allocation and phosphorus effluent concentration limitations in discharge permits. The allocation will provide the basis for the Water Quality Control Division (WQCD) to enforce the phosphorus control program and have the guarantee that a discharger is in compliance with the basin-wide allocation program.

4. Implementation of in-lake management techniques, such as application of alum (or other suitable substance) to precipitate dissolved phosphorus and “seal” the phosphorus sediments at the reservoir bottom. In-lake management is projected to reduce phosphorus loads by 2000 pounds per year. The Authority is also investigating other in-

lake management strategies, such as bio-manipulation, de-stratification of thermal layers, and optimization of Reservoir operation.

5. An operation and maintenance plan to insure PRFs continue to provide their phosphours removal effectiveness.

1.6 Monitoring and Enforcement

Programs in the Cherry Creek basin include reservoir and watershed monitoring, regulations for stormwater controls, studies to monitor the impacts of ISDS, and public education/outreach programs.

NPDES permits for point source discharges require monitoring of effluent phosphorus, regardless of disposal method. Phosphorus contributions by the individual plant operators are reported to the WQCD and the Authority.

Beyond this, due to the broad scope of nonpoint sources in the Cherry Creek basin, several programs have been in progress and will continue. These programs include reservoir and watershed monitoring, regulations for stormwater controls, studies to monitor the impacts of ISDS's, and public education/outreach programs. To monitor drinking water quality, several constituents (nitrogen, sulfate, chloride, coliforms, metal ions, gross alpha activity, and trihalomethanes) have been monitored for trends.

1.7 Future Cooperative Programs and Capital Improvement Projects

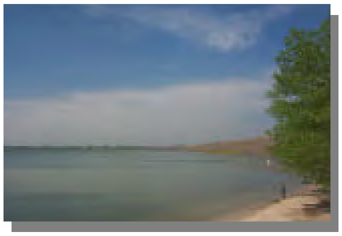
The Authority encourages PRF construction by third parties through a comprehensive BMP enhancement program.

Because of the size and number of BMPs constructed by third parties as part of growth in the watershed, there is an opportunity to enhance these facilities to PRF status, thereby providing benefits to the owner and the Authority. Enhancements could include construction of littoral zones, pre-treatment area, enlargement of water quality pools, constructed wetlands, or other technology to remove phosphorus from stormwater. The Authority would like to take advantage of these opportunities through a cooperative enhancement program, some of which could be classified as PRFs after modification.

Section 2 Introduction and Overview

2.1 Objectives

The Authority identified four key objectives of the 2000 Watershed Plan.



The Authority identified 4 key objectives of the 2000 Watershed Plan...

- *Develop a watershed approach for Reservoir protection*
- *Re-evaluate the phosphorus standard, the chlorophyll a goal, and the allowable annual loading*
- *Re-evaluate the Cherry Creek TMDL*
- *Identify projects necessary to achieve objectives*

1. Develop a watershed approach for protection of the Reservoir, surface streams, and the alluvial aquifer.

The 2000 Watershed Plan addresses water quality throughout the watershed, including the streams and alluvial groundwater and their interrelationships with the Reservoir. Actual data and water quality models have been applied to the Cherry Creek watershed to help provide a scientific basis for the update.

2. Re-evaluate the phosphorus standard, the chlorophyll a goal, and the allowable annual loading to the Reservoir based on water quality monitoring and modeling.

Previous models did not acknowledge phosphorus-loading mechanisms within the watershed or accurately predict the phosphorus-chlorophyll a relationship in the Reservoir. A more predictive model was necessary to relate changes in loads from the watershed under future conditions to in-lake phosphorus concentrations. There is sound and viable data about the Reservoir and its watershed that fully supports reconsideration of the standards and TMDL. Data collected over the past decade strongly suggests that previous assumptions about the relationship between chlorophyll a and phosphorus contained in the original plan do not correspond with what is observed in the Reservoir.

3. Re-evaluate the Cherry Creek Total Maximum Daily Load.

Based on total allowable loading to the Reservoir and in-lake modeling, phosphorus load among various categories have been reallocated. The TMDL process results in the determination of:

- The amount of a specific pollutant that a segment can receive without exceeding the water quality standard (the TMDL),
- Apportionment to the different contributing sources of the pollutant loading (the allocation). The TMDL includes a margin of safety, WLA (for point sources, commercial and industrial stormwater), and a load allocation for municipal stormwater and natural background sources.

The original TMDL for the Reservoir was set at 14,270 pounds. Annual phosphorus loads were previously modeled for the Cherry Creek basin as part of the 1985 Master Plan.

4. Identify control measures for the various sources of phosphorus loading in the watershed.

The Authority has identified as well as implemented several watershed and in-lake management strategies to control phosphorus loading into the watershed, such as stormwater quality regulations to implement, enforce and monitor BMPs, PRFs, alum application and continued monitoring.

2.2 Historical Background

The Clean Lakes Study identified phosphorus as the major nutrient causing algal productivity and, therefore, potential eutrophication of the reservoir.

The Clean Lakes Study of Cherry Creek Reservoir conducted in 1982 identified that eutrophication of the Reservoir could negatively impact the beneficial uses of the reservoir, primarily recreational uses and potentially aquatic life uses (DRCOG 1984). The Clean Lakes Study identified phosphorus as the major nutrient causing algal productivity and, therefore, potential eutrophication of the reservoir. Based on the Clean Lakes Study, the Colorado WQCC established an in-reservoir total phosphorus (TP) standard of 35 µg/L (as a July to September seasonal mean). This seasonal mean total phosphorus standard was set to maintain an average, in-reservoir chlorophyll a goal of 15 µg/L (also a July-September seasonal mean) using the total phosphorus-chlorophyll relationship of Jones and Bachmann (1976).

The Cherry Creek Basin Water Quality Authority's mission is to promote the protection of water quality in the Cherry Creek Watershed for the benefit of the public for recreation, fisheries, water supplies, and other beneficial uses.

In 1985, to meet the reservoir standard and TMDL, the Cherry Creek local governments, private interest groups, and representatives of the state and federal agencies developed a TMDL of 14,270 pounds total phosphorus annual load to the Reservoir (Table 2-1). The TMDL was presented in the Cherry Creek Basin Water Quality Management Master Plan (1985 Master Plan) and approved by the WQCC. Key elements of the TMDL and 1985 Master Plan were included as the "Regulation for Control of Water Quality in Cherry Creek Reservoir" (Sect 4.2.0, 5 C.C.R. 3.8.11) effective December 30, 1985.

Table 2-1. Original 1985 TMDL
[from DRCOG's Cherry Creek Basin Water Quality Management Plan, 1985]

Allocation Category	Annual Load, pounds
Point Sources	2,310
Nonpoint Sources	10,290
ISDS	450
Industrial Sources	50
Background	1,170
Critical Load (TMDL)	*14,270*

Over the past four years, the focus of the Authority has been evolving from phosphorus loading in the Reservoir to a broader understanding and protection of water quality throughout the watershed.

The 1985 Master Plan was updated in 1989 and provided general strategies for water quality improvement for Cherry Creek Reservoir; however, it did not re-evaluate the technical basis for the TMDL or the 35 µg/L seasonal mean phosphorus standard. Since 1985, the Authority has conducted extensive water quality monitoring of Cherry Creek, its tributaries, the alluvium, and the Reservoir. The Authority has also constructed a number of PRFs in the basin since 1985 and monitors these annually.

In 1997, the Authority commenced reevaluating phosphorus and chlorophyll a relationships and phosphorus loading estimates with over 12 years of data. The Authority conducted a workshop in February 1997 with Authority members, state and regional agencies, and other interested parties to discuss the goals of the 1998 Master Plan. The workshop also served as a forum to educate attendees on technical issues and the status of the Basin and to formulate a strategy for completing the update. On October 15, 1999, the Authority co-sponsored a one-day symposium titled "Stewardship of the Cherry Creek Watershed and its Reservoir." Topics covered included watershed dynamics, impacts and issues, stakeholder activity panel, and other related Front Range issues.

Over the past four years, the focus of the Authority has been evolving from emphasizing controls of phosphorus loading to the Reservoir, to a broader understanding and protection of water quality throughout the watershed.

2.3 Watershed and Reservoir Characterization

Cherry Creek Reservoir is located in Arapahoe County west of Parker Road and south of I-225. The Reservoir is fed primarily by Cherry Creek and Cottonwood Creek, as well as smaller watersheds that are drain directly to the Reservoir (Figure 2-1). The Reservoir and land surrounding the Reservoir were leased to the State of Colorado in 1957 for use as the Cherry Creek State Recreation Area. The 3,915 acre-park almost immediately received extensive recreational use, a pattern that has continued to the present day.

2.3.1 Cherry Creek Watershed Geography and Hydrology

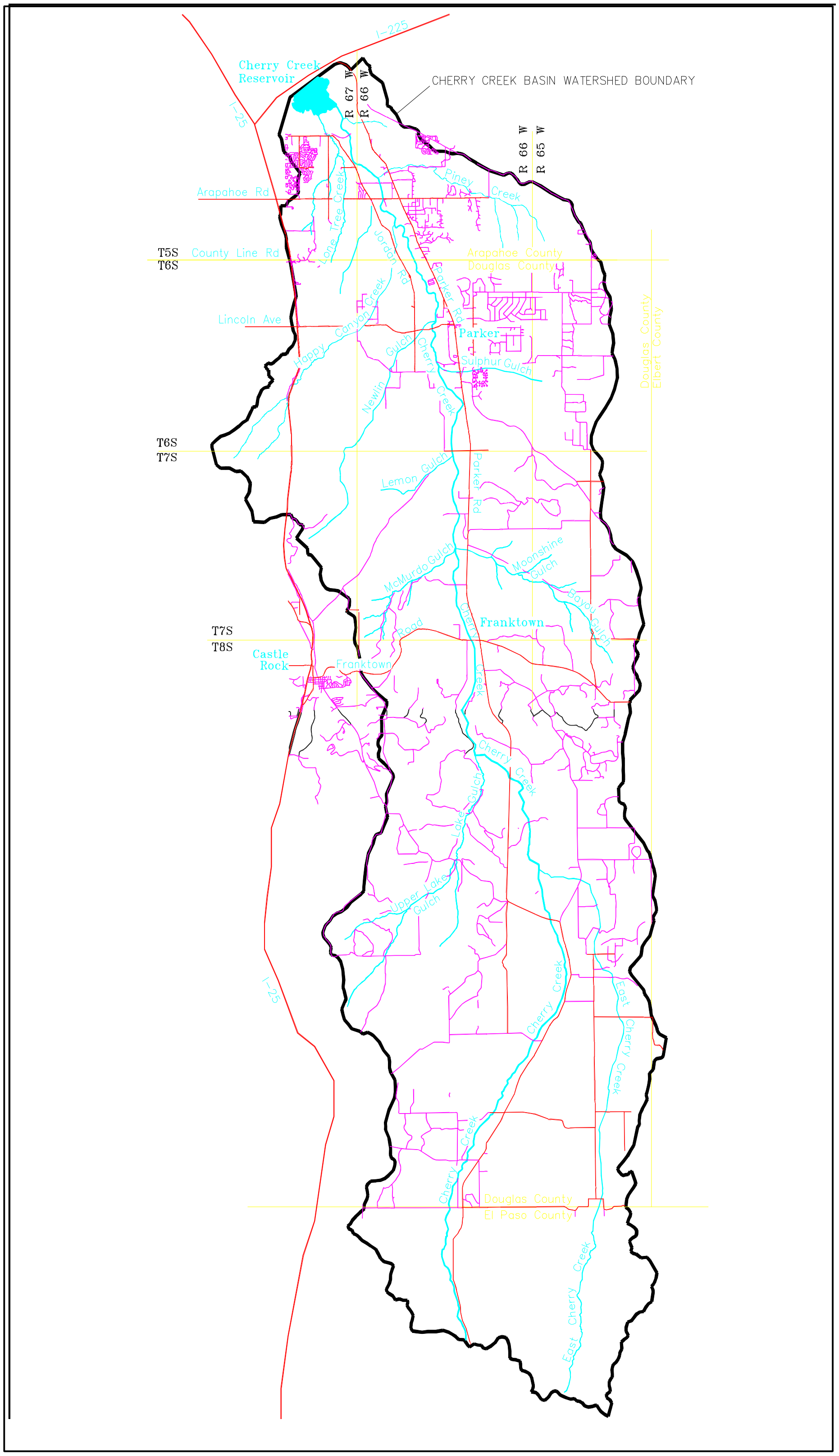
Cherry Creek drains an area of 386 square miles, and is made up of 31 sub-basins.

Cherry Creek drains an area of 386 square miles, including portions of Arapahoe, Douglas and El Paso counties. The watershed is made up of 31 sub-basins, with the Reservoir at the terminus of the watershed. The basin drains northward, from elevations reaching approximately 7,700 feet along the southern perimeter in El Paso County, to approximately 5,600 feet where it flows into the Reservoir. Topography within the watershed is quite variable – consisting of pinyon pine covered hillsides, short grass prairie, and canyons, such as those found at Castlewood Canyon State Park.

Cherry Creek and Cottonwood Creek are the major surface water streams within the basin, each having its own alluvial aquifer, while many other tributaries only have visible flows following storm events.

Cherry Creek and Cottonwood Creek are the major surface water streams within the basin, each having its own alluvial aquifer. Although water flows continuously through the aquifer, surface flows in Cherry Creek and Cottonwood Creek are intermittent. Many other tributaries only have visible flows following storm events. Temporal variations in flow are due to snowmelt runoff and summertime thunderstorms. Snowmelt runoff is observed early, typically starting in March, and continuing through May. Historic gauged flow of Cherry Creek near Melvin, located at Arapahoe Road, averaged approximately 5,900 acre-feet/year for the period 1956 to 1969. Cherry Creek at Parker gage records averaged approximately 5,300 acre-feet/year for the period 1991–1996. Flows in Cherry Creek near Franktown averaged approximately 6,900 acre-feet for the period 1956 to 1996. The average inflow into the Reservoir, measured by Chadwick Ecological averaged 7,171 acre-feet/year (1992–1997).

Figure 2-1. The Cherry Creek Basin



A precipitation gage at the Cherry Creek Dam COE site office has been maintained since 1969. Annual precipitation at this gage averaged 16.54 inches for the period 1951 to 1996. Within the overall watershed, the annual precipitation varied from 11 inches to over 19 inches, with a 10 year average of 15 inches (see Appendix I).

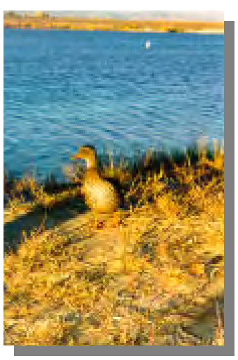
The Cherry Creek alluvium is deposited in a valley incised into the Dawson Formation. The alluvium consists of stream deposited, unconsolidated, sand, gravel, cobbles, silt, and clay. The alluvial channel is 3,000 to 6,000 feet wide between Parker and Cherry Creek Dam. The United States Geological Survey (USGS) lithologic well logs were used to create cross-sections of the alluvial channel, indicating that the paleo-channel is up to 110 feet thick.

Cherry Creek and the aquifer are hydraulically connected; therefore changes in water table elevation can transition Cherry Creek from a losing stream to a gaining stream, and vice versa.

Cherry Creek and the aquifer are hydraulically connected; therefore changes in water table elevation can transition Cherry Creek from a losing stream to a gaining stream, and vice versa. This affects runoff characteristics in the basin. Similarly, increases in the historic pumping pattern in the alluvium are likely to alter Cherry Creek in various segments from a gaining to a losing stream. An analysis of flow data shows that Cherry Creek is a losing stream for many of its segments (Authority, 1989).

The Cherry Creek dam is an earth fill structure with a partial cutoff trench into bedrock. Through most of the dam, the cutoff trench was excavated down to bedrock and replaced with impermeable material. However, the depth of the alluvium exceeds the depth of the cutoff trench at two locations by as much as 50 feet. These two zones allow groundwater to flow beneath the dam and to continue downstream in the Cherry Creek alluvium (Authority, 1989).

2.3.2 Cherry Creek State Park Biota



Cherry Creek State Park uplands are dominated by mixed prairie communities, the species composition determined by the substrate and historic land use. Dominant species include western wheatgrass, blue grama, purple threeawn, mat muhly, needle-and-thread grass and false buffalograss. Other associated plant species include threadleaf sedge, woolly plantain, copper mallow, buckwheat, Nuttall violet, sand lily, prickly pear cactus, snakeweed and rabbitbrush. Diverse wetland, riparian and aquatic plant communities have become established along Cherry Creek, tributary drainages, around the reservoir, in retention ponds and below the dam.

More than 150 species of migratory and resident birds have been observed here.

More than 150 species of migratory and resident birds have been observed here, including the plains species of lark bunting, horned lark and meadow lark, several raptors, waterfowl and shorebirds attracted to the reservoir. A nesting colony of black-crowned night herons uses wooded wetlands on the west side of the reservoir and burrowing owls use prairie dog burrows for nesting and brood-rearing. Rare birds such as the bald eagle, white pelican and American peregrine falcon may also be observed here as migrants or winter or summer residents. Mule and white-tail deer are common, as are cottontail rabbit, coyote, beaver, muskrat, raccoon, weasel, prairie dog and ground squirrel; a total of 43 mammal species are known for the park. Many anglers are attracted by the warm-water fishing opportunities in the Reservoir.

2.3.3 Cherry Creek State Park Geology

Cherry Creek State Park lies in the Cherry Creek Valley of southwestern metropolitan Denver. The park occupies a gently rolling, eastward-sloping plain, recently mantled with Pleistocene and Recent silty loess, thick eolian sand and alluvial deposits. Pleistocene and Recent deposits cover interbedded sandstones and shales of the Cretaceous Dawson and Denver formations. Alluvial deposits on the park are described as Pleistocene Slocum, Louviers and Broadway and Recent Post-Piney Creek and Piney Creek alluvium and eolian sand; they consist of gravel, sand, silt and clay.

2.3.4 Cherry Creek Reservoir Flora and Fauna

Plant and animal life are important to the water quality and health of the Reservoir. To understand water quality changes in the Reservoir, phytoplankton, zooplankton, and fish populations are of particular interest.

2.3.4.1 Phytoplankton Population

Densities of phytoplankton in the Reservoir have varied by as much as 20 times, with species richness varying from 9 to 23 taxa in 1999. Different taxa dominate the phytoplankton community at different times of the year. Forty-six different taxa of algae were identified in the past sampling year. Historically, blue-green algae have dominated the algal population in the Reservoir, accounting for 64percent or more of the population density in all sampling years. Data also suggest that algal density has decreased in the Reservoir somewhat since 1992. However, the relationship between chlorophyll a levels and abundance of algae has not been consistent from year to year.

Reduction is density of small bodied taxa (i.e.; blue-green micro algae) constitutes a large proportion of the difference between observed algal densities in later monitoring years. However, these particular algae are very small and contribute very little chlorophyll relative to their abundance. Larger bodied taxa such as green algae and cryptomonads have more modest reduction in their densities, while densities of diatoms and euglenoids have remained fairly constant over time. Therefore, in spite of overall decreased algal densities, the abundance of larger algae continues to contribute to an intermittent exceedance of chlorophyll a reservoir goals.

2.3.4.2 Zooplankton Population

Mean zooplankton (i.e.: protozoa, rotifera, and crustacea) densities have varied more than 3 orders of magnitude, with highest densities in June and April. Certain species of crustacea have showed distinct seasonal patterns, with highest densities in late spring and early summer, and virtually disappearing from the zooplankton community by end of July into August. This pattern for some populations has been documented in other temperate lakes and in Cherry Creek Reservoir may be attributed to increases in densities of zooplanktivorous fish.

Seasonal patterns for zooplankton densities are often a "mirror image" of phytoplankton densities and chlorophyll over the course of a sampling season. The increases in phytoplankton abundance observed during the period of lowest zooplankton densities suggests a possible loss of control mechanism when zooplankton grazing is minimized.

2.3.4.3 Fish Populations

Changes in zooplankton community caused by fish predation can be dramatic in eutrophic lakes, such as Cherry Creek Reservoir.

Historically, the fish community in Cherry Creek Reservoir has been composed of many species including omnivores (e.g.: common carp suckers), insectivores (e.g.: trout, yellow perch, green sunfish), zooplanktivores (e.g.: bluegill, gizzard shad) and piscivores (e.g.: largemouth bass, walleye, wiper). Stocking data from the Colorado Division of Wildlife (CDOW) shows that since 1985ten species and two hybrids have been stocked in the Reservoir. The two stocked hybrids were the wiper (i.e.: a cross between striped bass and white bass) and the tiger musky (i.e.: a cross between a northern pike and muskellunge). Of these 12 taxa, channel catfish, rainbow trout and walleye have been stocked every year.

Fish can exert a strong influence on the structure and productivity of phytophankton and zooplankton communities. This influence occurs through food web pathways between different levels of the aquatic ecosystem. Changes in zooplankton community caused by fish predation can be dramatic in eutrophic lakes, such as Cherry Creek Reservoir. In addition, these trophic dynamics can affect the variability, distribution, and ratios of limiting nutrients such as phosphorus and nitrogen. Mechanisms that may result from fish predation include decreased herbivory by zooplankton when fish are abundant, modification of nutrient cycling rates by herbivorous zooplankton as fish abundance varies, and nutrient recycling by fish.

2.3.4 Cherry Creek Reservoir Uses

The Reservoir has many uses. Primary functions are flood control and recreation.

2.3.4.1 Flood Control

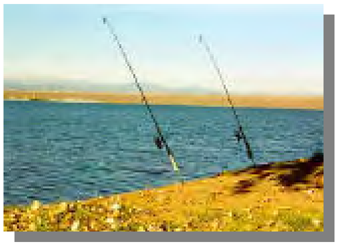
The Reservoir has many uses. Primary functions are flood control and recreation.

The Cherry Creek dam is an earth-fill embankment constructed by the COE as a flood control structure. The dam, which controls the runoff from the 386 square mile high plains watershed, was completed in 1953. The total storage capacity in the lake is 228,400 acre-feet, with 70,960 acre feet for flood control, 13,960 acre feet for multi-purpose storage and 134,500 acre feet for surcharge storage (COE, 1974.) Water was first stored in the lake in 1957.

No major flood-protection structures exist in the Cherry Creek basin upstream of the Reservoir. The Natural Resource Conservation Service has completed construction of 32 structures as part of the "Franktown-Parker Tributaries of Cherry Creek Watershed" and "West Cherry Creek Watershed" projects. The structures were constructed for design floods having a 25-year recurrence interval. These reservoirs generally affect only the normal flow on Cherry Creek and offer limited flood protection downstream of the dams.

2.3.4.2 Recreation

Wagon train travelers first crossed into the Cherry Creek Valley along the "Smoky Hill Trail" in the 1800's. They crossed grassland prairie dotted with yucca trees, never imagining that in the future, more than 1.5 million visitors per year would enjoy Cherry Creek State Park. The Park offers a multitude of recreation opportunities:



Twenty six fish species are recorded for the lake. Fishing is enjoyed all year long

- *Fishing.* Twenty six fish species are recorded for the lake, including stocked trout, walleye, tiger muskie, largemouth bass, wiper, yellow perch, bluegill, green sunfish, black bullhead, crappie, catfish, and northern pike. The State record walleye was caught at the Reservoir. Fishing is enjoyed all year long, with ice fishing also a popular activity. One of the favored fishing spots in the Park is Tower Loop, which was recently improved as part of the Authority's pollution reduction facilities (Section 5).
- *Boating.* The Park offers a fully supplied marina and provides lessons and rentals for windsurfing, water skiing.
- *Camping.* There are 102 camping sites of all types, offering showers, laundry facilities, and electrical hookup.
- *Trails.* The Park has several self-guided nature trails for everyone to enjoy year round. Hikers can expect to see verdant grasslands and fluffy cottonwood trees during the spring and summer.
- *Shooting Range.* There are fixed targets for pistols and rifles, 25- to 100-yard ranges for sighting, and a trap area with skeet for sale.
- *Model Airplane Field.* The Park provides asphalt runways with frequency posts for the model enthusiast. There are field regulations for radio controlled craft.
- *Swim Beach.* Food concessions, a bathhouse and a first-aid station are located at the beach area for visitors convenience
- *Interpretive Program.* The Park offers trained staff in various naturalist skills with scheduled programs ranging from falconry to science camps. The Authority has participated in interpretative signage program for Authority sponsored water-quality projects, including Shop Creek, Tower Loop and East Shade Shelter.
- *Horseback Riding.* A fully equipped equestrian center is located within the Park, offering guided and unguided rides.
- *Dog Training.* An extensive area has been set aside for exercising and training of dogs.

2.4 Problem Identification

The Authority retained Dr. John Jones of the University of Missouri in 1992 as a consulting limnologist to evaluate the status and condition of

Data collected since 1985 strongly suggest that the original assumptions about the relationship between chlorophyll and phosphorus contained in the Jones-Bachmann model do not adequately predict the response of chlorophyll in Cherry Creek Reservoir.

Cherry Creek Reservoir and to make recommendations regarding reservoir modeling dynamics. Data collected since 1985 strongly suggest that the original assumptions about the relationship between chlorophyll and phosphorus contained in the Jones-Bachmann model do not adequately predict the response of chlorophyll in Cherry Creek Reservoir. Based on recent sampling data compared to previous years, Dr Jones has observed the following, which are inconsistent with the Jones-Bachmann model.

- Over the past 13 years of monitoring by the Authority, seasonal means of phosphorus have ranged from 39 µg/L in 1989 to 96 µg/L in 1997, with a long-term average value of 66 µg/L. The July-September seasonal means of total phosphorus over the entire monitoring period have all exceeded the target of 35 µg/L.
- Average chlorophyll content have ranged from 5.6 µg/L in 1989 to over 25 µg/L in 1998 and 1999, with a long-term average of 17 µg/L. Although this exceeds the goal of 15 µg/L, based on the Jones-Bachmann model, the long-term average total phosphorus of 66 µg/L should have resulted in an average chlorophyll value of 37 µg/L. This points to the lack of "fit" of the Jones-Bachmann model for conditions in Cherry Creek Reservoir.
- The lack of consistent relationships between in-lake nutrients, annual loads, and hydrology suggested perhaps that shorter-term variations in external and internal loads might also be factors controlling phosphorus in Cherry Creek Reservoir. (A finding confirmed by the Expert Panel's recommendation for the development of a Dynamic Model for the Reservoir.)

These observations support the need to update the master plan, TMDL, in-lake total phosphorus standard, and control regulation. The Jones-Bachmann model was reviewed and compared to other models (see Appendix E) and found to be inappropriate to Cherry Creek Reservoir for several reasons, including the following(see Appendix E).

- No data for Cherry Creek Reservoir was used to calibrate the model.
- The lakes used in the model were dominated by glacial lakes located in North America, Europe and Japan, which are not representatives of Cherry Creek Reservoir.
- Empirical data collected at the Reservoir, before and after the standard was set, show that model does not accurately reflect or predict the relationship between phosphorus and chlorophyll in the Reservoir.
- Comparison with several other published chlorophyll-phosphorus models show that other models better match monitoring data, predicting no greater than 60 µg/L total phosphorus to achieve a 15 µg/L chlorophyll concentration.

These previous modeling discrepancies discovered through monitoring and evaluation of the models, are discussed in further detail in Section 4 and in Appendix E. This review of the models, coupled with Expert Panel recommendations and a new in lake model (see below), provided the basis for the corrected hydrology-based, seasonal phosphorus standard of 60 µg/L, which in turn, dictated that new allowable loads for Cherry Creek Reservoir be determined. The new TMDL reduces the maximum loads to 11,944 pounds of phosphorus annually based on projected future inflows of 15,470 acre-feet per year. Based on the steady state model for the Reservoir, this increase in flows would still be expected to result in meeting the seasonal phosphorus standard of 60 µg/L more frequently than current conditions (assuming implementation of the Best Efforts Plan).

2.5 Expert Panel Review

An Expert Panel of scientists was formed to discuss and propose further steps in the development of water quality goals for the Cherry Creek Reservoir.

As part of the Master Plan update, Chadwick Ecological Consultants, Inc. (Chadwick) and Dr. Jack Jones conducted a review of the reservoir data, total phosphorus-chlorophyll relationships, and phosphorus loading models on behalf of the Authority. Calculations were updated with data collected since the Clean Lakes Study in 1983. Two reports were produced during 1998 providing a review of the phosphorus and chlorophyll a relationships in the reservoir and an analysis of the phosphorus loads (Chadwick 1998a, b). Concern regarding the results of these reviews were raised by a member of the Authority, City of Greenwood Village, and presented in two reports by Aquatic Solutions and Water & Waste Engineering.

An Expert Panel of scientists (Drs. Chris Holdren, Kent Thorton and Gene Welch) was formed and convened in November 1998 to discuss and propose further steps in the development of water quality goals for the Cherry Creek Reservoir. Based on presentations and reports provided by consultants for the Authority and the City of Greenwood Village, the panel concluded the following in November 1998 (see Appendix A for complete report).

- 'The lake monitoring data do not yet confirm there is a real trend in lake water quality as measured by phosphorus, chlorophyll, and transparency. Two or three more years of monitoring may be necessary to determine if there is real trend.
- Both internal and external loads of phosphorus contribute to lake water quality. Based on estimates of internal loads from the summers of 1996 and 1997, the external loads represent approximately 89 percent of the total phosphorus load. The average external loading over the past seven years is approximately 95 percent of the total annual load. While there is net internal loading in summer, it is felt that lake water quality is controlled more by external loads.
- Nitrogen can be limiting algal growth at times, but the Authority should continue to manage the basin for phosphorus.
- The Authority should begin using a dynamic model (i.e.: a mass balance model with resolution of a week) and should collect monitoring data to support such a model.

- Total phosphorus/chlorophyll relationships used to determine the current standard do not accurately reflect the lake's response. The 15 µg/L chlorophyll goal is a reasonable and necessary goal. However, it is unrealistic to believe that the Basin can meet the current phosphorus standard of 35 µg/L. As such, the Authority needs to do more to properly understand the dynamic relationship between phosphorus loads and concentrations.
- The Authority should continue to pursue phosphorus controls and, at a minimum, ensure that phosphorus loads do not increase over existing levels.'

Acknowledging the difficult mixing regime of the Reservoir that results in large seasonal variations of total phosphorus and chlorophyll, the panel proposed a time-dynamic model be developed. Such a model investigates the relationships between total phosphorus loads from external and internal sources and lake total phosphorus concentrations on a weekly basis during summer. As chlorophyll is highly dependent on total phosphorus the panel suggested that the parameters of the total phosphorus-chlorophyll relationships be estimated for the period of most concern, i.e. July to September.

As the result of the Expert Panel recommendations, additional data were collected from the Reservoir in 1999 and new in-lake models were prepared by Freshwater Research, based on a work plan submitted May 4, 1999 and approved by the Expert Panel. The Freshwater Research findings included development of a Dynamic Model and subsequent use of a steady state model to predict the lake's response to future conditions (Appendix J and K) were subsequently reviewed by the Expert Panel, who concluded:

"… *The dynamic model is considered to adequately represent lake total phosphorus during the spring-summer period and provides a semi-mechanistic explanation for the sediment-water phosphorus exchange operating in the lake. Based on rates from the dynamic model, predictions using the steady state model are considered valid to evaluate management scenarios. However, the dynamic model should be calibrated and verified on an annual basis when winter lake data become available.*"

Section 3 Current Conditions

3.1 Cherry Creek Watershed Quality Assessment

The 2000 Watershed Plan acknowledges site-specific characteristics and intricacies of the Cherry Creek Watershed. Although water quality in the Reservoir continues to be a major focus, this Plan also addresses water quality throughout the watershed, including tributary streams, alluvial groundwater, and their interrelationships with the Reservoir. Presented in this section are characterizations of the watershed and reservoir, including descriptions of the monitoring programs and summary of results.

3.1.1 Watershed Monitoring

The Authority conducts a comprehensive watershed water-quality monitoring program in the Cherry Creek mainstem upstream of the Reservoir.

The Authority conducts a comprehensive watershed water-quality monitoring program in the Cherry Creek mainstem upstream of the Reservoir. Sampling of alluvial flows provides a characterization of groundwater quality. Monitoring of surface water and groundwater quality in the upper Cherry Creek watershed, as described in Appendix B, was initiated in August 1994 and continues to date. Ten surface water monitoring stations and nine groundwater monitoring stations, for alluvial monitoring, were established for the Phase I Baseline Study. These stations were selected throughout the stream stretch to monitor upstream and downstream of discharges. (Figure 3-1) (Appendix B). Table 3-1 presents the water quality constituents that are being monitored as part of the watershed water-quality monitoring program. While there is a wide range of water quality constituents being monitored, the study has focused primarily on nutrients (i.e. nitrogen and phosphorus species) as it relates to their potential to impact the Reservoir.

Figure 3-1. Location of Monitoring Stations for the Cherry Creek Basin

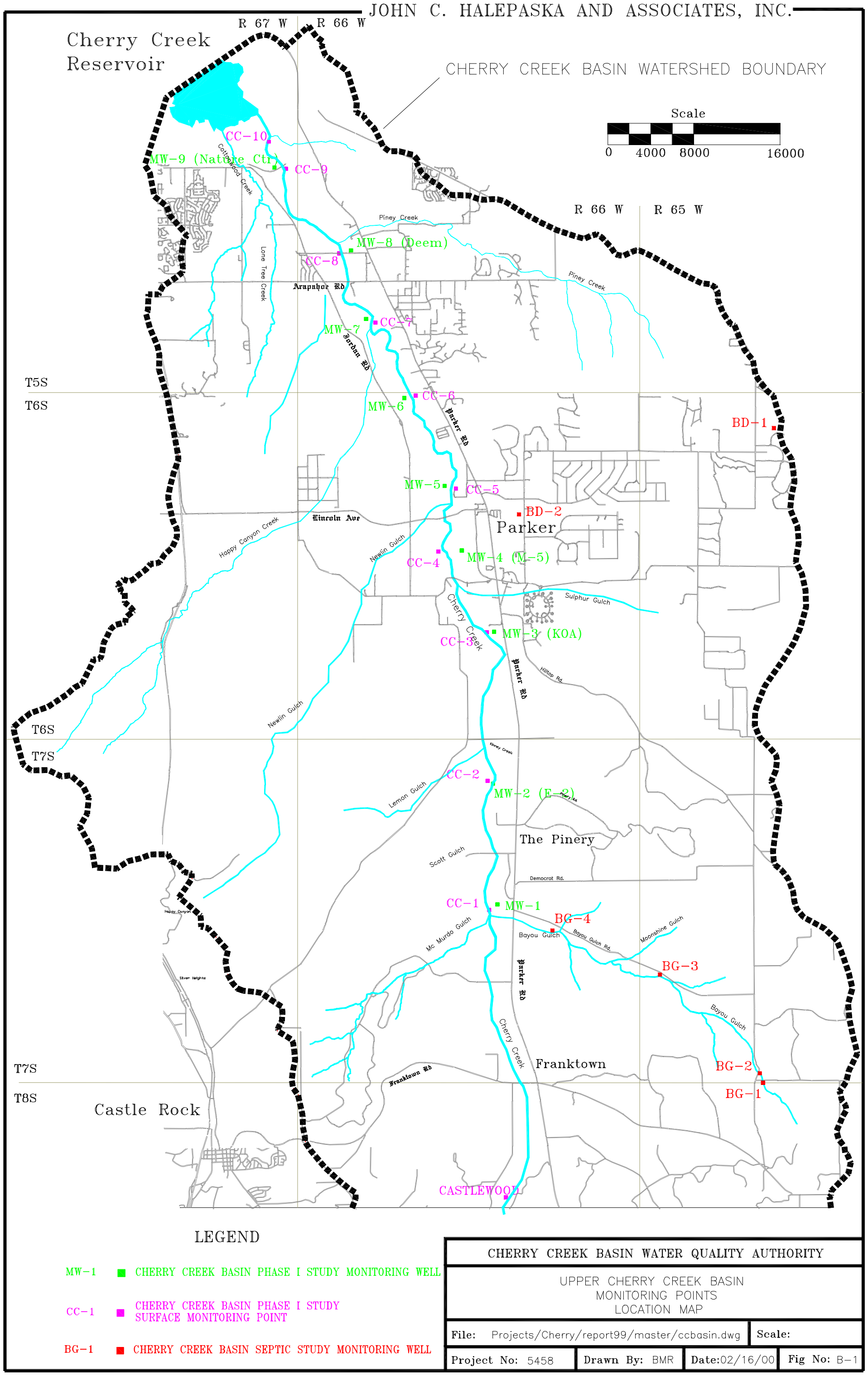


Table 3-1. Water Quality Monitoring Constituents List	
Monthly Water Sampling:[1]	
Ammonia	Chloride
Nitrate	Total Suspended Solids[3]
Total Dissolved Phosphorus	Total Coliform
Soluble Reactive Phosphorus	Sulfate
Total Phosphorus[3]	Fecal Coliforms[2]
Semi-Annual Sampling:[1]	
Gross Alpha	Copper[4]
Arsenic[4]	Iron[4]
Barium[4]	Manganese[4]
Cadmium[4]	Mercury[4]
Chromium[4]	Selenium[4]
	Silver[4]
Annual Sampling:[1]	
Chloroform	Iron[4]
	Manganese[4]

1. At all groundwater and surface water sampling sites.
2. At all surface water sampling sites.
3. Analyzed only in surface water samples.
4. Total concentrations measured in surface water samples and dissolved concentrations measured in groundwater samples.

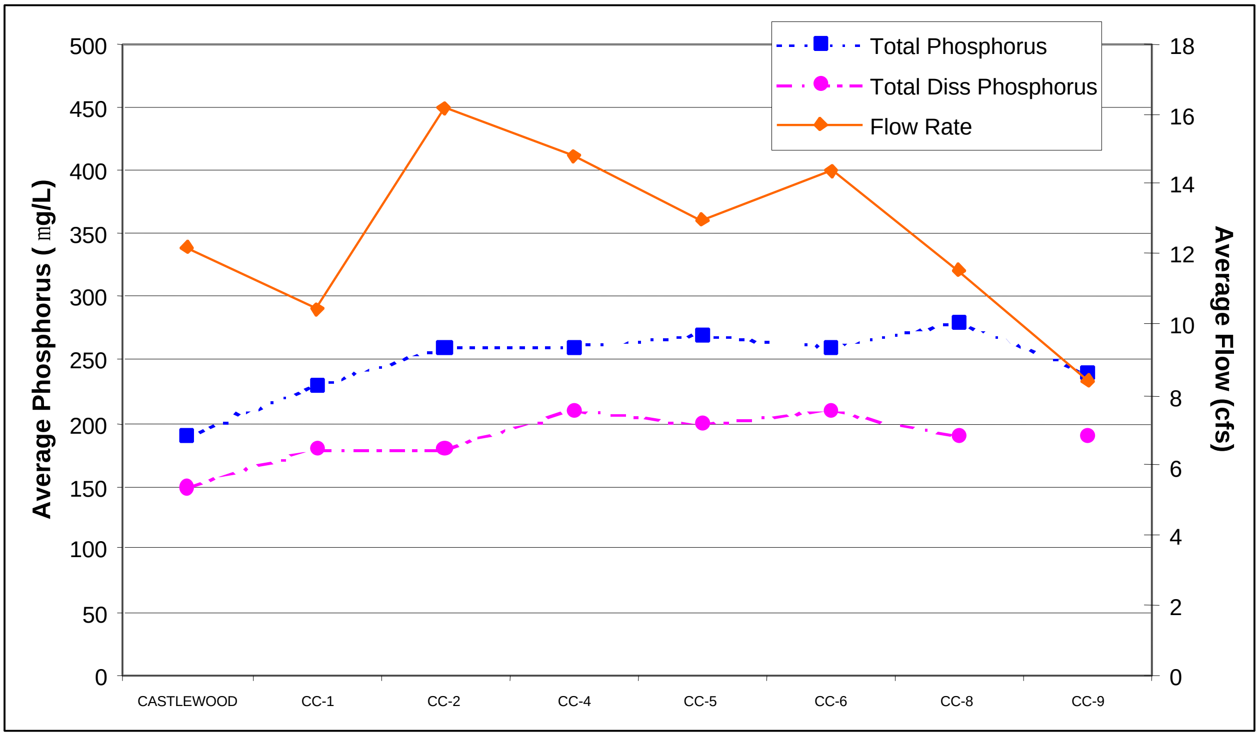
3.1.1.1 Water Quality in the Watershed

Water quality data collected indicate that phosphorus concentrations are relatively constant throughout the Cherry Creek mainstem and the underlying alluvial aquifer, ranging between 150 µg/L and 250 µg/L

Water quality data collected to date indicate that phosphorus concentrations are relatively constant throughout the Cherry Creek mainstem and the underlying alluvial aquifer, ranging between 150 µg/L and 250 µg/L (Figure 3-2). There are no discernible changes in concentrations at monitoring locations downgradient of direct dischargers that would imply that discharged effluent is currently impacting phosphorus loads to the creek or reservoir.

The principal variability in phosphorus loading to the Reservoir is related to greater volume of flow. Even at higher flows during spring runoff, phosphorus concentrations do not increase above ambient levels. Part of the reason for the consistent phosphorus concentrations throughout the study reach is the removal of phosphorus by municipal water users. The water that is pumped from the Cherry Creek alluvial aquifer is replaced by AWT plant effluent, which is 4 to 10 times lower in phosphorus concentrations than the water removed. This removal mechanism is minimizing changes in phosphorus concentrations that may be resulting from nonpoint sources in the study reach.

Figure 3-2. Average Total and Dissolved Phosphorus Concentration and Flow vs. Location (John C. Halepaska and Associates, Inc., 3/30/98)



Sulfate and chloride concentrations have been increasing, appearing to be related to the AWT process to reduce phosphorus concentrations in the effluent.

There are some observed increases in nitrate-nitrogen concentrations in the study reach; however, there is not a consistent increasing trend that is indicative of water quality degradation. It is believed that a combination of input from wastewater discharges and removal due to pumping and/or biologic assimilation of nitrate are the principal reasons for the variable nitrate-nitrogen concentrations observed in the basin (Halepaska, 1997). Water levels measured at the monitoring wells indicate depths to water of 10 to 20 feet, which likely does not produce significant sub-irrigation potential that could act as a nitrogen removal system. Cherry Creek was removed from the 1998 303(d) list for ammonia impairment because ammonia-nitrogen concentrations have consistently been at, or below, detection limits (200 µg/L). The database in the watershed indicates that ammonia is not currently a constituent of concern.

Sulfate and chloride concentrations have been increasing. The increase in sulfate appears to be related to the addition of aluminum sulfate as part of the AWT process to reduce phosphorus concentrations in the effluent. Concentrations of both constituents are below current drinking water standards of 250 mg/L. However, sulfate concentrations increase from approximately 20 mg/L near Castlewood to approximately 150 mg/L just upstream of the Reservoir. Chloride concentrations increase from 10 mg/L to 50 mg/L, between the upper and lower reaches of the Cherry Creek

Improved AWT techniques have improved phosphorus removal, but have side effects, such as increases in the levels of chloride and sulfate.

Basin dischargers are currently evaluating both constituents in the wastewater treatment process and alternative chemicals for phosphorus removal.

mainstem. While AWT techniques have improved phosphorus removal, other side effects, such as increases in the levels of chloride and sulfate, need to be examined. Basin dischargers are currently evaluating both constituents in the wastewater treatment process and alternative chemicals for phosphorus removal.

Both iron and manganese were found consistently in surface water of the main stem of Cherry Creek, while their presence in ground water is sporadic. Sporadic concentrations in ground water are likely related to geology near the well. The presence of iron and manganese concentrations in the upper Cherry Creek Basin appears to be a naturally-occurring phenomenon related to the presence of these minerals in soils, not related to any anthropogenic activity in the basin (Appendix B).

The presence of coliforms throughout the study reach in the surface water appears to be related principally to soil bacteria, with only minor inputs from the wastewater dischargers (Halepaska, 1998). This is indicated by fecal coliforms representing less than 10 percent to 15percent of the total coliform counts and the presence of high total coliforms at Castlewood Canyon (above the direct dischargers in the Basin).

Chloroform sampling has not indicated the presence of any disinfection by-products in surface waters or groundwater associated with Cherry Creek.

Sampling of chloroform has not indicated the presence of any disinfection by-products in the surface waters or groundwater associated with Cherry Creek. Future conversion of direct dischargers to ultraviolet disinfection, rather than chlorination, serves to further reduce the potential for the formation of trihalomethanes (THMs) in the disinfection process.

3.1.1.2 Evaluation of Flows and Loads to Cherry Creek Reservoir

While both phosphorus and nitrogen are potentially important with regard to nutrient loading to the Reservoir, past analyses by the WQCD and the DRCOG have concluded that the Reservoir is generally phosphorus limited (WQCD 1983, DRCOG 1985).

3.1.1.2.1 Monitoring Activities for Derivation of Phosphorus Loads

Phosphorus loads have been determined for Shop Creek, Cherry Creek, Cottonwood Creek, the Cherry Creek alluvium, and direct precipitation.

Phosphorus loads from several primary sources has been determined since monitoring began. These sources include the three primary influent streams Shop Creek, Cherry Creek, and Cottonwood Creek, the Cherry Creek alluvium (using Halepaska data) and from direct precipitation (Figure 3-3). Flow monitors were located on the streams to provide flow data for baseflows and storm events. Water quality (nutrient) sampling was conducted during baseflow conditions over the summer, with from 2 to 16 baseflow samples collected in any one year. In addition, storm samples were collected during the summer from the sites to provide information on water quality during these important events. While samples were not collected for every storm, an effort has been made to sample 5 to 10 storms throughout the summer. These data are used to develop flow/phosphorus relationships for each stream site. When applied to continuously monitored flow data, daily total phosphorus loads are calculated and summed to provide annuals loads for that site.

Currently, alluvial flows in the Cherry Creek mainstem are monitored by Halepaska & Associates at locations upstream and downstream of the Reservoir. As an example during water year 1997, approximately 30 percent more phosphorus (as pounds) was measured in the alluvium upstream of the Reservoir than was measured downstream. This suggests a net inflow of alluvial water and phosphorus to the Reservoir. This net inflow of alluvial water is accounted for in the annual load calculations.

In addition to the influent streams, loading from direct precipitation to the Reservoir was also determined. Precipitation is measured at a meteorological station maintained by the COE on Cherry Creek dam. Rainfall was also collected from summer storm events near one of the stream monitoring sites and analyzed for nutrients.

Since the outflow is controlled by the Reservoir operations of the COE, storm flows, per se, are not an issue at that site. Outflow data are available from the COE and USGS gauging station located just downstream of the Reservoir. Baseflow water quality sampling, conducted from August 1994 to present, allows calculations of loads leaving the Reservoir.

3.1.1.2.2 Final Calculations of Reservoir Inflows and Phosphorus Loads

The Authority flow values were adjusted to match COE inflow volumes (inflow to the Reservoir monitored as a function of change in storage, lake level) and combined with the direct precipitation and net alluvial inflow to estimate total

The COE monitors inflow to the Reservoir as a function of change in storage, lake level, outflow, and evaporation. A monthly inflow is calculated by adding outflow and evaporation to the change in Reservoir level. Due to differences between the Authority's monitoring approach and the COE's approach for determining inflow, an exact match is not expected. Therefore, Authority flow values were adjusted to match COE inflow volumes and combined with the direct precipitation and net alluvial inflow to estimate total phosphorus loading to the Reservoir.

3.1.1.2.3 Phosphorus Loads from Streams and Precipitation

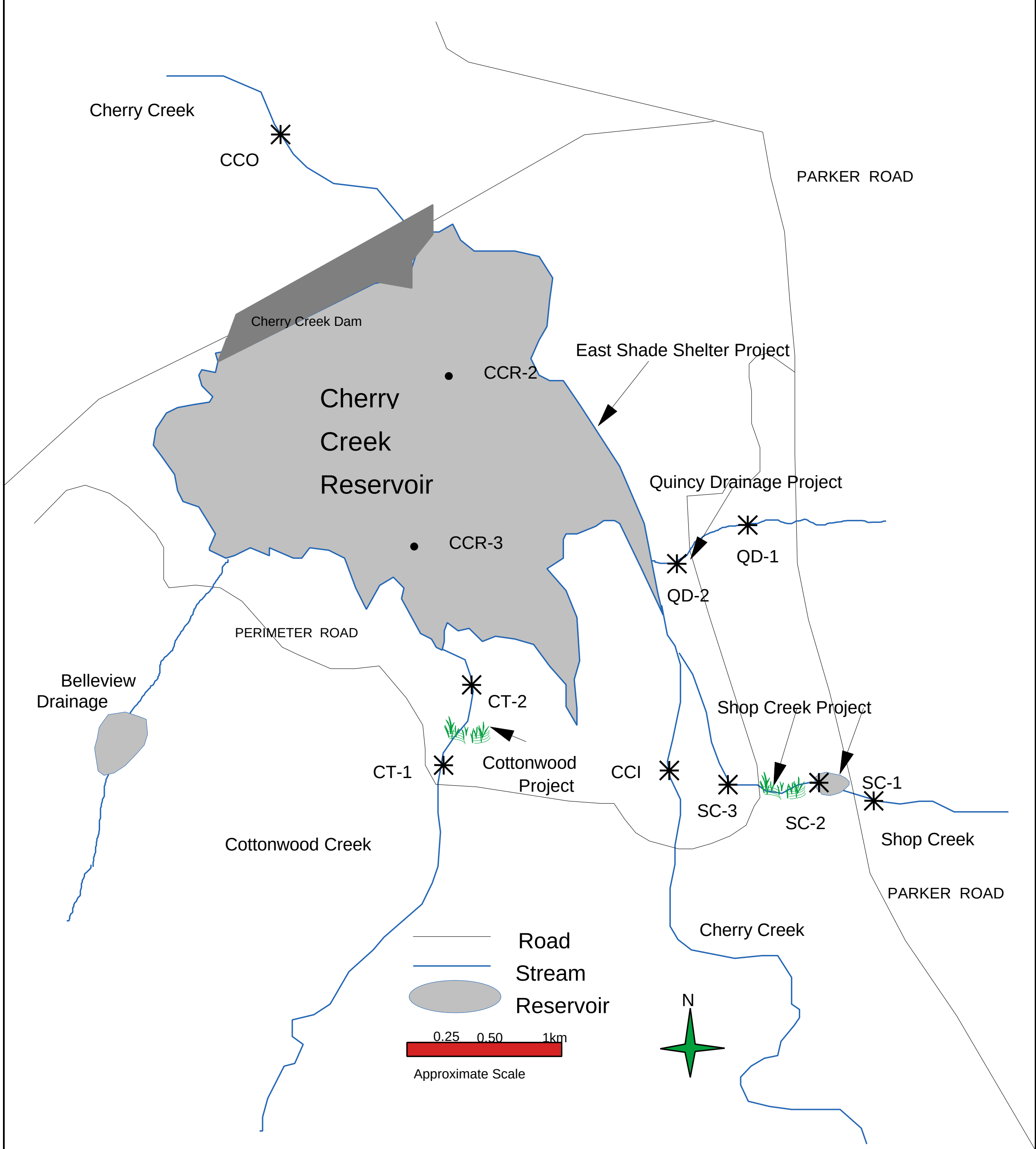
Annual loads of phosphorus to the Reservoir have been determined since 1987. These values have been summarized for 1992 to 1999 to match the in-reservoir analysis, as adjusted to COE volume calculations.

As shown on Figure 3-4, there are four primary sources of phosphorus loads to the Reservoir:

- Shop Creek, as monitored at Site 3.
- Cherry Creek mainstem inflow, as surface flows at Site CC10 and net alluvial inflow.
- Cottonwood Creek inflow, as CT1 from 1996 to 1995 and CT2 from 1996 to 1997.
- Direct precipitation (Table 3-4).

Phosphorus loads from Belleview Drainage, a small intermittent stream, is not included in Table 3-7. This stream provides approximately 10 pounds of total phosphorus on an annual basis, or roughly 0.1 percent.

Figure 3-3. Location of Sampling Sites and PRFs in Cherry Creek State Park



Pollutant Reduction Facilities (PRFs) at Cherry Creek Reservoir

Annually, total phosphorus loads into the Reservoir have ranged from 4,764 pounds to 20,199 pounds, with an eight-year average of 9,502 pounds (Table 3-2). On average, Cherry Creek and its alluvium are responsible for 73 percent of the total loads, with approximately 14 percent from Cottonwood Creek, 11 percent from direct precipitation, and 2 percent from Shop Creek.

Table 3-2. Estimated Phosphorus Loading (pounds/year) into Cherry Creek Reservoir, 1992-1997 [1]

Source of Data	1992	1993	1994	1995	1996	1997	1998	1999	Mean
Shop Creek 3	1138	136	134	108	116	186	206	162	148
Cherry Creek	5,470	2,971	3,739	5,372	3,782	3,714	11,665	14,736	6,431
Cottonwood Creek	947	366	226	3,319	570	1,103	1,830	3,868	1,529
Subtotal for Streamflows	**6,555**	**3,473**	**4,099**	**8,799**	**4,468**	**5,003**	**13,701**	**18,766**	**8,108**
Cherry Creek Alluvium	555*	555*	470	597	635	520	476	537	543
Direct Precipitation	877	736	484	1,202	740	1,020	854	896	851
Total Load	**7,987**	**4,764**	**5,053**	**10,958**	**5,843**	**6,543**	**15,298**	**20,199**	**9,502**
Cherry Creek Outflow	1,314	711	993	2,049	992	996	4,207	9,650	2,614
Net Load	**6,673**	**4,053**	**4,060**	**8,549**	**4,851**	**5,547**	**10,824**	**10,549**	**6,888**

[1] Based on mean of 1994-1997 alluvial inflows minus alluvial outflows, or net alluvial loads.

3.1.1.2.4 Phosphorus Load to the Cherry Creek Mainstem

As part of the Phase I Baseline Study, water quality is monitored along the mainstem of Cherry Creek in both the Cherry Creek surface flow channel and in the underlying alluvial aquifer. Upstream of Castlewood Canyon it is believed that the majority of phosphorus and nitrogen input to the stream is related to either (a) background concentrations and/or (b) agricultural activities. There are no direct dischargers upstream of Castlewood Canyon or activities and facilities related to urbanization that produces nonpoint discharges.

Urbanization activities include overland stripping for subdivision development, paving and stormwater runoff associated with subdivision development, and installation of ISDS's for large lot developments. Therefore, it is believed that phosphorus loading data at Castlewood Canyon are representative of non-urbanized and agricultural conditions in the upper Cherry Creek Basin. Inputs downstream of Castlewood Canyon to the Reservoir are more related to urbanization along the Cherry Creek corridor.

Using this premise, Halepaska and Associates (Appendix C) evaluated phosphorus loading to the surface water and groundwater systems to evaluate:

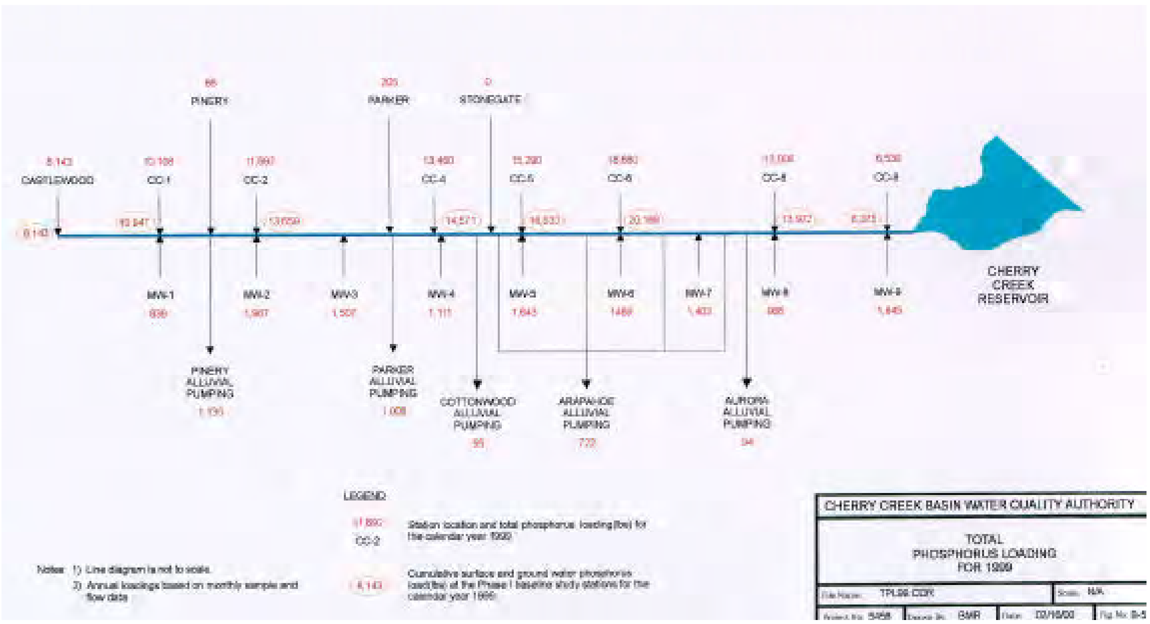
(a) Interactions between the surface water and groundwater,

(b) Increases in loads that are not attributable to known sources (i.e. nonpoint contributions), and

(c) Potential assimilation of phosphorus species along the study reach.

Presented on Figure 3-4 is a sample line-diagram for 1999 with locations of monitoring stations (i.e.: CC-1 and MW-1), individual dischargers (i.e.: Pinery and Parker WSDs), alluvial pumping (i.e.: Cottonwood WSD and ACCWA), and calculated loads (i.e. numbers inside of ovals representing surface and groundwater total loads). For 1999, calculated phosphorus loads at Castlewood monitoring station were 8,143 pounds and at station CC-9 were 8,375 pounds. The relatively small increase in loads throughout the stream system demonstrates impacts of alluvial pumping and assimilation of phosphorus by the stream system, both reflected in the IDR (see Section 4).

Figure 3-4. Total Phosphorus Loading for 1999



Estimates can be made of the nonpoint source contributions in the study reach.

Unidentified increases in phosphorus loads are assigned as a nonpoint discharge, or short term delayed return flows from stormwater, and unknown decreases are assigned as either assimilation of phosphorus or others in the basin pumping.

Using a mass balance approach, and knowing the inputs and outputs of phosphorus loading by municipal entities, estimates can be made of the nonpoint source contributions in the study reach (additional inputs). Estimation can also be made of the biologic assimilation of phosphorus and/or additional pumping in the study reach (e.g., irrigation and water supply wells). To make this evaluation, Halepaska took the cumulative phosphorus loads at each of the study reach locations and identified known inputs and outputs (municipal wastewater discharges and municipal alluvial pumping). Where there is an unidentified increase in phosphorus load, it is assigned as a nonpoint discharge, or short term delayed return flows from stormwater, and when there is an unknown decrease in phosphorus load, it is assigned as either assimilation of phosphorus or others in the basin pumping.

As shown on Table 3-3, for the period 1995 through 1997, cumulative annual phosphorus loads at Castlewood Canyon and CC-10 (upstream of the reservoir) were generally declining. The principal cause of the reduction in phosphorus loads from 1995 through 1997 appears to be related to lower flows. The reduction in total loads reversed in 1998 and 1999, because both years had above-average runoff. In 1998, the above-average flows resulted in significant increases in phosphorus load which were primarily realized through the study reach, as there was only minimal increase in the phosphorus load at the upstream end of the study reach at Castlewood Canyon. However, in 1999, there were continued high flows both at the upstream end of the study reach and at the reservoir, which resulted in high phosphorus loads throughout the study reach.

Table 3-3. Phosphorus Loads on Cherry Creek Mainstem

Year	Castlewood Canyon, pounds	Upstream of Reservoir, pounds
1995	2,887	3,002
1996	2,173	2,923
1997	1,424	1,989
1998	2,820	11,412
1999	8,143	16,259

Phosphorus loads in the alluvial groundwater associated with the Cherry Creek mainstem showed relatively small variations, while major fluctuations occurred in the surface water.

Overall, total phosphorus concentrations are very steady.

In 1998 and 1999, there was a large measured phosphorus load increase from the upstream end of the study reach to the downstream end of the study reach, related to higher flows.

Phosphorus loads in the alluvial groundwater associated with the mainstem of Cherry Creek showed relatively small variations, while the major fluctuations occurred in the surface water. This is principally related to the changes in flow rather than changes in phosphorus concentration. While there are gaining and losing reaches of the stream where phosphorus is either moving from the surface water into the groundwater, or vice versa, total phosphorus concentrations are very steady, and variations in load in the groundwater are, therefore, very minimal.

The total phosphorus load from surface water and groundwater entering the Reservoir minus the total phosphorus load at Castlewood Canyon was relatively consistent for the three-year period from 1995 to 1997. However, in 1998 and 1999, there was a large measured phosphorus load increase from the upstream end of the study reach to the downstream end of the study reach. In 1998, the load increase was almost 8,600 pounds, and in 1999 the load increase was approximately 8,100 pounds. Since phosphorus concentrations remained relatively consistent even in 1998 and 1999 compared to data from 1995 to 1997, the phosphorus load increases are principally attributed to surface flows observed in each of these years, with lower loads during low flow years and higher loads during high flow years.

3.1.1.3 Soil and Sediments

In-situ soil samples were collected in the watershed by Halepaska (Appendix D) and analyzed for phosphorus content. Fifty samples were collected from four primary soil associations. Samples were obtained from undisturbed areas for the surface soil (up to 6 inches deep). One sample consisted of a composite of 4 or 5 random sites and twelve samples were obtained for each soil type.

Soils in the Cherry Creek channel over the past five years have contained up to 1,500 mg/kg total phosphorus.

The orthophosphate concentration for each soil type varied from non-detection to 3.9 milligram per kilogram (mg/kg) of soil, with an average of 1.5 mg/kg. There is very little variation in orthophosphate concentration among the four soil types. Orthophosphate concentrations from these unsaturated samples are less than 1 percent of the total phosphorus concentrations observed in the quarterly sediment sampling of saturated soils in the Cherry Creek channel over the past five years (i.e.: 300 to 1,500 mg/kg). This would indicate that very little of the phosphorus stored in the stream sediments is soluble.

3.2 Cherry Creek Reservoir Quality Assessment

3.2.1 Reservoir Monitoring

The Reservoir monitoring program began as early as 1975, with sampling conducted by the COE. Another monitoring program (1984 to 1986), conducted by the USGS, sampled roughly on a biweekly program throughout the summer growing period. This monitoring program was assumed by the Authority in 1987 and continues to the present. For the past 10 years more or less, Reservoir monitoring consisted of bi-monthly sampling, primarily throughout the May-September season. To provide additional information on seasonal cycles in the Reservoir, weekly sampling was conducted during the 1993 to 1999 monitoring periods.

Reservoir monitoring efforts have consisted of water quality sampling (primarily for nutrient analysis), physical measurements (temperature and dissolved oxygen profiles, Secchi depth), and algal biomass (chlorophyll a). Information on biological populations, such as, phytoplankton and zooplankton populations, has also been collected. CDOW has collected fish population data. Figure 3-3 identifies sampling sites on the Reservoir and tributaries on State Parks' property.

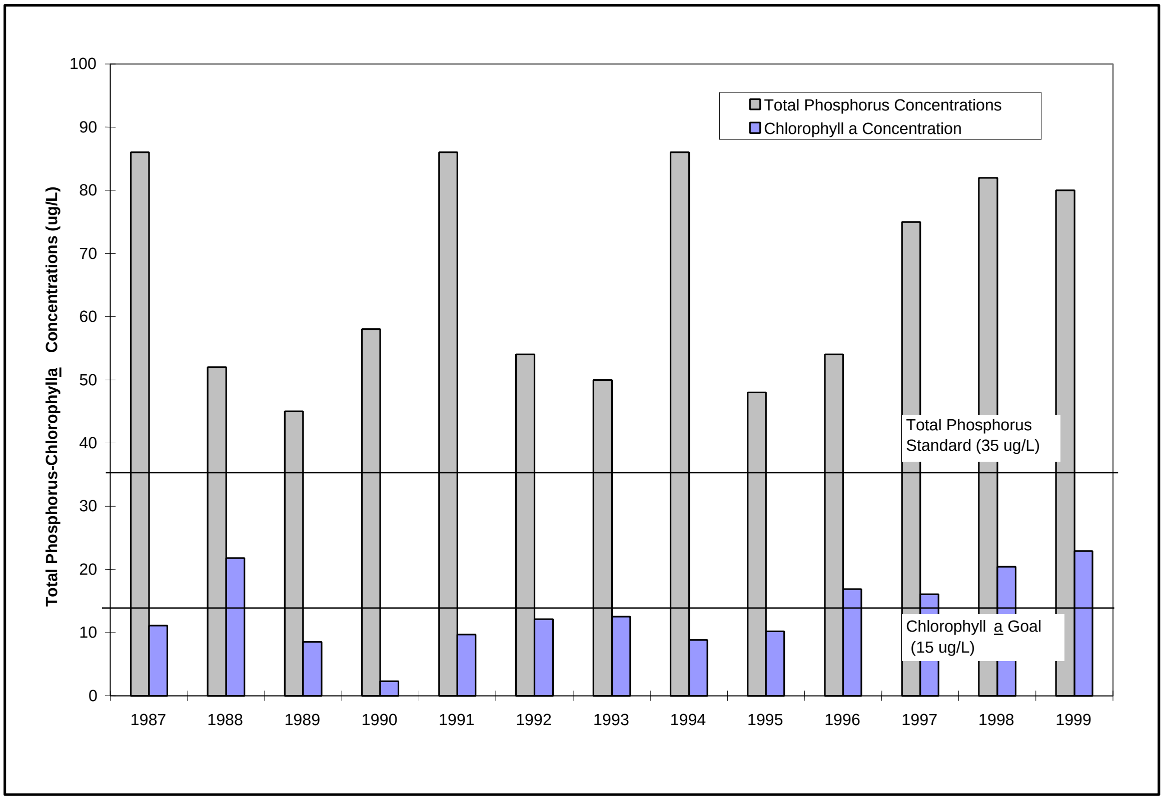
Additional efforts undertaken during monitoring in 1998 and 1999 included:

- Re-establishment of a third monitoring site in the reservoir (CCR-1).
- Continuous monitoring of temperature at various depths in the reservoir and at the Cherry Creek and Cottonwood Creek inflow sites.
- Collection of nutrient profile samples at the two deep-water sites (CCR-1 and CCR-2).

The addition of CCR-1 provided information on the spatial variation in the Reservoir. Data from the continuous temperature monitoring indicate that there is rarely more than 2° C difference from the surface to the bottom of the Reservoir, with periods of stratification separated by mixing events. Nutrient profiles indicated that much of the upper 5 meters of the Reservoir has similar phosphorus concentrations, with increasing concentrations at depth approaching the lake bottom often observed. Additional data collected in 1998 and 1999 were also used to develop the dynamic in-lake model (see Section 4).

Presented on Figure 3-5 is a comparison of annual averages for total phosphorus and chlorophyll a from 1987 to 1999. The annual total phosphorus standard has been exceeded for all 13 years of record, whereas the chlorophyll a goal has been exceeded for four years (i.e.: 1988, 1996, 1997 and 1998), which demonstrates the need to re-evaluate the phosphorus and chlorophyll a relationship.

Figure 3-5. Total Phosphorus and Chlorophyll a Concentrations in Cherry Creek Reservoir



3.2.2 Reservoir Quality Summary

Based on data collected by the Authority since 1987, water quality and aquatic biological conditions in Cherry Creek Reservoir were assessed. The following conclusions can be made:

- Over the 13 years of Authority monitoring, July-September seasonal means of phosphorus have ranged from 39 µg/L in 1989 to 96 µg/L in 1997, with a long-term average value of 66 µg/L, well over the current total phosphorus standard of 35 µg/L.
- Average July-September chlorophyll a content has ranged from 5.6 µg/L in 1989 to 31.8 µg/L in 1999, with a long-term average value of 16.9 µg/L, greater than the chlorophyll a goal of 15 µg/L.

- Season mean Secchi depth (transparency) has averaged approximately 1 meter over the period of record with a slight increase in Secchi depth being observed since 1987 (i.e., greater clarity).
- Annual loads of phosphorus to the Reservoir since 1992 have ranged from just under 4,764 pounds in 1993 to 20,199 pounds in 1999, with an eight-year average load to the Reservoir of 9,502 pounds. Cumulative effects of high flows resulted in the higher loads in the past two years, representing the first years that gross loads had exceeded the TMDL of 14,270 pounds. There is a strong influence of inflow volume on phosphorus loads to the Reservoir.

Sampling of aquatic biota and nutrients in reservoir and influent streams, conducted by Chadwick Ecological Consultants, Inc., demonstrated that water transparency varied throughout the year, with lowest values corresponding to periods of high phytoplankton density. Water temperature data suggest that Cherry Creek Reservoir experiences periods of complete mixing interspersed with short periods of minimal thermal stratification during the summer.

Blue-green algae were consistently the most abundant algal group in Cherry Creek Reservoir. Zooplankton populations (which serve as grazers of algae) were comprised primarily of protozoans and rotifers during much of the summer. During late summer, periods of low zooplankton densities often correlated to periods when phytoplankton densities and chlorophyll a concentrations were generally high. The fish community in Cherry Creek Reservoir has historically been dominated by gizzard shad, and effective zooplanktivore. Such planktivorous fish may also be influencing nutrient dynamics in Cherry Creek Reservoir through their predation on zooplankton.

Data on fecal coliforms and *E. coli* indicated that pathogenic bacteria in the main body of the reservoir probably meet water quality standards for swimming and body contact recreation.

As noted earlier, the Authority's monitoring program began in 1987. Over this time period, July-September seasonal mean phosphorus in the reservoir has averaged 66 µg/L (Table 3-4), well above the current standard of 35 µg/L . In fact, that standard has not been met throughout the 13 years of Authority monitoring efforts. Trend analysis using these data reveals no significant trend for increasing or decreasing summer phosphorus during the monitoring program.

Table 3-4. Mean Total Phosphorus on Cherry Creek Reservoir, July to September

	Total Phosphorus ug/L	
	Annual Mean	July-September Mean)
1987	86	93
1988	52	49
1989	45	39
1990	58	55
1991	86	56
1992	54	66
1993	50	62
1994	86	59
1995	48	48
1996	54	62
1997	75	96
1998	82	89
1999	80	81
Average	**66**	**66**

3.3 Land Uses

Increase in development in the watershed started nearest the Reservoir in Arapahoe County and City of Aurora, and have progressed rapidly upstream to the Parker area in Douglas County, the nation's fastest growing county.

Other than undeveloped land., residential continues to be the largest land use, with commercial/office uses also playing a major role in watershed development trends.

Development in the watershed started nearest the Reservoir in Arapahoe County and City of Aurora and has progressed rapidly upstream to the Parker area in Douglas County, the nation's fastest growing county. The northern and central portion of the watershed has been urbanizing over the past ten years, especially in the sub-basins directly tributary to the Reservoir (i.e.: Cottonwood Creek and Piney Creek). Recently, development pressures in the middle 1/3 of the watershed have also come from the Castle Rock area. Whereas residential continues to be the largest land use (other than undeveloped uses, including open space, parks, floodplains, and agriculture), commercial and office uses also play and major role in watershed development trends.

Douglas County, part of which is within the Cherry Creek basin has experienced 550 percent growth in the past 20 years, 190 percent growth in the past 10 years, and reached a population of 124,770 in January of 2000. Although Douglas County does not fall entirely within the Cherry Creek Basin, and the northern portion of the Basin falls within Arapahoe County, these growth statistics for Douglas County give a good indication of the extent of growth in the Basin. Table 3-1 shows the growth in residential units within Douglas County. Castle Rock and Parker represent two of the fastest growing portions of the Basin.

Existing land use information was available from DRCOG for each of the 31 sub-basins (DRCOG 1997). DRCOG categories included single family, multifamily, commercial, office, public, agriculture, parks and recreation, vacant, and special. The DRCOG categories were combined into five categories: low/medium density residential, multi-family residential, commercial, industrial and undeveloped (including open space, parks, floodplains, and agricultural uses). Existing distribution of land use in the Cherry Creek Reservoir watershed is presented in Table 3-5 below.

Table 3-5. Land Use Distribution in the Cherry Creek Reservoir Watershed	
Land Use Category	Percentage of Total Watershed
	1997
Residential	12.8
Commercial	1.8
Industrial	0.4
Undeveloped	85.0
Total	100.0

3.4 Municipal Water Sources

The importance of this alluvial water supply has driven entities to be progressive with ground water quality protection.

Municipal water sources in the Cherry Creek Basin come from the alluvial and deep nontributary aquifers. There are five principal municipal water supply entities in the upper Cherry Creek Basin that utilizes Cherry Creek alluvial aquifer wells. These entities include ACCWA, City of Aurora, Cottonwood WSD, Parker WSD, and the Pinery WSD. Because of the importance of this alluvial water supply to municipalities and district's, entities have been quite progressive with respect to ground water quality protection. For example, all districts have initiated ultraviolet disinfection in their wastewater treatment processes, and the Authority board implemented effluent limits protective of drinking water supply, as shown in Table 3-6.

Table 3-6. Effluent Limits	
Constituent	Limit
Fecal	2.2 per 100 mL
Nitrate	10 mg/L
Ammonia	
May-August	2.0 mg/L
August-September	4.0 mg/L
October, November, March, April	6.0 mg/L
December, January, February	8.0 mg/L

Presented in Table 3-7 are reported alluvial pumping volumes by each of these water providers during the period from 1989 to 1998. Total pumping from alluvial aquifers ranges from 3,495 to 7,547 acre-feet annually, with an average around 5,400 acre-feet. Return flows were measured by the Pinery WSD and averaged around 36 percent of the total pumping volumes for the 10-year period.

Table 3-7. Summary of Reported Alluvial Pumping Volumes (acre-feet)											
Water Provider	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**Average**
City of Aurora	3,578	4,091	4,762	4,948	4,008	977	1,485	1,548	1,024	2,207	2,863
Arapahoe County Water & Wastewater Authority	0	0	0	756	744	836	623	1,059	847	976	584
Pinery Water & Sanitation District	1,519	1,405	1,342	1,433	1,300	1,214	1,345	1,624	1,488	1,560	1,423
Cottonwood Water & Sanitation District	0	0	0	0	85	150	128	204	219	115	90
Parker Water & Sanitation District	0	124	244	410	377	318	474	569	897	937	252
Totals	**5,097**	**5,620**	**6,348**	**7,547**	**6,513**	**3,495**	**4,055**	**5,004**	**4,475**	**5,795**	**5,395**

3.5 Wastewater Treatment Facilities

WWTPs provide for phosphorus removal and treatment using either secondary treatment followed by land application, or AWT followed by land application or direct discharge (Table 3-8). The NPDES permits require dischargers to monitor and quantify the concentration and total ponds of phosphorus discharged, regardless of disposal method. Table 3-9 presents the phosphorus allocations and loads for the wastewater dischargers during 1997 and 1998 (Authority 1999).

Table 3-8. Summary of Treatment Plants and Disposal Methods		
Facility	**Treatment Process**	**Disposal Method**
Arapahoe County Water and Wastewater Authority/Cottonwood Water & Sanitation District	AWT	Land Application Direct Discharge
Pinery Water & Sanitation District (f/k/a) Denver Southeast Water & Sanitation District	AWT	Rapid Infiltration Basin
Inverness Water & Sanitation District	AWT	Land Application
Meridian Water & Sanitation District	AWT	Land Application
Parker Water & Sanitation District	AWT Secondary	Direct Discharge Land Application
Stonegate Village Metropolitan District	AWT Secondary	Direct Discharge Land Application

Phosphorus loads have diminished at each discharge point from 1997 to 1998. While treatment flows have increased at each WWTP, treatment facilities have consistently instituted new processes to reduce phosphorus concentrations or refined chemical addition to achieve the same result. ACWWA is now using microfiltration membranes rather than clarifiers, while the Pinery WSD has changed from using ALCOFIX to sulfuric acid and aluminum sulfate in the AWT process.

Table 3-9. Cherry Creek Basin Point Source Allocation and 1997/1998 Point Source Phosphorus Contribution in Pounds [1]			
Facility	**Allocation and Point of Discharge (pounds)**	**1997 Phosphorus (pounds)**	**1998 Phosphorus (pounds)**
Arapahoe Water & Wastewater Authority/ Cottonwood Water & Sanitation District [2]	567	250	193
Pinery Water & Sanitation District (f/k/a) Denver Southeast Water and Sanitation District	213	158	110
Inverness Water & Sanitation District [3]	68	0	0
Parker Water & Sanitation District	533	207	94
Meridian Water & Sanitation District [3]	114	0	0
Lincoln Park Metropolitan District (f/k/a) Stonegate Village Metropolitan District	53 (+40) [7]	0	0
Castle Rock (Mitchell Plant) [4]	128	-	-
Castle Rock (Cherry Creek Plant) [5,6]	21	-	-
Castle Rock (McMurdo Plant) [5]	64	-	-
Castle Rock (Newlin Gulch) [5]	86	-	-
Rampart Range [5]	160	-	-
Reserve Pool	203 (-40)	-	-
Emergency Pool	100	-	-
Total	**2,310**	**615**	**397**

[1] The 1997 and 1998 phosphorus pounds reported were provided by the individual plant operators.

[2] In 1992, the Arapahoe County Water and Wastewater Authority began treating and discharging wastewater from the Cottonwood Water and Sanitation District. A DRCOG Plan Amendment transferred the Cottonwood allocation of 213 pounds to Arapahoe for use in Douglas County.

[3] Inverness and Meridian reported zero phosphorus contributions in 1997 and 1998 (i.e. no leachate in down-gradient lysimeters). Effluent was applied at agronomic rates.

[4] Castle Rock (Mitchell Plant) was constructed, but has not been operating. Wastewater from this drainage is being transferred to the Plum Creek Treatment Plant.

[5] Castle Rock (Cherry Creek Plant, McMurdo Gulch Plant, Newlin Gulch Plant) and Rampart Range Plants have not been constructed.

[6] The Castle Rock (Cherry Creek Plant) will probably serve a portion of the Newlin Gulch facility up to 51 pounds annually. In this case, 51 pounds would be subtracted from the 86 pounds listed and added to the Castle Rock (Cherry Creek) facility.

[7] See trading section 5.2.2.2.3.

Source: Cherry Creek Basin Water Quality Authority 1997/98 Annual Report, April 1999

3.6 Land Application Zones

The Authority has prepared a map of the Cherry Creek Basin that uses geologic conditions and distances from streams to evaluate potential return flows to the stream system from land application areas. In areas where the land application overlies alluvial materials associated with a stream system, it is anticipated that the return flows would contribute directly to the stream recharge. In these areas, it is assumed that there would be 100 percent return flows (Figure 3-6) (Appendix H).

In areas located adjacent to the alluvial systems, there will be some return flows to the stream system due to soil types. However, there will also be attenuation of flow due to retention of water in the unsaturated zone and water use by phreatophytes. In these areas, it was estimated that return flows would be more on the order of 50 percent of the return flows immediately below land application areas (Figure 3-2).

Outside these two zones in upland areas, soils are not conducive to water movement or areas are large distances from existing stream channels. For upland zones, it is assumed that there would still be return flow from these areas. Return flows for these zones are estimated to be 25 percent of land application rates.

3.7 Stream Preservation Areas

The Authority has identified stream preservation areas requiring additional levels of water quality protection

The Authority has identified stream preservation areas requiring additional levels of water quality protection. Stream preservation areas include those areas within the Cherry Creek Basin that transport a higher percentage of stormwater runoff and associated pollutants to the water system and Reservoir, such as:

- The Reservoir,
- Direct flow sub-basins to the Reservoir,
- All of Cherry Creek State Park,
- Drainage discharged to the Park within 100 feet of the Park Boundary,
- Lands overlying the Cherry Creek alluvium (Figure 3-6), and
- All lands within the 100-year floodplain, as defined by the Urban Drainage and Flood Control District (UDFCD).

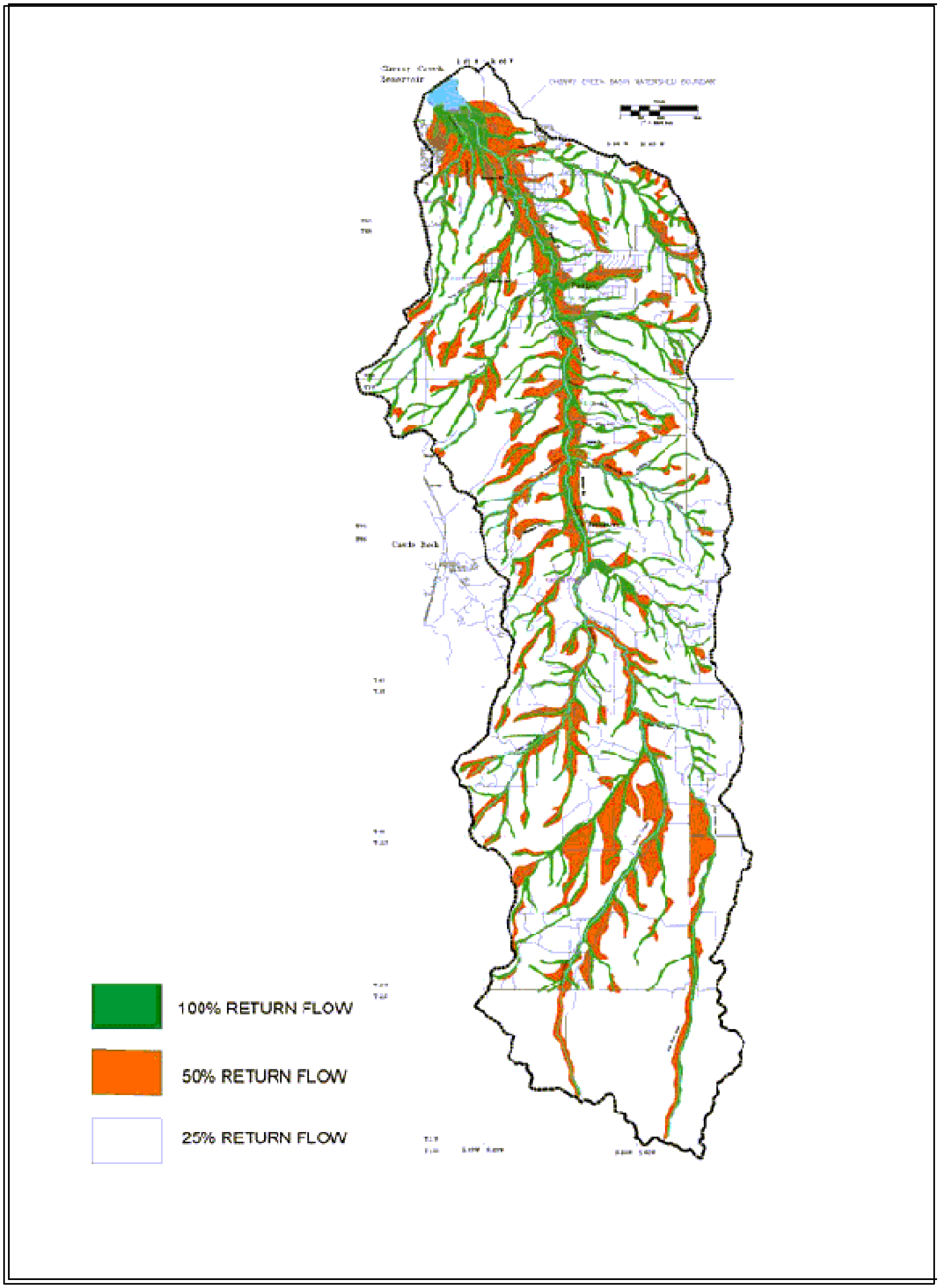
As described in Section 5, when a land disturbance occurs in a Stream Preservation Area, additional BMPs are required to stabilize streams and to maximize phosphorus removal through a combination of permanent BMPs. Specific requirements are identified in Appendix L.

3.8 Assessment of Phosphorus Sources

Total phosphorus, TP, discharged to the stream system is the result of natural and man-made activities in the Cherry Creek Basin. Natural or background sources include vegetation, soils, wildlife, and organic deposits. Man-made sources include stormwater runoff from industrial, mining, urban and agriculture land uses, ISDS's, and wastewater treatment facilities.

The primary mechanisms for phosphorus transport through the watershed, both natural and man-made, are storm runoff and erosion. Most of the total phosphorus removed from soils occurs through soil erosion. One of the greatest impacts of watershed urbanization on phosphorus transport is the significant increase in storm runoff volume over undeveloped conditions. On a long-term average basis, development can increase storm runoff volumes by 10 to 20 times over undeveloped conditions. In addition, by increasing volume and frequency of runoff, urbanization also increases erosion potential, unless controlled by BMPs.

Figure 3-6. Cherry Creek Basin Zone Map for Land Application Return Flows



In natural systems, phosphorus occurs as the orthophosphate anion, which may exist in inorganic or organic forms (Novotny, 1981). The origin of all inorganic orthophosphate is the class of minerals known as apatites. These minerals are insoluble calcium phosphates existing in several forms, and the orthophosphate ions are liberated by chemical weathering processes.

Phosphorus is also introduced to the watershed as man-made by-products, such as fertilizers, detergents, chemicals, fuels and lubricants. Other man-made sources are the result of agricultural activities and products, and individual sewage-disposal systems. Another important man-made factor is the introduction of large quantities of waste, both organic and inorganic, both by-products of urbanization.

Primary total phosphorus sources include precipitation, soil erosion, atmospheric fallout, oxidation of organic materials, automotive products, animal manure, ISDS, and commercial fertilizer,

A summary of primary total phosphorus sources, relative to load allocation, is presented below. Waste load contributions are discussed in other paragraphs in Section 3. The following sources have not been quantified, but are ordered in general importance to the Reservoir:

- *Precipitation.* Rain and snow scour the air, accumulating airborne phosphorus and other pollutants, which are deposited in the watershed. Scavenging efficiency is greater for snow than for rain, due to the larger specific surface of snowflakes. Phosphorus in precipitation directly on the Reservoir has ranged from 735 pounds to 1,262 pounds over the period from 1992 to 1997, but is accounted for separately in the TMDL.
- *Soil Erosion.* When vegetation is removed and subsoils are disturbed, soil erosion can occur, transporting phosphorus to the stream system. Soil erosion occurs during the urban development process when land is stripped and graded, but also during mining activities.
- *Atmospheric fallout ("dry fall").* Wind currents deposit phosphorus (and other pollutants) attached to sediment carried from areas outside the watershed.
- *Oxidation (decomposition) of organic materials.* Plants, atmospheric fallout, liquid and solid wastes accumulate in streets and parking lots. These wastes are decomposed, producing phosphates (organic form) and then washed into the stream system with urban runoff.
- *Automotive products.* Hydraulic fluids, fuels, tires, and rubber compounds deposited on impervious surfaces, all containing phosphorus, are washed into drainage ways and streams with urban runoff. Washing of automobiles can add phosphorus to base flows and urban storm runoff.
- *Animal manure.* Wastes from horses, cattle, and sheep, domestic and wild animals that are exposed to stormwater produce phosphates that are washed into the stream system with urban and rural runoff.
- *Individual Sewage Disposal Systems.* Leach fields and leaking ISDS's contribute phosphorus to the groundwater. However, based on

monitoring results in Bayou and Baldwin Gulches (CCBWQA 1999), there does not appear to be a water quality impact due to the concentrated use of ISDS's at this time.

- *Commercial fertilizer*. Over application of fertilizers adds nutrients (phosphorus and nitrogen) to irrigation return flows and storm runoff.

Section 4 Future Projections

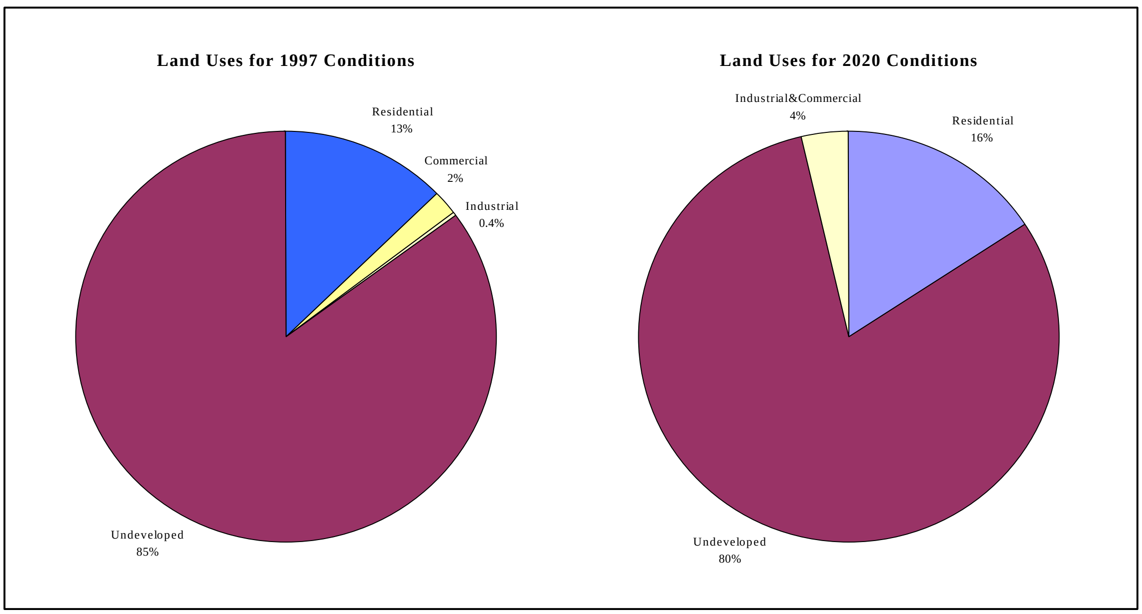
Growth in the watershed is progressing at a rapid rate, in both Arapahoe and Douglas Counties. Whereas future conditions are difficult to estimate, trend projections are necessary to develop a comprehensive plan. To minimize risk associated with projecting the future, conservative assumptions were sometimes made in an attempt to cover a greater range of possible scenarios. Presented in this section is a description of projected future conditions in the watershed and the Reservoir.

4.1 Growth in the Watershed

4.1.1 Land Uses and Population Projections

As shown on Figure 4-1, DRCOG has projected that a relatively large percentage of the basin remains undeveloped or agricultural in comparison to residential, commercial, and industrial percentages in the year 2020 (DRCOG, 1998). This coincides with information provided by the local governments that undeveloped uses (including open space, parks, floodplains, and agricultural uses) are expected to be the predominant use in the Basin.

Figure 4-1. Comparison of Land Uses for 1997 and 2020 Conditions (DRCOG, 1998)



Projections of population and employment were developed for each WWTF area for the planning years 2000, 2005, 2010, 2015 and 2020 from DRCOG's adopted regional population and employment forecasts. Table 4-1 summarizes population projections for the Cherry Creek Basin service area. The population numbers are based on Traffic Analysis Zones, which are loosely based on employment, number of houses and land use. The forecasts were developed from the 1990 census data and subsequently updated through the ongoing MetroVision 2000 planning process. According to DRCOG, the estimated 1997 basin population is 30,997, increasing to 62,534 by the year 2020. These population estimates are quite low in comparison to projections by Districts in the watershed. Ongoing coordination with DRCOG, local land use agencies, and 2000 census results will further refine these population estimates.

Table 4-1. Cherry Creek Basin Service Area Population Projections: 2000-2020 (DRCOG, 1998)

Service Area	1997	2000	2005	2010	2015	2020
Arapahoe-Lone Tree	6,556	6,911	7,521	8,401	9,760	12,240
Pinery	7,320	7,433	8,146	9,066	10,275	11,903
Inverness	20	21	47	145	669	3,854
Meridian	87	87	85	85	90	155
Parker	13,131	13,921	15,467	17,484	20,357	25,393
Stonegate	3,009	3,249	3,474	3,744	4,159	5,228
Totals	30,123	31,622	34,740	38,925	45,310	58,773

4.1.2 Service Areas

Service areas are the designated boundaries of those areas for which each wastewater treatment provider could potentially provide service. Service areas may include lands within the municipality or special district's jurisdiction, lands the municipality or special district contractually commit to serve, or lands surrounded by a service provider.

DRCOG's urban growth boundaries and the municipal and county comprehensive boundaries set limits on the extent of the wastewater utility service area. Figure 4-2 shows the Cherry Creek Clean Water Plan boundary and wastewater utility service areas within the Clean Water Plan boundary.

The urban growth boundaries, established through DRCOG's Metro Vision 2000 process, and a more detail discussion of Cherry Creek Service Areas, flexibility in service, overlapping service areas and new wastewater treatment facilities, can be found in Appendix P.

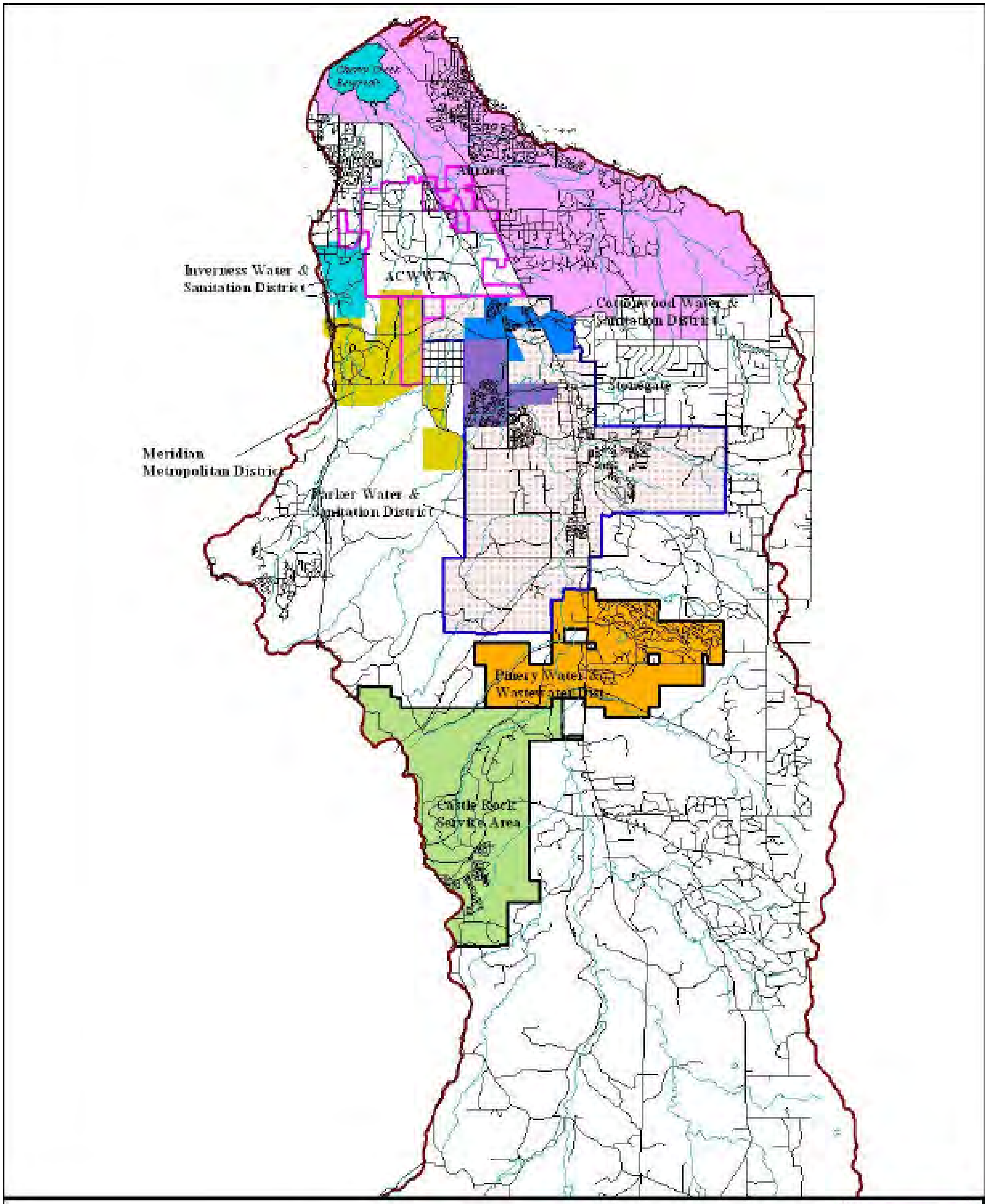


Figure 4-2. Water and Sanitation Service Areas in the Cherry Creeek Basin

4.1.3 Municipal Water Sources

In the future, municipal water requirements in the Cherry Creek Basin will result in increased pumping from alluvial and deep non-tributary aquifers. Currently, municipal pumping from alluvial aquifers ranges from a low of about 3,500 to over 7,500 acre-feet annually, with an average around 5,400 acre-feet. Some projections have estimated total pumping at over 10,000 acre-feet annually. Pumping from the alluvium directly affects runoff volume (and phosphorus loads) delivered to the Reservoir, both of which can have an effect on Reservoir water quality. Future alluvial pumping is also an alternative PRF that will be investigated further by the Authority (see Section 5.2.2.2.5).

For projecting future phosphorus loads delivered to the Reservoir, it has been assumed that no change will occur in historic patterns of average annual pumping volumes (Refer to discussion under "Cherry Creek Watershed Model"). This assumption is considered conservative, since increased pumping will reduce loads and volumes to the Reservoir.

4.1.4 Wastewater Treatment Facilities

Growth in the watershed will require expansion of existing WWTFs and, possibly, additional facilities for development not efficiently treated by existing systems, such as ISDS.

Growth in the watershed will require expansion of existing WWTFs and, possibly, additional facilities for development not efficiently treated by existing systems, such as ISDS's. Current dischargers have projected for their discharges, which have been used to estimate future phosphorus loads. Load projections account for instream delivery ratios, land application zones, change in point of discharge, and other variables discussed below.

4.1.4.1 Discharge Projections

Presented in Table 4-2 is a summary of projected discharges and permitted phosphorus loads delivered to the Reservoir. These projections were provided by the various dischargers or their representatives (see notes at bottom of Table 4-2). The projected loads account for the WLA/IDR discussed below and in further detail in Appendix I, as well as land application return flow factors. The projections include the following assumptions:

- WLA are based upon phosphorus concentration for future direct discharges of 0.05 mg/L and for land application is 0.2 mg/L.
- Land application return flow factor derived by John C. Halepaska and Associates (1997).
- Future discharge of ACWWA reflect a change in the point of discharge from Lonetree Creek to Happy Canyon Creek.
- No discharge projections for new developments and expansions are included at this time.

In January 2000, the Board agreed on a phosphorus allocation method that included present capacity of existing discharges and phosphorus for expansion through 2010. This allocation method also required new

WWTPs or expansions of WWTPs beyond existing allocations to acquire allocations from a phosphorus pool. (See Appendix F)

Table 4-2. Summary of Projected Discharges and Permitted Load

Phosphorus Concentration for Future Direct Discharge = 0.05mg/L; 0.2 mg/L land application

Existing Dischargers	2010 Projection						2020 Projection					
	Projected				Land		Projected				Land	
	Discharge 10 years (MGD)	Phosphorus Conc. (mg/l)	Load at Dischg. Pt (lbs/yr)	Instream Delivery Ratio1	Applic. Return Flow Factor2	Load to Reservoir (lbs/yr)	Discharge 20 years (MGD)	Phosphorus Conc. (mg/l)	Load at Dischg. Pt (lbs/yr)	Instream Delivery Ratio[1]	Applic. Return Flow Factor[2]	Load to Reservoir (lbsyr)
Pinery W&SD	2.03	0.05	309	0.29		90	2.00	0.05	304	0.29		88
Parker W&SD	3.75	0.05	571	0.31		177	5.75	0.05	875	0.31		271
Stonegate	1.10	0.05	167	0.49		82	1.80	0.05	274	0.49		134
Arapahoe W&SD[3]	2.53	0.05	385	0.53		204	3.34	0.05	508	0.53		269
Cottonwood	1.00	0.05	152	0.53		81	1.16	0.05	176	0.53		94
Meridian W&SD[4]	0.80	0.20	487	0.94	0.25	114	3.80	0.20	2313	0.94	0.25	543
Inverness W&SD	0.84	0.20	511	0.94	0.25	120	0.91	0.20	554	0.94	0.25	130
Direct TV	0.03	0.10	10	0.15		2	0.03	0.10	10	0.15		1
Total	**12.08**		**2592**			**869**			**5014**			**1532**
Pool - New Development & Expansions												
Aurora												
Castle Rock												
The Canyons												
Rangeview												
Rampart[8]												
New Development Allocation						**1,411**						
TOTAL WASTELOAD ALLOCATION						**2,280**						

1 Instream Delivery Ratio=1-Phos loads lost to alluvial pumping + Unknown phos gains/losses in the segment/(Phos loads at upstream sampling + Phos loads in discharges to segment + phosphorus loads in sub basin runoff) + 15 percent margin

2 Land Application Return Flow Factor derived by Halepaska and Assoc., (1997)

3 Discharge values taken from ACWWA & CWSD Wastewater Utility Master Plan, June 1999 and Dec 1, 1999 memo to J. Vlier, Brown and Caldwell, from W. Lorenz, Wright Water Engineers; ACWWA currently discharges to Lone Tree Cr. Future direct discharges are proposed at Happy Canyon Creek, contingent on approval of the augmentation/exchange plan..

4 Source of data for projected discharge 2020: 12/8/99 data from R.Bullock, Meridian W&SD

4.1.5 Cherry Creek Watershed Model

The watershed models provide a characterization of storm runoff volumes and phosphorus loads for current (1997) and future (2020) conditions.

The watershed models provide a characterization of storm runoff volumes and phosphorus loads to Cherry Creek and the Cherry Creek Reservoir resulting from point and nonpoint sources for two development conditions - current (1997) and future (2020). The watershed models can be applied to support a number of evaluations within the basin, including:

- Estimation of current and future pollutant loads and runoff volumes in the watershed,
- Identification of sub-basins with the greatest potential for phosphorus loads, and
- Development of priority areas for phosphorus controls.

The watershed models can also be linked to in-lake models for the Cherry Creek Reservoir (such as dynamic and steady state models) to provide a comprehensive picture of water quality within the Cherry Creek Reservoir Basin.

The Watershed Model is divided into two parts: a) the water yield model to estimate total runoff volume, and b) the phosphorus load model. Ten years of in-stream flow and phosphorus load measurements were used to calibrate the 2000 basin model, which considers the following:

- Variation in precipitation throughout the watershed using data from five, one-hour recording precipitation gages with a period of record from 1989 to 1998 (NCDC).
- Effect of different land uses (i.e., residential, commercial, industrial and undeveloped) within each of the 31 sub-basins in the watershed for existing (1997) and future (2020) conditions.
- Losses to the system from alluvial pumping and potable water consumptive use.
- Long-term average event-mean-concentrations for phosphorus in storm runoff, based on data collected and analyzed by the UDFCD.
- Reductions in phosphorus loads reflected by the in-stream delivery ratios, IDR. IDR's are based on surface and groundwater measurements at eight stations along Cherry Creek, from Castlewood Canyon to the Reservoir, and stations at Shop Creek, Belleview Creek, Quincy Drainage and Cottonwood Creek.

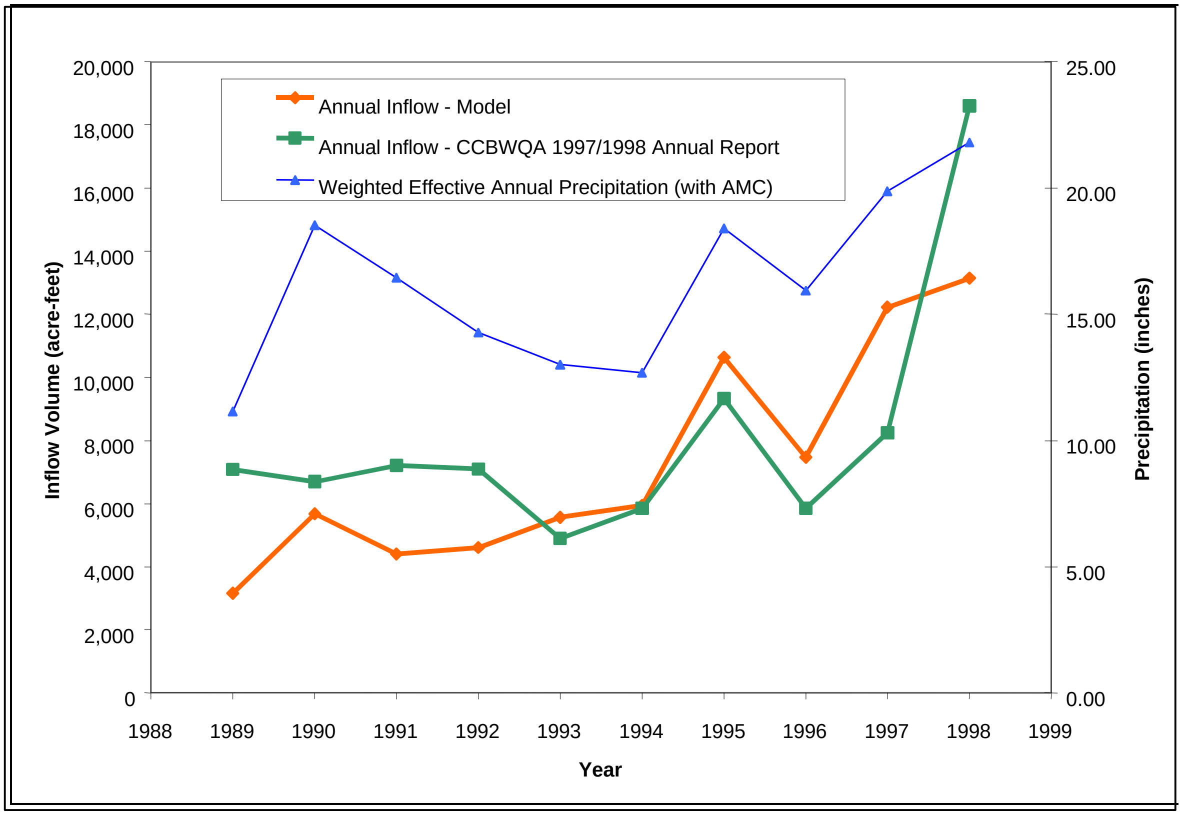
4.1.5.1 Water Yield Model

Primary assumptions made in the 2000 basin model are:

- Measured runoff volume by Chadwick Ecological Consultants include surface and groundwater flow, which are considered to represents all runoff from precipitation, either directly as surface runoff or indirectly as the result of sub-surface runoff to Cherry Creek.
- The geology of Cherry Creek is such that groundwater and surface flow in Cherry Creek are directly connected. Therefore, infiltrated precipitation becomes sub-surface runoff and is part of direct runoff, but is delayed from surface runoff.

Details of the water yield model are provided in Appendix I. A comparison of measured and predicted storm runoff volumes is presented below on Figure 4-3.

Figure 4-3. Comparison of Measured and Calculated Runoff Volumes



4.1.5.2 Phosphorus Load Model

The phosphorus load model accounts for storm runoff volume, phosphorus concentrations in storm runoff, an instream delivery ratio (see below) and point source discharges (see above). Annual load estimates were calculated for the period of 1989 to 1998 using the water yield model and discharge information for each wastewater treatment facility.

4.1.5.2.1 In-Stream Delivery Ratios

The IDR represents the fraction of phosphorus loads that are actually delivered to the downstream stream segment or Reservoir.

In-stream delivery ratio, IDR, is defined as the ratio of phosphorus leaving a stream segment to phosphorus gains in the stream segment of Cherry Creek. The IDR, therefore, represents the fraction of phosphorus loads that are actually delivered to the downstream stream segment or Reservoir. Field measurements have shown a reduction in total phosphorus mass at downstream monitoring stations accounting for losses and gains between stations, including phosphorus removed by alluvial pumping. Using the continuity of mass, the sum of all phosphorus inputs (or gains) are equal to the sum of all outputs (or losses), which provides the basis for calculating IDRs.

Presented on Figure 4-4 are IDRs for WLA (i.e.: WLA/IDR) and on Figure 4-5, IDRs for load allocation (LA/IDR). WLA/IDR are the wet year IDRs (i.e., 1998) and include a 15 percent margin of safety. The LA/IDR represents the median IDRs based on data collected from 1995 to present.

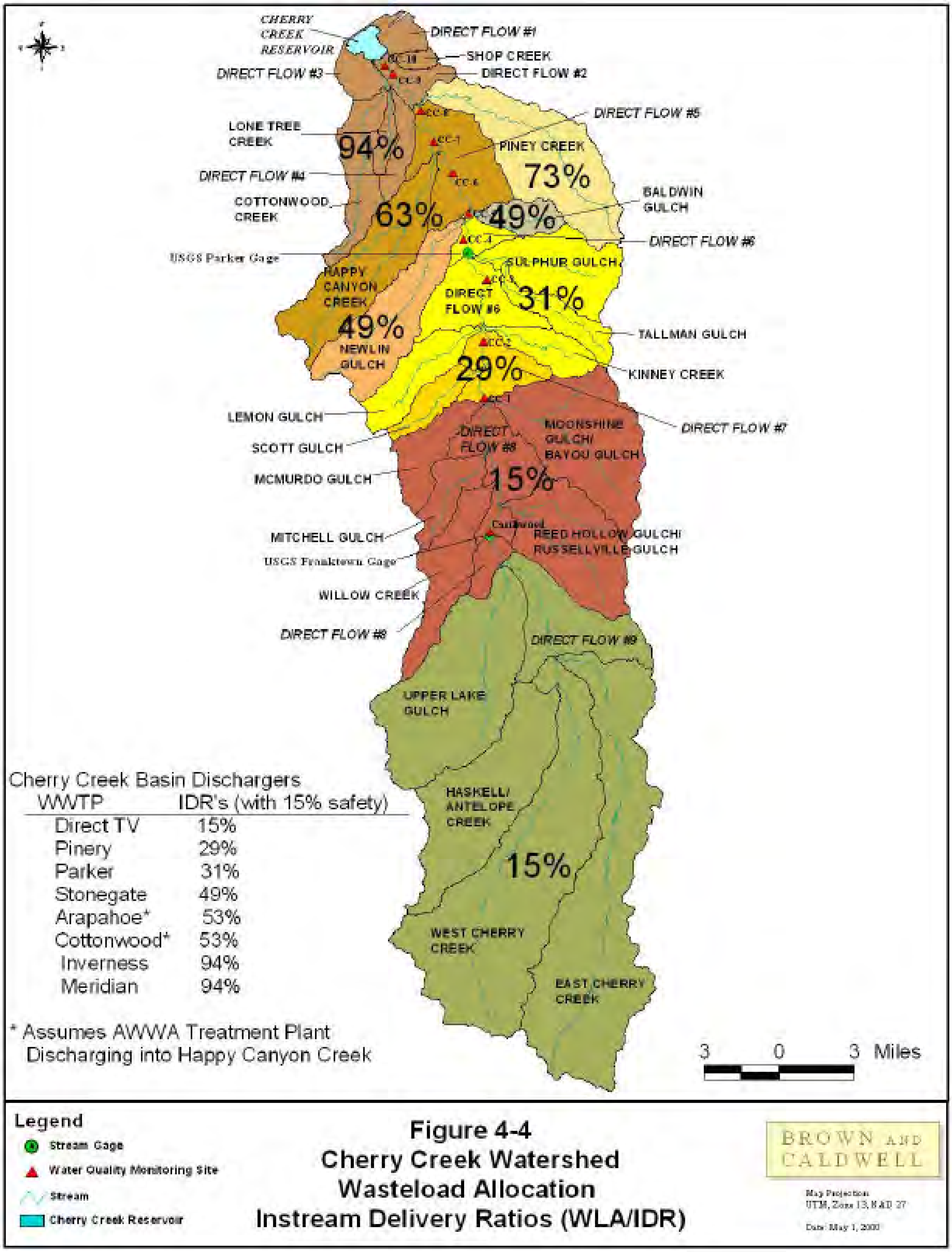
Median IDRs were used to calibrate nonpoint source and stormwater loads, as determined by the model, to measured values at the reservoir. Median IDRs were also used to estimate reduction of loads at the reservoir for implementation of BMP's and PRFs.

The IDRs presented on Figure 4-4 and 4-5 only apply to the mainstem of Cherry Creek. Site specific monitoring data are required to calculate IDRs and data were not available for any tributary of Cherry Creek. Therefore, the IDRs do not apply to any tributaries within the watershed. If data becomes available within a tributary subbasin, the Authority may calculate other IDRs.

4.1.5.3 Modeled and Predicted External Phosphorus Loads

There is a reasonably good agreement between measured and modeled phosphorus loads, as demonstrated by the following observations (Figure 4-6).

- Calculated magnitudes from 1992 to 1998 have an average difference of 2,000 pounds from measured values. Therefore, on an annual basis, calculated loads would be within 2,000 pounds from measured values. If the average difference is calculated using plus and minus values, the average difference is only 430 pounds. Therefore, on a long-term basis, the sum of calculated loads would be relatively close to the sum of measured loads. This suggests that the model is reasonable for predicting long-term average impacts.
- The increase and decline in loads from 1994 to 1996 was reasonably duplicated.
- The increase in loads from 1996 to 1998 was also predicted, but the magnitude in 1998 was low by around 40 percent. No explanation for this difference has been developed.



Cherry Creek Basin Dischargers

WWTP	IDR's (with 15% safety)
Direct TV	15%
Pinery	29%
Parker	31%
Stonegate	49%
Arapahoe*	53%
Cottonwood*	53%
Inverness	94%
Meridian	94%

* Assumes AWWA Treatment Plant Discharging into Happy Canyon Creek

Figure 4-4
Cherry Creek Watershed Wasteload Allocation Instream Delivery Ratios (WLA/IDR)

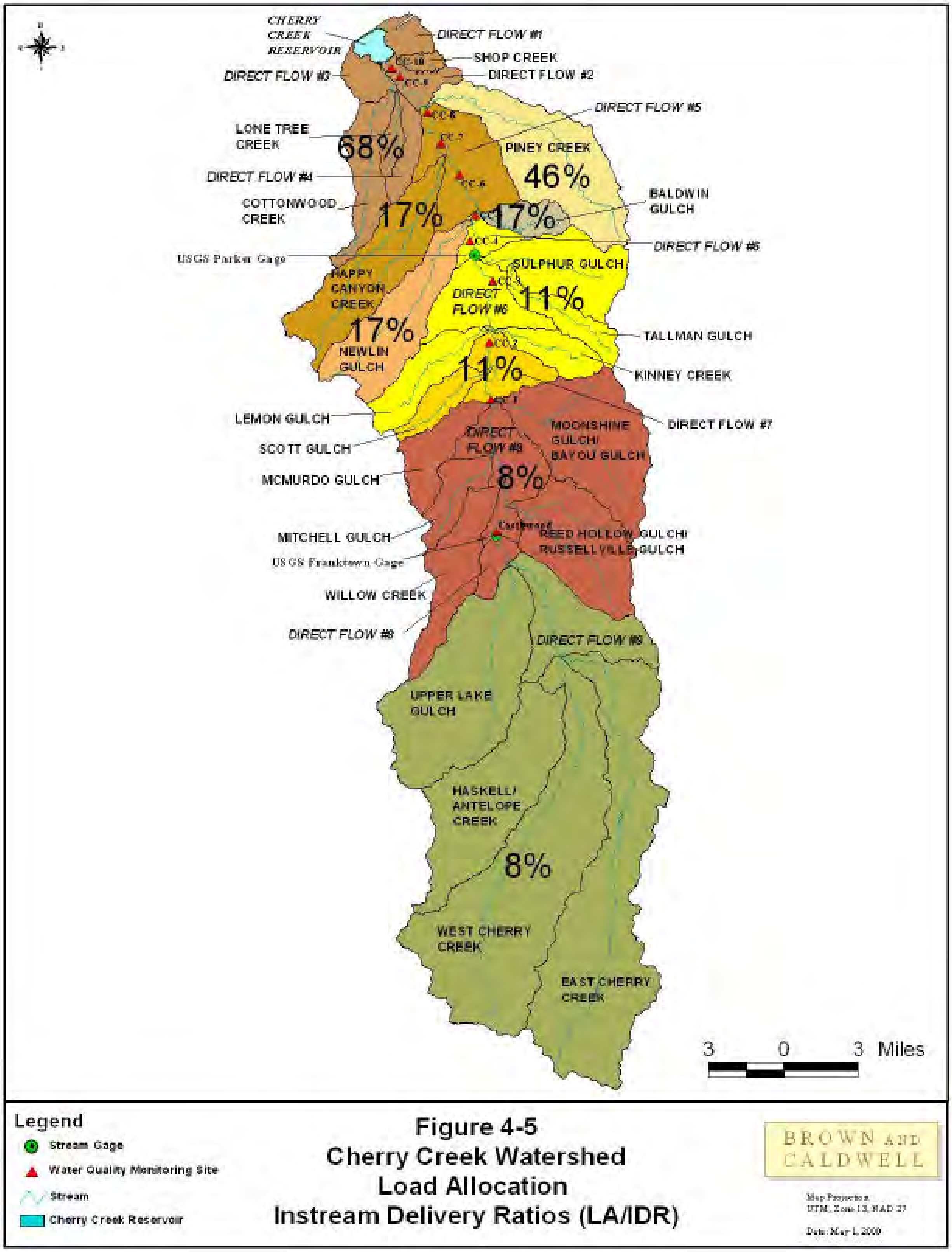
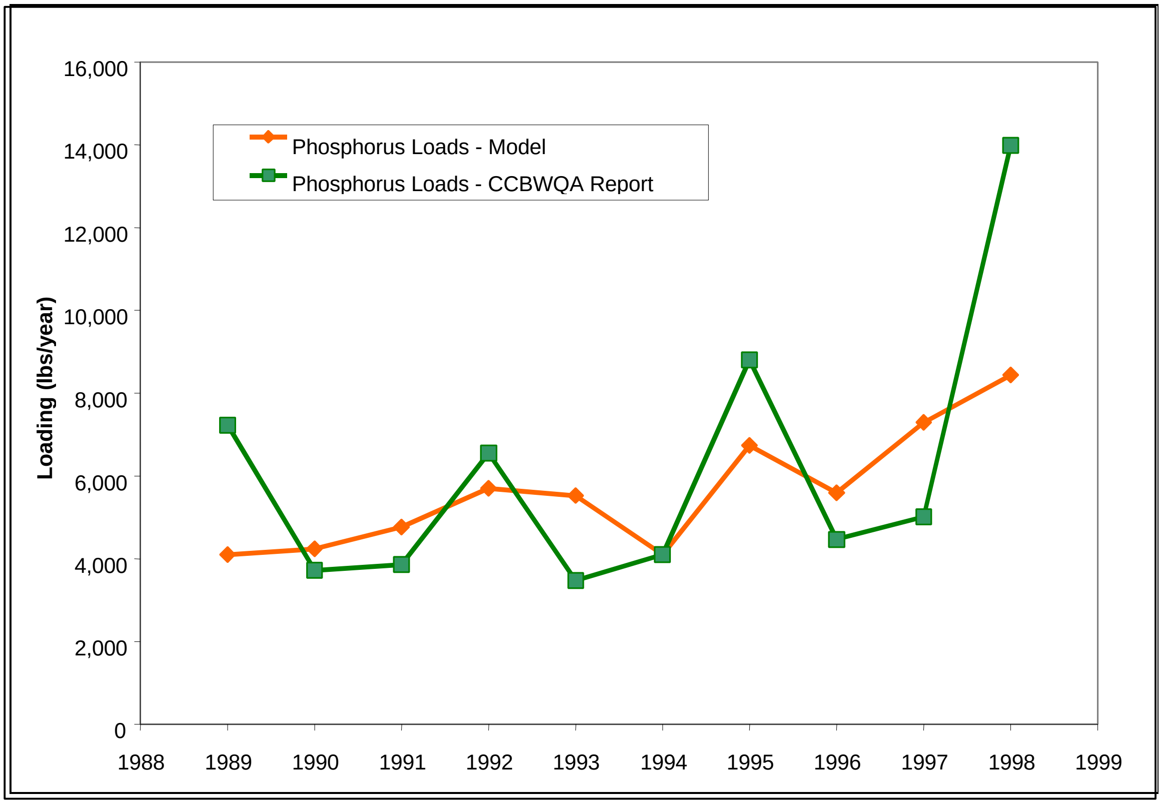


Figure 4-5
Cherry Creek Watershed
Load Allocation
Instream Delivery Ratios (LA/IDR)

Figure 4-6. Comparison of Measured and Predicted Phosphorus Loads



4.1.5.4 Effects of Alluvial Pumping

Because of unknowns in projecting future alluvial pumping, conservative assumptions have been made for the purposes of projecting phosphorus loads and load-reductions, depending on the specific application. Calculated runoff volumes delivered to the reservoir (except for precipitation) for current (average of 7,285 acre-feet) and year 2020 land use conditions (average of 11,435 acre-feet) show an average increase in runoff volume of 57 percent. Runoff volumes include reductions based on pumping from the alluvium. However, future pumping volumes were assumed equal to historic pumping volumes. This approach likely results in over estimate of future runoff volume, which over estimates phosphorus loads from storm runoff.

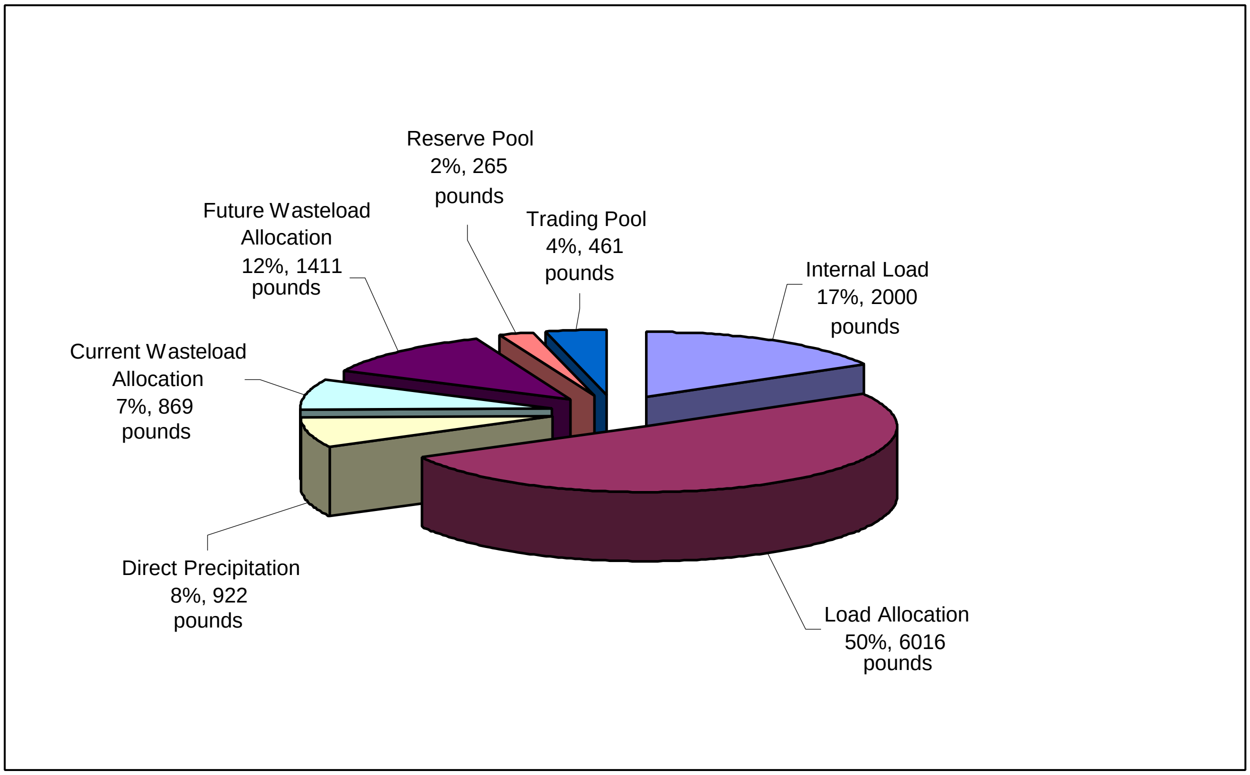
Total annual allowable loads of phosphorus are predicated upon modeling that predicts future loads will result in an in-lake total phosphorus value of 60-µg/L, on average.

4.1.6 The Cherry Creek TMDL

Total annual allowable loads of phosphorus to Cherry Creek Reservoir of 11,944 pounds are predicated upon modeling that predicts future loads (at 15,470 acre-feet per year inflows to Cherry Creek Reservoir) will result in an in-lake seasonal mean total phosphorus value of 60-µg/L, on average. The total allowable phosphorus load is distributed between internal sources and external sources. The Cherry Creek Total Phosphorus Load = Internal Load + External Load (Load Allocation + Direct Precipitation +

Wasteload Allocations + Reserve Pool + Trading Pool). The TMDL is illustrated in Figure 4-7.

Figure 4-7. The Cherry Creek TMDL



4.1.6.1 Load Allocation

The External Load of 9,944 pounds of phosphorus is comprised of Load Allocation (6,016) + Direct Precipitation (922) + Wasteload Allocations (2280) + Reserve Pool (265) + Trading Pool (461). The Load Allocation is the annual phosphorus from surface and subsurface flows comprised primarily of nonpoint sources, background loads and municipal stormwater. Nonpoint source includes phosphorus loads from ISDS's, that are considered part of the Load Allocation. The load allocation increases with increased inflow volume. The inflow volume of 15,470 results in a load of 6,016 pounds phosphorus after implementation of BMPs to reduce phosphorus and PRFs removing 2,730 pounds of phosphorus annually.

4.1.6.2 Wasteload Allocation

WLAs for point source dischargers and industrial and commercial stormwater are based on an effluent concentration of 0.05 mg/L total phosphorus for direct dischargers and land disposal, and 0.2 mg/L total phosphorus for land application. The TMDL includes "current wasteload allocations" of 869 pounds allocated to seven dischargers within the Basin for their predicted 2010 wastewater discharges in the watershed. Direct dischargers will be required to reduce phosphorus concentrations from 0.2 mg/L total phosphorus to 0.05 mg/L total phosphorus as the volume of their wastewater flows nears their WLA.

Future allocations of 1,411 pounds may be allocated to any existing discharger for expansions or new facilities or facilities serving new areas. Allocations from the future allocation pool must also be based on 0.05 mg/L total phosphorus for direct dischargers and land disposal and 0.1 mg/L total phosphorus for land application. Additionally, a reserve pool of 265 pounds is available for interim allocations to prevent exceedances of WLAs due to bypasses, failures of processes, construction, or other temporary causes. The TMDL recognize that the trading pool of 461 pounds exists. No modifications were made to the trading pool, however, the 461 pounds is now explicitly incorporated into the TMDL.

4.1.6.3 Margins of Safety

The TMDL incorporates margins of safety because numerous conservative assumptions were utilized for projections and modeling.

The TMDL incorporates margins of safety because conservative assumptions, explicit and implicit, were utilized for projections and modeling. Those assumptions include:

1. WLA/IDR's are based on wet year plus 15 percent margin of safety, which gives substantially less credit to point source dischargers for the delivery ratio phenomena and the pumping and treatment of groundwater.
2. LA/IDR's are used to estimate load reductions from PRFs in the watershed. This is conservative because it does not include the margin of safety (i.e.: 15 percent) and therefore results in higher estimates of phosphorus loads from PRFs.
3. Values greater than averages were used for precipitation loads and stormwater loads in the TMDL indicating long-term over-estimation of loads.
4. In estimating benefits of BMP implementation, credit is only taken for an average 40 percent reduction, even though the expected performance ratio (re: UDFCD) is 45 to 55 percent for the minimum BMP.
5. The modeling did not credit implementation of BMPs to reduce sediment and phosphorus loads from construction activities that would be delivered to the reservoir during the growth period. Due to extensive development in the watershed over the last 10 years, it is likely that a portion of the measured loads is due to construction activities.
6. The annual TMDL is to achieve protection for a seasonal standard, which provides increased protection for the Reservoir throughout the year.

Calculations were prepared to quantify the implied margin of safety, where possible, relative to total external loads delivered to the Reservoir. Estimates were made to determine effects of increased pumping, the

15 percent explicit margin on WLA/IDR's, greater than 50th percentile difference, and BMP implementation. Based on these estimates, margins of safety provide a buffer of at least 15 percent on estimated loads delivered to the Reservoir.

4.2 Future Conditions In Cherry Creek Reservoir

Various in-lake models have been used in the past to predict the relationship between chlorophyll a and phosphorus. Future conditions in the Reservoir, however, are predicted based on a new dynamic, in-lake model to calculate the relationship, as well as the results of future development scenarios. Presented in this section is a discussion of previous models, the new dynamic model, modeling future scenarios for the Reservoir, and proposed chlorophyll a and phosphorus standard for the Reservoir.

4.2.1 Phosphorus/Chlorophyll Models

Using the Jones-Bachmann equation, an average concentration in the Reservoir of 35 µg/L total phosphorus would result in a chlorophyll a concentration of 15 µg/L, on average. This is the basis for the original Cherry Creek Reservoir Control Regulation. However, the Jones-Bachmann model does not appear to fit measurements in the Reservoir.

Rapid sedimentation of particulate phosphorus carried into reservoirs, such as Cherry Creek, has been a feature of phosphorus modeling, which has resulted in reservoirs being treated differently from natural lakes.

The Jones-Bachmann chlorophyll a and phosphorus model was heavily weighted towards natural lakes and did not include data from the Reservoir. Recent studies has demonstrated that chlorophyll-phosphorus relations can differ among geographical areas, lakes with different morphology and hydrology, and origin (i.e.: natural versus man-made). One reason is that, like many reservoirs, Cherry Creek Reservoir appears to have a high rate of phosphorus sedimentation. Rapid sedimentation of particulate phosphorus carried into reservoirs has been a feature of phosphorus modeling, which has resulted in reservoirs being treated differently from natural lakes.

In an initial analysis of this relationship, using data collected by the University of Missouri (MU) from 1992 to 1997, the relationship between chlorophyll a and phosphorus was determined specifically for the Reservoir. The regression equation obtained from individual observations from the Reservoir 1992 through 1997 was:

$$\log(\text{chlorophyll } \underline{a}) = 1.15 \log(\text{total phosphorus}) - 0.89.$$

Using this equation, the goal of 15 µg/L chlorophyll a could be attained with an average concentration of 63 µg/L total phosphorus. This chlorophyll a-phosphorus relationship specific to the Reservoir again indicates that the value of 35 µg/L phosphorus in the Control Regulation is inappropriate and lower than necessary to maintain a 15 µg/L chlorophyll a level in this reservoir.

A publication by the Organization for Economic Cooperation and Development (OECD, 1982) includes regression equations relating annual mean chlorophyll a to in-lake phosphorus concentrations for a suite of shallow lakes and reservoirs. The OECD model is:

log chlorophyll a = -0.367 + 0.88 (log total phosphorus).

Both chlorophyll a and phosphorus are seasonal means expressed as the average within the photic zone (similar to the sample depths used in Cherry Creek Reservoir). This chlorophyll a-phosphorus relation from OECD suggests that for a lake to have an average chlorophyll a value of 15 µg/L, the lake would be expected to have an average phosphorus concentration of about 57 µg/L.

The relation between chlorophyll a and phosphorus in the Reservoir is also well described by several other published models (Appendix E). The Cherry Creek data closely fit the models by Vollenweider and Kerekes (1980) and Canfield (1983). Based on these models, a lake supporting an average chlorophyll a concentration of 15 µg/L would have an average total phosphorus value of 58 µg/L to 60 µg/L. The model by Jones et al. (1989), based on lakes in Nepal, shows a total phosphorus value of about 70 µg/L results in average chlorophyll a values of 15 µg/L. Collectively, these models show that in a large number of lakes, chlorophyll a and phosphorus behave similarly to values measured in the Reservoir (Table 4-3).

Table 4-3. Chlorophyll a-Phosphorus Models (Jones and CEC, 1998)

If Chl = 15 µg/L, then:			
Jones and Bachmann	TP = 35	Canfield	TP = 60
White et al. TP=99	TP = 99	Vollenweider and Kerekes	TP = 58
Jones (Nepal)	TP = 71	OECD	TP = 57

These analyses show that the relation between chlorophyll a and phosphorus in the Reservoir differs from that which underpins the Jones-Bachmann chlorophyll a-phosphorus relation used to set the existing phosphorus standard. Relationships based on empirical data for the Reservoir and other published lake models indicate that phosphorus concentrations can average around 60 µg/L and still achieve the chlorophyll a goal of 15 µg/L.

The Reservoir model, prepared by Freshwater Research, is a time-dynamic, total phosphorus lake mass-balance model that predicts lake water total phosphorus concentrations over the year using a daily or weekly time step.

Collectively, these data suggest that the Jones-Bachmann model over-predicts the yield of chlorophyll a per unit of phosphorus in the Reservoir. As such, use of this model in 1985 resulted in inappropriate phosphorus standard. Given this lack of fit to existing models and to provide better information on lake function, a dynamic model was developed by Freshwater Research, based on recommendations from the Expert Panel.

4.2.2 Reservoir Dynamic Model

The Reservoir dynamic model is a time-dynamic, total phosphorus lake mass-balance model that predicts lake water total phosphorus concentrations over the year using a daily or weekly time step. The model was prepared by Freshwater Research (Appendix J) in response to the

The goal of the model was to determine relative importance of seasonal changes in vertical total phosphorus fluxes between water and sediment to changes in-lake water total phosphorus concentrations.

recommendation of the Expert Panel (Appendix A). Photoplankton chlorophyll can be empirically estimated from the model's predicted TP. In its simplest form, the lake mass-balance model uses one or more, well-mixed lake water compartments and requires basis lake morphometry, hydrology and external total phosphorus load as data inputs. Model outputs include outflow of total phosphorus load and well as in-lake total phosphorus and chlorophyll concentrations.

The primary goal of the Reservoir model was to determine relative importance of seasonal changes in vertical total phosphorus fluxes between water and sediment to changes in-lake water total phosphorus concentrations. Thus, a sediment compartment with its associated fluxes to and from the water compartments was also incorporated in the model. Of special importance is the prediction of late summer and early fall (July-September) total phosphorus and chlorophyll. This is the period when, historically, chlorophyll tends to be highest and blue-green algae dominate the algal community.

In preparing the dynamic model, Freshwater Research followed guidance from the Expert Panel. Of particular interest were suggestions addressing mixing and stratification, external and internal total phosphorus fluxes, seasonal and annual total phosphorus variability, the TP-chlorophyll relationship.

4.2.2.1 Mixing and Stratification

Freshwater Research concluded that the Reservoir is best modeled by assuming two well-mixed lake compartments - an upper layer (most of the volume), and a bottom layer from which the outflow drains.

An evaluation of temperature and Relative Thermal Resistance to Mixing (RTRM) profiles in Cherry Creek Reservoir indicates that the reservoir is usually well mixed. However, a high total phosphorus and low dissolved oxygen zone still developed below 6 meters in late summer 1998. This zone produced an increase in total phosphorus throughout the Reservoir and indicated a sediment-derived source of TP. Because the Reservoir outflow drains this high total phosphorus zone from the bottom, Freshwater Research concluded that the Reservoir is best modeled by assuming two well-mixed lake compartments. The compartments include an upper layer (down to 6 meters) that comprises most of the Reservoir volume, and a bottom layer from which the outflow drains.

4.2.2.2 External and Internal Total Phosphorus Fluxes

Daily external input total phosphorus fluxes were obtained from observed hydrological and monitoring data. Internal fluxes (i.e.: sedimentation, re-suspension and release from the bottom sediments) were estimated by model calibration of predicted versus measured in-lake TP. Empirical estimates and published values of internal flux rates were used to guide and evaluate model design and calibrations. During July to September 1998, the model partitions total phosphorus loads into 47 percent from external sources and the remainder from internal sediment load. The proportion of external load increases to 69 percent when calculated on an annual basis. The proportion of internal load is even more important to late summer total phosphorus concentrations in other years and less external load during this period. In general only models with internal sediment load could adequately predict the late summer increase in Reservoir total phosphorus and the elevated levels of total phosphorus in the bottom water.

4.2.2.3 Modeling Seasonal and Annual Total Phosphorus Variability

Models with increasing complexity were created to reproduce the seasonal variation of in-lake TP. A model that includes temperature dependent internal phosphorus load and sedimentation rates dependent on calcite co-precipitation of total phosphorus appear to fit the 1998 data best. A simpler model, requiring less input data but also including temperature-dependent internal phosphorus load, can be applied to those years where there is insufficient data to apply the more complex model.

Application of the simpler model to a seven-year time series from 1992 to 1998 gave reasonable fits for five of these years. One of the two, nonconforming years (1995) was over-predicted, perhaps because of very cold, inflow water not mixing before leaving the Reservoir. Freshwater Research was not able to explain why the 1997-year was under-predicted. The 1999 verification year was reasonably fit with the simpler model and well fit with the detailed model. Nonetheless certain discrepancies were noted and suggestions for model improvement were made.

4.2.2.4 Modeling Chlorophyll

Using data collected from the Reservoir, a good chlorophyll-total phosphorus relationship was recalculated with data for July to September period for the years 1992 to 1998. This relationship was used to predict July to September chlorophyll in the dynamic Reservoir models. Other factors such as nitrogen fractions and N/P ratios did not substantially improve this relationship.

Several analyses were made to determine the average total phosphorus levels in the Reservoir associated with chlorophyll a objective of 15 µg/L in July to September. The results covered the range of 59 µg/L to 63 µg/L total phosphorus.

4.2.3 Modeling Future Scenarios for Cherry Creek Reservoir

The Dynamic Model provides important information on lake function, especially seasonality of the phosphorus in the water column.

The Dynamic Model provides important information on lake function, especially seasonality of the phosphorus in the water column. However, its usefulness in predicting future conditions in the lake is limited due to the need for daily flow inputs for the model. Since the watershed model is calibrated to annual flows/loads, it was necessary to develop a steady-state, annual load lake model for Cherry Creek Reservoir. This model was also developed by Freshwater Research and used input variables from the Dynamic Model, which allowed better calibration.

Examining the Reservoir on an annual basis is a conservative approach to estimating lake response to external phosphorus loads. The lake's response to annual loads, rather than seasonal loads, reflects the cumulative effect on phosphorus releases and loads to the reservoir.

The steady state model was applied to long-term hydrologic conditions for the years of normal Reservoir operation from 1960 to 1999. Hydrological and loading conditions were quite variable over this 40-year period. Therefore, medians, 25th and 75th percentile values were reported to characterize these long-term baseline conditions as Scenario 1 in Table 4-4. The percentage below which a specific lake concentration is predicted (i.e.: approximate target total phosphorus concentration of 60 µg/L) is presented as well. Three more scenarios considering the long-term baseline conditions (Scenario 2 to 4) predict decreases in total phosphorus concentration averages because of external and internal load reduction.

Four scenarios (Scenario 5 to 8) were modeled according to future (year 2020) development projections. Scenarios 5 and 6 investigate effects of increased growth without implementation of BMP and PRFs. Scenario 5 projects loads and concentrations based on increases in flow (36 percent) and external load (54 percent). Scenario 6 adds increases (54 percent) in internal loads to Scenario 5. Scenario 7 and 8 investigate effects of increased growth with implementation of BMP and PRFs. Scenario 7 projects loads and concentrations with BMP and PRF programs in place, but without in-lake management, whereas Scenario 8 demonstrates benefits of both watershed and in-lake management. Lowest July-September total phosphorus averages are predicted in scenarios where both external and internal sources are addressed (i.e. Scenarios 7 and 8). Table 4-4 Summarizes the long-term conditions and results for Scenarios 1 to 8.

In Scenario 8, external phosphorus loads are reduced substantially through implementation of BMPs, construction of PRFs, in-lake management and maintaining alluvial pumping at current levels.

The Authority recommended modeling for "Future Scenario 8," a scenario which incorporates flow increases by 36 percent, but only 7 percent external phosphorus load increase. In this Scenario 8, the external phosphorus loads are reduced substantially through implementation of BMPs, construction of PRFs, in-lake management and maintaining alluvial pumping at current levels. A 50 percent reduction of internal loads through in-lake management was also incorporated in Scenario 8. With these internal and external loading controls, the model predicted 71 percent compliance over time with the 60 µg/L seasonal mean total phosphorus standard over time. Based on the reanalysis of total phosphorus-chlorophyll relationships conducted as part of the Dynamic Model outlined above, this would also be expected to result in a 71 percent compliance with the chlorophyll a goal of 15 µg/L, on average.

The City of Greenwood Village and the Authority developed a scenario to improve PRFs to remove a long-term average of 2,730 pounds of phosphorus annually - "Best Efforts Scenario" - the basis for the TMDL implementation plan and for approval of portions of the Control Regulation revisions.

However, the City of Greenwood Village, an Authority member, requested that the Authority consider whether additional external load controls were feasible to improve water quality compliance. Collectively, the City of Greenwood Village and the Authority developed a scenario to improve PRFs to remove a long-term average of 2,730 pounds of phosphorus annually ("Best Efforts Scenario"). The Best Efforts Scenario, as presented in the 2000 Watershed Plan, is based on a 57 percent increase in runoff volume (i.e.: assumes no increase in alluvial pumping) and a 10-year average external load increase of 10 percent. These are conservative assumptions that have been accounted for in the margin of safety estimate (see Section 4.1.6.3). Under this Best Efforts Scenario, additional modeling indicates that the 60 µg/L standard should be consistently attained (greater than the 71 percent compliance predicted earlier). Further, it predicts the resulting

Table 4-4. Long-term Conditions and Results for Scenarios 1-8

Table 3- March 13, 2000. Longterm conditions and results for Scenarios 1 to 8.

Scenario	Inflow	Outflow	Ext. Load		qs	R_sed	Int. Load	TP
	AF	AF	lbs	mg/m2/yr	m/yr		mg/m2/yr	mg/L
Longterm Baseline Conditions								
1 *Longterm (1960 - 1999) conditions*								
Minimum	1,460	0	1,544	175	0.00	0.64	450	
Maximum	37,050	35,496	29,362	3,328	10.94	1.00	450	125
Median	5,793	2,938	4,931	559	0.91	0.95	450	50
25%	2,450	0	2,318	263	0.00	1.00	450	
75%	13,805	9,354	11,193	1,269	2.88	0.87	450	78
63%	8,568	5,491	7,100	805	1.69	0.92	450	60
2 *Cherry Creek Inflow Treatment, 35% external load decrease*								
50%	5,793	2,938	3,205	363	0.91	0.95	450	40
25%	2,450	0	1,507	171	0.00	1.00	450	
75%	13,805	9,354	7,275	825	2.88	0.87	450	58
78%	15,614	12,917	8,194	929	3.98	0.83	450	59
3 *50% internal load decrease*							50%	
50%	5,793	2,938	4,931	559	0.91	0.95	225	39
25%	2,450	0	2,318	263	0.00	1.00	225	
75%	13,805	9,354	11,193	1,269	2.88	0.87	225	68
71%	11,375	7,551	9,294	1,053	2.33	0.89	225	59
4 *Like Scenario 2, plus corresponding 35% internal load decrease*							0.65	
50%	5,793	2,938	3,205	363	0.91	0.95	293	33
25%	2,450	0	1,507	171	0.00	1.00	293	
75%	13,805	9,354	7,275	825	2.88	0.87	293	51
85%	19,895	16,881	10,370	1,175	5.20	0.79	293	60
Future (2020) Conditions								
5 *36% flow and 54% external load increase*								
50%	7,878	5,038	7,593	861	1.55	0.93	450	63
25%	3,332	839	3,570	405	0.26	0.99	450	
75%	18,775	15,104	17,237	1,954	4.66	0.80	450	101
45%	7,034	4,258	6,846	776	1.31	0.94	450	60
6 *Like Scenario 5, plus corresponding 54% internal load increase*								
50%	7,878	5,038	7,593	861	1.55	0.93	693	75
25%	3,332	839	3,570	405	0.26	0.99	693	
75%	18,775	15,104	17,237	1,954	4.66	0.80	693	111
30%	4,265	1,700	4,395	498	0.52	0.97	693	60
7 *36% flow and 7% external load increase*								
50%	7,878	5,038	5,276	598	1.55	0.93	450	50
25%	3,332	839	2,480	281	0.26	0.99	450	
75%	18,775	15,104	11,977	1,357	4.66	0.80	450	76
63%	11,653	8,525	7,597	861	2.63	0.88	450	60
8 *Like Scenario 7, plus 50% internal load decrease*								
50%	7,878	5,038	5,276	598	1.55	0.93	225	40
25%	3,332	839	2,480	281	0.26	0.99	225	
75%	18,775	15,104	11,977	1,357	4.66	0.80	225	66
71%	15,470	12,051	9,944	1,127	3.71	0.84	225	59

Note: When outflow is below 850 AF (out of model range), TOP is not predicted, but should be below 50 ug/L (see text).

chlorophyll a goal of 15 µg/L should be attained at a much higher frequency. The Best Efforts Scenario is the basis for the TMDL implementation plan and for portions of the Control Regulation revisions being approved.

4.2.4 Proposed Chlorophyll a and Phosphorus Standards

It is recommended that the Reservoir maintain a goal of 15 µg/L chlorophyll a measured as a July-September seasonal mean. Compliance with the total phosphorus standard would be determined annually based upon achieving 60 µg/L total phosphorus or less.

For setting lake standards, it is recommended that the Reservoir maintain a goal of 15 µg/L chlorophyll a measured as a July-September seasonal mean. Compliance with the total phosphorus standard would be determined annually based upon achieving 60 µg/L total phosphorus or less (as a July-September seasonal mean) for all years with flows less than 8,578 acre-feet per year (the baseline inflow that matches the 60 µg/L standard). Results of the Dynamic Model and steady state modeling efforts indicate that in-lake total phosphorus (and resulting chlorophyll a values) are closely tied to external loads (although, internal loads are also important). As such, it would be expected that the 60 µg/L seasonal mean total phosphorus standard (or the chlorophyll a goal) would be difficult to meet in wet years.

To account for the relationship between flow/loads and in-lake total phosphorus (and chlorophyll), an index was developed for the lake providing predicted total phosphorus based on inflow.

To account for this relationship between flow/loads and in-lake total phosphorus (and chlorophyll), an index was developed for the lake providing predicted total phosphorus based on inflow (Table 4-5), based on the existing hydrology to phosphorus load relationship (i.e., baseline conditions). For years with inflows exceeding 8,578 acre-feet per year, compliance would be determined based upon the deviation of the measured total phosphorus from the predicted total phosphorus (Table 4-5). Considering deviations between measured total phosphorus and predicted total phosphorus incorporates natural variability of the Reservoir and watershed system and model variation. For compliance, the average of those deviations for 10 consecutive years would be less than or equal to zero (i.e., the in-lake total phosphorus would have to be less than or equal to the total phosphorus standard over time to ensure that worsening water quality was not occurring). Table 4-5 shows how long-term compliance would be evaluated:

Table 4-5. Predicted versus Measured Total Phosphorus

Year	Flow (acre-feet)	Predicted Total Phosphorus (µg/L)	Measured Total Phosphorus (µg/L)	Deviation (µg/L)
1992	9,230	63	52	-11
1993	5,868	60*	59	(0)
1994	7,029	60*	58	(0)
1995	11,801	71	47	-24
1996	7,691	60*	63	+3
1997	10,427	66	103	37
1998	20,895	95	87	-9
1999	27,690	109	77	-32

* For years with flows at or below 8578 acre-feet per year the 60 µg/L standard must be met.

For example, compliance for 1992 to 1999 would be: (-11) + 0 + 0 + (-24) + 3 + 37 + (-9) + (-32) ÷ 8 = -4.5

The total phosphorus-chlorophyll relationship developed during the Dynamic Model effort would indicate that chlorophyll would also vary with these in-lake total phosphorus values. As such, while the 60 µg/L seasonal mean total phosphorus standard would result in meeting the 15 µg/L seasonal mean chlorophyll a goal, on average, this goal will be exceeded during those years when higher inflows and loads cause the in-lake total phosphorus to rise above 60 µg/L.

4.3 Calculation of Allowable Loads Based on Future Conditions

Table 7 (Appendix I) provides a summary of predicted runoff volumes and external phosphorus loads for three conditions, current land use (1997), year 2020 land use without BMPs and PRFs, and year 2020 land use with BMPs and PRFs, called the Best Efforts Scenario. The loads and volumes were calculated based on watershed models discussed above, projected discharges from WWTP, and estimated reductions from BMPs and PRFs (see Appendix I). Total external loads are divided into point source, stormwater, and precipitation. For year 2020 land use and BMP/PRF implementation, stormwater loads are further divided into load reductions expected with BMP (average of 991 pounds) and PRF implementation (2,730 pounds).

Also shown is the recommended external TMDL (9,944 pounds) which is compared to projected external loads. The difference between the TMDL and total external loads is referred to as “residual loads”. The following observations are presented:

- Total external loads delivered to the reservoir with current development average 6,573 pounds. With year 2020 development and without BMP/PRF implementation, average loads are 10,189 pounds. With year 2020 development with BMP/PRF implementation, external loads average of 7,390 pounds. The average increase in total external loads would be 55 percent without implementation of BMP/PRF and would exceed the proposed TMDL 6 out of 10 years. With implementation of BMP/PRFs, total external loads will increase around 10 percent and the phosphorus standard would be met 9 out of 10 years.
- Calculated runoff volumes delivered to the reservoir (except for precipitation) year 2020 land use conditions could increase by 57 percent. Runoff volumes include reductions based on pumping from the alluvium. However, future pumping volumes were assumed equal to historic pumping volumes. This approach likely results in over estimate of future runoff volume.
- Both average and 71-percentile values are provided for the 10 years of analysis. The 71-pecentile represents a previous estimate of frequency of compliance with 60 µg/L in-lake, phosphorus concentrations, which

was based on only 36 percent increase in net runoff volume to the Reservoir. The lower predicted runoff volume increase of 36 percent represents a corresponding increase in pumping volume by the dischargers.

- As demonstrated by calculation of residual loads in the table, the proposed management plan (see Section 5) for the watershed will meet the TMDL 9 out of 10 years, which is based on the higher predicted runoff volume increase of 57 percent. It is likely that runoff volumes will be somewhere between the two estimates of 36 percent and 57 percent.
- The proposed load allocation of 6016 pounds represents approximately the 85th percentile of net, stormwater loads with implementation of BMPs and PRFs and a 57 percent increase in runoff volume. If the runoff volume is only 36 percent, then 6016 pounds represents the 71st percentile. With lower predicted runoff volumes of 36 percent, phosphorus concentrations in stormwater will be higher. Therefore, for conservatism, the load allocation has been based on greater than 50th percentile value.

Section 5 Implementing the TMDL Best Efforts Plan

The goal is to limit the quantity of pollutants that enter the Reservoir and to maintain watershed health through controls on loads, wasteloads, and internal loads.

The ultimate goal is to limit the quantity of pollutants that enter the Reservoir and to maintain watershed health through controls on external loads, wasteloads, and internal loads. Management of these loads will be achieved by:

- Application of alum or other suitable substance to the reservoir to reduce and control internal phosphorus loads;
- Implementation of stormwater management controls including:
  - ✓ Implementing the Cherry Creek Stormwater Regulation requiring baseline BMPs to control erosion and phosphorus discharges, and
  - ✓ Constructing facilities, called PRFs, that provide removal beyond baseline stormwater BMPs;
- Requiring discharge permits for WWTF that include limits on effluent concentrations and total phosphorus loads; and
- Continuing comprehensive water quality monitoring in the watershed and the Reservoir to ensure that water quality objectives are being met.

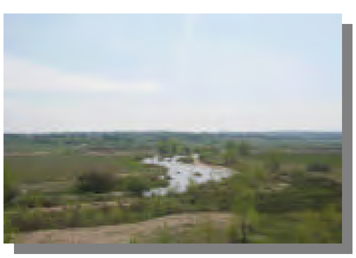
5.1 Managing Reservoir Loads

Analysis of 15 years of water quality monitoring data and new modeling suggests a TMDL of 11,944 pounds, of which 6,016 pounds are allocated to nonpoint sources (including ISDS) and stormwater. Construction phase and post-construction phase (i.e.: permanent) BMPs are to be implemented throughout the watershed to reduce external loads to load allocation amounts.

The Authority has adopted a long-range plan to manage stormwater in the watershed, with the common goal of reducing phosphorus pollutant loads delivered to the stream system and ultimately to the reservoir.

5.2 Stormwater Quality Management

The Authority has adopted a long-range plan to manage stormwater in the watershed, with the common goal of reducing phosphorus (and other pollutants) loads delivered to the stream system and ultimately to the reservoir (Appendix M). The management plan includes the following.



1. Adopted stormwater quality regulations to implement, monitor, and enforce through the land use agencies technical measures (BMPs) that control stormwater pollution during construction.
2. Adopted stormwater quality regulations to implement, monitor, and enforce through the land use agencies technical measures (BMPs) that control stormwater pollution after construction, called permanent BMP, to address impacts from residential, commercial, mining, and industrial development. The goal for all new development is to implement minimum BMPs, as specified in the regulations.

3. Implementation of PRFs that provide protection beyond BMPs. Site specific PRFs were identified as part of the Storm Drainage Quality Plan (Appendix M) and costs and phosphorus load reductions were estimated (below).

4. Implementation of in-lake management techniques, such as application of alum (or other suitable substance) to precipitate dissolved phosphorus and "seal" the phosphorus in sediment at the reservoir bottom.

5. An operation and maintenance plan to insure technical measures continue to serve their purpose.

However, ensuring good quality water throughout the Reservoir watershed requires that storm water management efforts go beyond controlling just phosphorus (Appendix N). Most BMPs mitigate for other pollutants, as well, including sediment, nitrogen, and metals. Some BMPs can also provide a net environmental benefit by improving riparian health and adding to or improving existing wildlife habitat. These types of environmental benefits are valued by local communities.

The elements of the Authority's stormwater management plan are described in further detail below.

5.2.1 Best Management Practices

BMPs are defined by the Control Regulation, 5 C.C.R. 1002-72 § 72.2(11). BMPs are any practices or a combination of practices that are effective, practicable means to prevent or control point and nonpoint pollutants at levels compatible with environmental quality goals. Practicable means includes technological, economic, and institutional considerations.

The Authority adopted Stormwater Quality Regulations related to construction activities and post-construction control of stormwater quality.

BMPs for construction and post-construction have been identified and included in the Authority's stormwater quality regulations to address impacts from residential, commercial, mining, and industrial development. The regulations also address protection of groundwater drinking supplies and stream preservation areas.

5.2.1.1 Stormwater Quality Regulations

In 1999, the Authority adopted Stormwater Quality Regulations related to construction activities and post-construction control of stormwater quality (Appendix L) . The purpose of these Cherry Creek Reservoir Watershed Stormwater Quality Requirements (Requirements) is to:

The recommended BMP requirements serve to reduce and maintain nonpoint source and stormwater phosphorus loads below their load allocation, in accordance with the TMDL.

- Recommend substantive requirements to control the quality of stormwater runoff in the Cherry Creek Basin from private and public property.

- Reduce the loads of contaminants reaching Cherry Creek and Cherry Creek Reservoir in furtherance of health, safety, and general welfare in the Cherry Creek Basin.

The recommended BMP requirements are necessary to reduce and maintain nonpoint source and stormwater phosphorus loads below their load allocation, in accordance with the TMDL set forth in the Cherry Creek Control Regulation.

5.2.1.2 Construction Erosion and Sediment Control

Control of construction erosion and sediment is the first tier of nonpoint source and stormwater protection in the watershed.

Control of construction erosion and sediment is the first tier of nonpoint source and stormwater protection in the watershed. Conventional wisdom and water quality data collected in the watershed strongly suggest that the most significant pollutant loads are generated during construction activities. The objective is to limit erosion and sediment transport from the property during the development process to no greater than undisturbed conditions. This is achieved through a combination of source reduction (e.g., minimizing exposure of disturbed land surfaces), sediment transport minimization (e.g., grass swales, terraces), and treatment of runoff (e.g., sediment ponds).

5.2.1.3 Permanent Best Management Practices

Permanent BMPs, the second tier of protection, address pollutant reduction after development is complete.

Permanent BMPs, which are the second tier of nonpoint source and stormwater protection, address pollutant reduction after development is complete. Permanent BMPs minimize pollutant generation at the source and/or retain pollutants on-site. Design criteria and standards have been prepared for permanent BMPs that have proven effective in the Denver-metropolitan area, including the following.

Permanent BMPs include...

- *Storm drainage and flood control practices*
- *Stormwater quality control practices*
- *Industrial BMP requirements*

- Storm drainage and flood control practices. The UDFCD has developed standards and criteria for design, construction and maintenance of storm drainage facilities (Urban Storm Drainage Criteria Manual, Volumes 1 and 2). These BMPs include flattened, grassed slopes for channels, check structures to control channel grade, and detention facilities to reduce post-developed peak flows rates to pre-developed peak flows rates. Local jurisdictions have adopted and implemented these standards, which is the first step to minimizing erosion during minor and major storm events.

- Stormwater quality control practices. The UDFCD also developed standards and criteria for design, construction and maintenance of stormwater quality facilities (Urban Storm Drainage Criteria Manual, Best Management Practices, Volume 3). Those BMPs in Volume 3 that capture and treat the 80th percentile storm meet the Authority's goal to remove approximately 50 percent of the phosphorus generated by development and have been adopted by the Authority. These BMP include "wet" and "dry" detention ponds, constructed wetland basins, detention basins with sand filters, and other combinations of detention with filtration. See Appendix L for more detailed discussion.

- Industrial BMP requirements. Additional requirements are placed on all industrial activities within the watershed. Categories of industry include the five categories established by the Colorado Division of Public Health and Environment (CDPHE): "light industrial", "heavy industrial", metal mining, auto recyclers, sand and gravel mining. The Regulations also include the remaining industrial activities, as defined by the Standard Industrial Classification (SIC) code. In addition to the stormwater quality control practices discussed above, industrial facilities are required to include source reduction, exposure reduction, and emergency plans for spills and leaks in their BMP plans.

5.2.1.4 Protection of Groundwater Drinking Supplies

The Cherry Creek alluvium as an important water source, and the Authority has been very proactive in protecting drinking water. The Authority has applied a variety of measures aimed towards groundwater protection, including:

- Ultraviolet treatment,
- Effluent limits,
- Evaluation of new AWT technologies that reduce phosphorus without increasing sulfates and chlorides (current side effects from sulfate or ferric chloride application),
- Implementation of comprehensive groundwater and stormwater quality monitoring programs to observe trends, and
- Implementation of stormwater BMPs that remove sediments and contaminants capable of settling.

In addition, BMPs that have the potential to impact groundwater supplies through enhanced infiltration must incorporate the following design considerations.

- Minimum Setback from Drinking Water Wells.
- Minimum Separation from Water Table.
- Prohibition from Wellhead Protection Areas.
- Consideration of Impermeable Barriers.

These requirements, which compliment the requirements of the Safe Drinking Water Acts, Source Water Assessment Planning, are discussed in more detail in Appendix L.

5.2.2 Pollutant Reduction Facilities

PRFs, the third tier for nonpoint source and stormwater protection in the watershed, provide levels of protection beyond permanent BMPs for development.

They are located to take advantage of opportunities to enhance water quality in the watershed.

"Controls to Reduce Watershed Loading" describes a range of measures to reduce pollutant loading from nonpoint sources and stormwater within the Reservoir lower watershed (Appendix N). As a first level of control, baseline BMPs are applied throughout the watershed during construction and on a permanent basis (above). In addition, the Authority has implemented PRFs, which go beyond baseline BMPs to further reduce pollutant loading. The pollutant reductions associated with the PRFs have been incorporated into a watershed-based Trading Program within the Cherry Creek watershed.

PRFs are the third tier for nonpoint source and stormwater protection in the watershed. PRFs provide levels of protection beyond permanent BMPs for development and PRFs are located to take advantage of opportunities to enhance water quality in the watershed. Baseline BMPs must be implemented and operating effectively within the sub-basin served by a PRF before credits may be considered for the PRF under the Cherry Creek Trading Program. Specific objectives of PRFs include the following:

- To increase or enhance the level of treatment from baseline BMPs within a specific sub-watershed of Cherry Creek, and
- To protect stream corridors within the Reservoir watershed, while enhancing water quality protection.

5.2.2.1 Description of Existing PRFs

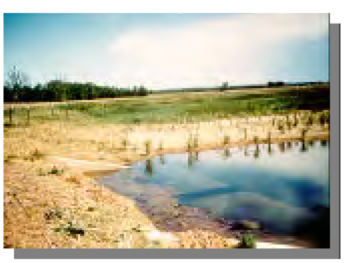
The Authority has constructed and is operating, maintaining, and monitoring several major PRFs in the Cherry Creek watershed, as shown in Figure 5-1: Shop Creek (1990), Quincy Outfall (1996), Cottonwood Creek (1997), East Side Shade Shelter (1996). These initial PRFs, which are described below, are included in Phase I of the Trading Program. The Authority has also recently constructed (1999) additional improvements along the north shore, called Tower Loop/Dixon Grove project. In addition, the Cottonwood/Peoria Street project in the southwest part of the Park is in the final design stages.

Prior to constructing these projects, the Authority estimated their phosphorus removal efficiencies. Since their construction, the Authority has regularly monitored the projects to determine actual removal rates. The Authority will continue to track these facilities to monitor phosphorus and other pollutant removal capabilities. Additional information about the PRF effectiveness calculations is included in Appendix N.

5.2.2.1.1 Shop Creek

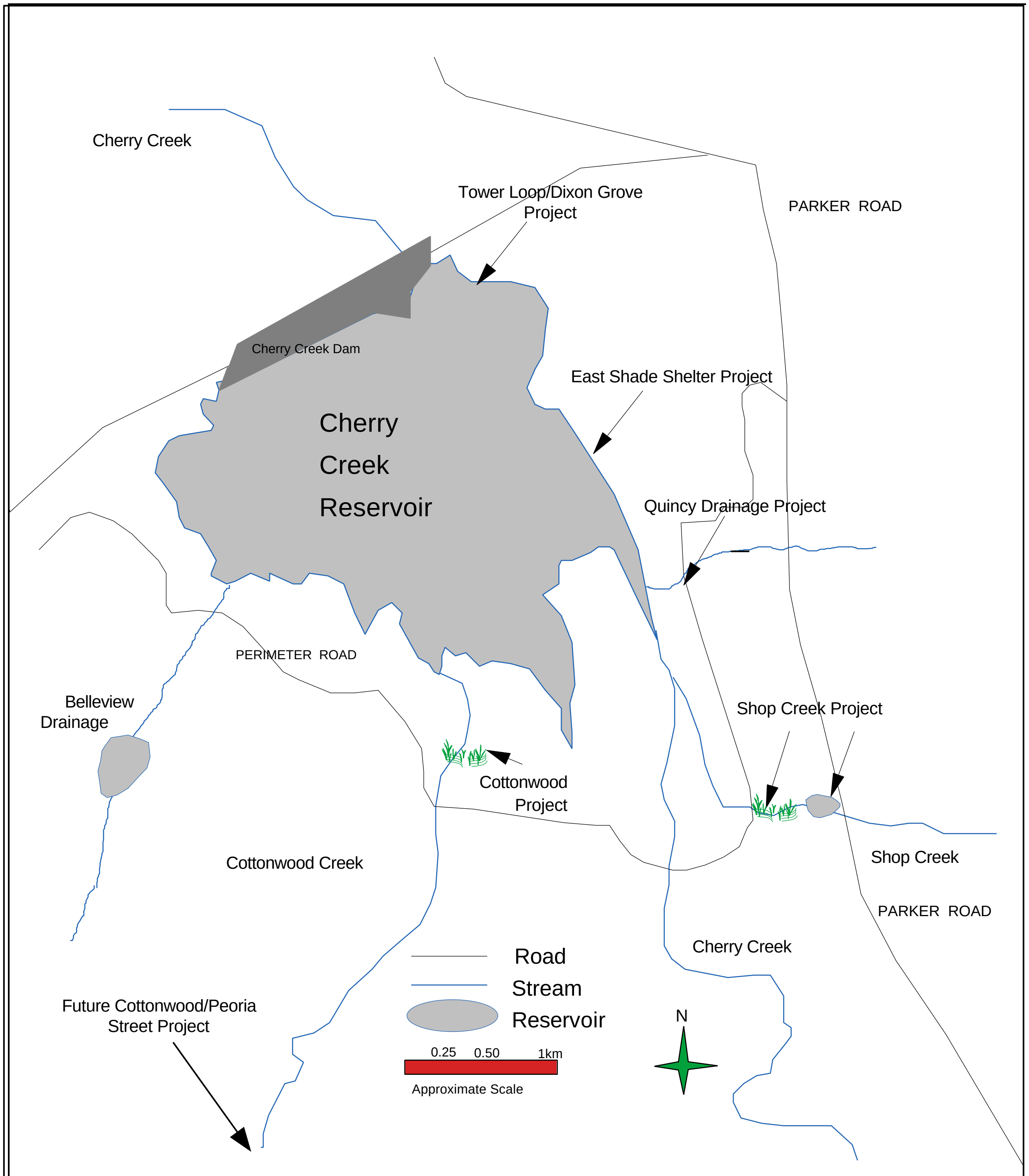
The purpose of the Shop Creek PRF is to slow storm runoff and base-flows from its 725-acre drainage area, allowing suspended particles to be filtered and to settle. Therefore, phosphorus, which is adsorbed to the suspended sediment, is also removed from the water column. The series of seven wetland ponds that follows the initial retention pond at Shop Creek further controls and polishes flows and allows for infiltration to groundwater. At times, according to the natural processes that occur in wetlands, phosphorus is removed from the water column as it moves through the wetland system. At other times, phosphorus can be introduced into the system. While this cyclical phenomenon has been documented for individual sampling events, the Shop Creek PRF has always shown an annual net removal of phosphorus.

5.2.2.1.2 Cottonwood Creek/Perimeter Road



The Cottonwood Creek PRF (at Perimeter Road) is essentially the same type of facility as the Shop Creek PRF with the purpose of slowing storm runoff and base-flows. However, the initial retention basin for the Cottonwood Creek PRF is much larger than the Shop Creek facility's initial retention basin, to accommodate the additional runoff volume that results from its much larger drainage area, which is 7,500 acres. A second modification from the Shop Creek design is that the Cottonwood Creek

Figure 5-1. Location of Pollutant Reduction Facilities in Cherry Creek State Park



Pollutant Reduction Facilities (PRFs) at Cherry Creek

PRF is followed only by a single wetland for polishing, due to its proximity to the Reservoir.

5.2.2.1.3 Quincy Drainage

The purpose of the Quincy Drainage PRF is to contain base-flows and slow storm runoff by allowing rapid infiltration into the sandy soils at the terminus of this 530-acre drainage area. Captured runoff quickly infiltrates into the sandy alluvium where it is detained behind the downstream berm at the Quincy facility. Native grasses that are typical of a semi-arid climate populate the pond. Typically, no surface flow exits the Quincy Drainage PRF during base-flow conditions. Outflow during precipitation/runoff events has been very limited, based on existing data.

5.2.2.1.4 East Side Shade Shelter, Tower Loop and Dixon Grove

Tower Loop –
Pre-shoreline Stabilization

The East Side Shade Shelter, Tower Loop, and Dixon Grove PRF differ from the other three PRFs in its design and purpose. These PRFs were constructed as a demonstration project to determine the effectiveness of shoreline stabilization. The projects are located on the Reservoir shore immediately adjacent to popular access areas for fishing and picnics within Cherry Creek State Park.

Tower Loop –
Shoreline Stabilization

Improvements at all sites involved controlling pedestrian access, rerouting erosive storm drainage, grading and stabilizing steep banks, and stabilizing the shorelines, such as with rock toe or willow plantings, or bio-logs. These improvements have provided for water quality enhancement by controlling erosion (with attached pollutants) using measures to minimize bank erosion, control pedestrian access, and infiltration of parking lot runoff. Adjacent to the picnic area at East Shade Shelter is a paved parking lot that has historically drained directly into the Reservoir. Storm runoff is captured in wetland filter areas before seeping into the lake. In addition, the improvements created an amenity for park users.

5.2.2.1.5 Cottonwood/Peoria Street

The Cottonwood/Peoria Street project, which is in progress, is a portion of the facilities recommended in the Lower Cottonwood Creek Water Quality Plan (CH2Mhill 1996). The project consists of a large water quality (11.6 acre-feet) and quantity pond (31.5 acre-feet) constructed upstream of the improved Peoria Street embankment. The project also includes reaches of stream stabilization upstream and downstream of the pond.

5.2.2.2 Storm Drainage Quality Plan

The Quality Plan serves to direct investments in capital projects and provides the basis to implement PRFs.

The Cherry Creek Reservoir Storm Drainage Quality Plan (Quality Plan) was approved by the Authority to direct investments in capital projects. The Quality Plan provides the basis to implement PRFs that reduce external phosphorus loads into Cherry Creek Reservoir (Appendix M). The Quality Plan specifically:

- Identifies potential phosphorus-reduction technologies,
- Identifies sites for potential PRF projects,

- Applies evaluation criteria to screen ten potential priority projects,
- Presents conceptual design of priority projects,
- Estimates probable construction and maintenance costs for projects,
- Estimates expected phosphorus loads and potential removal rates for projects, and
- Provides recommendations for prioritization and implementation of projects.

Those facilities offering the best performance at a reasonable cost were adopted by the Authority for their long-range capital improvement program.

5.2.2.2.1 Analysis of Potential Projects

43 potential PRF sites were identified throughout the watershed, and a conceptual design was prepared for the 10 most effective projects.

The first priority is in-lake alum application to control internal phosphorus, then implementation of one or more of the watershed projects to control external phosphorus sources.

Forty-three potential PRF sites were identified throughout the watershed from Castlewood Canyon to Cherry Creek State Park. A conceptual design was prepared for the 10 most effective projects, which included sizing of required facilities, and estimating phosphorus loads, potential load reductions, and annualized capital and operation and maintenance (O&M) costs. These projects were then prioritized and placed in three groups, with the highest rated projects included as Group 1 (Table 5-1). In all cases, the first priority is in-lake alum application to control internal phosphorus, then implementation of one or more of the watershed projects to control external phosphorus sources. Significant findings of the investigation are:

1. In-lake alum application and in-stream alum injection are the two most cost effective technologies investigated to reduce internal and external phosphorus loads, respectively.
2. Retrofit of ACWWA Pond L-3 (Project No. CCB-7) and CCSP Wetlands (Project No. CCB-1) are the two most cost effective natural system technologies investigated to reduce external phosphorus loads.
3. The range of cost per pound of phosphorus removed by project varies from $10 to $1,658 assuming cost sharing. This range of unit costs for most promising projects is reduced, when cost sharing opportunities are considered. In addition, opportunities to include water quality facilities with drainage quantity projects in progress can also reduce costs to the Authority.
4. Projects CCB-8 and CCB-9 in Group 3 show promise to enhance current technology of phosphorus removal. These projects (including CCB-2) are not recommended at this time until additional information regarding performance and cost are obtained.

Table 5-1. Priority Grouping of Pollutant Reduction Facilities				
Priority Group Number	**Project Designation**	**Pounds of Phosphorus Removed**	**Project Title**	**Comment**
n/a	**CCB-3**	**n/a**	**In-lake Alum Application**	Recommended as a management component for all watershed PRFs.
Group 1	CCB-4	580	In-stream Alum Injection	Address design and implementation issues.
	CCB-1	630	CCSP Wetlands	Represents the best natural technology to remove dissolved phosphorus
	CCB-7	94	ACWWA Pond L-3 Retrofit	Best opportunity for retrofit project
Group 2	CCB-5	180	Cherry Creek Stream Stabilization	Best opportunity for cost sharing
	CCB-6	1566	Piney Creek Stream Stabilization	Good opportunity for cost sharing
	CCB-10	72	Newlin Gulch Stream Stabilization	
Group 3	CCB-8	85	Limestone Filter Bed	Promising technology
	CCB-9	117	ACWWA Pond W-8 Retrofit	
	CCB-2	380	CCSP Storage	Not recommended

5.2.2.2.2 Recommended Pollutant Reduction Facilities

Table 5-2 summarizes the recommended PRF facilities to meet the TMDL goals discussed in Section-4, Future Conditions. Table 5-2 includes in-lake management, Group 1 and Group 2 projects from Table 5-1, as well as “other projects”. “Other projects” include facilities listed in the Quality Plan master-list of potential projects (Appendix M).

Projects CCB-3, CCB-4, and CCB-1 are located within Cherry Creek State Park and CCB-7 is within Cottonwood Creek. These projects are within Segment 0 of Cherry Creek and have the highest IDR, therefore, the greatest reduction in total phosphorus delivered to the Reservoir. However, projects CCB5, CCB-6, and CCB-10 are further up the watershed in Segment 1 and several facilities in the “other” category are located in Segment 2, which extends upstream to Castlewood Canyon. This distribution of projects illustrates the Authority’s commitment to the entire watershed, while balancing the economics associated with projects closer to the Reservoir.

Table 5-2 shows that with implementation of all facilities, external loads to the reservoir (i.e.: not including in-lake management), phosphorus loads to the reservoir would be reduced by 2,730 pounds by PRFs on an average annual basis, assuming all of the assumptions of the PRF are met. Load reductions take into account load-allocation, in-stream delivery ratios (Section 4). Capital costs for all projects is estimated at $17,394,000,with the Authority’s portion $7,290,000. Annual costs for the Authority are estimated at $619,800, which includes capital, capital replacement, and operations/maintenance. Recommended facilities are described in further detail below.

Table 5-2. Summary of Recommended Pollutant Reduction Facilities

Project Designation	Description	Phosphorus Removed (pounds)			Project Costs		Equivalent Annual [4] (dollars)	Unit Cost (dollars/pound)
					Capital Costs			
		(at site)	IDR	(at Reservoir)	Total (dollars)	Authority Portion (dollars)		
CCB-3	In-lake Alum Application	2000	1	2000	104,000	104,000	19,000	10
CCB-4	In-stream Alum Injection	580	1	580	170,000	170,000	32,000	55
CCB-1	CCSP Wetlands	630	1	630	1,260,000	1,260,000	117,000	186
CCB-7	ACWWA Pond L-3 Retrofit	94	0.68	64	185,000	185,000	20,000	313
CCB-5	Cherry Creek Stream Stabilization [2]	180	0.17	31	4,893,000	978,600	32,400	1,059
CCB-6	Piney Creek Stream Stabilization [1, 3]	522	0.46	240	5,915,000	1,479,000	59,300	247
CCB-10	Newlin Gulch Stream Stabilization [3]	72	0.17	12	1,112,000	278,000	20,300	1,658
n/a	Other facilities			1273	3,755,000	2,835,500	319,800	251
	Sub-Total			**4830**	**17,394,000**	**7,290,100**	**619,800**	**128**

1 Assumed 1/3 of stream stabilization, costs, and phosphorus reduction.

2 Assumed 20 percent participation by the Authority.

3 Assumed 25 percent participation by the Authority.

4 For Authority portion, includes capital, capital replacement, and annual O&M costs at 7 percent.

- In-lake Application

  This project consists of applying an alum solution over the portion of the lake greater than 5 feet in depth. Alum (aluminum sulfate) at considerably higher concentrations is regularly used at water treatment plants to clarify drinking water and at WWTPs to remove phosphorus. In lakes, alum controls algae by reducing the amount of phosphorus available for uptake by algae in the water column by preventing the release of phosphorus from sediments. On contact with water, alum forms an aluminum-hydroxide precipitate called a floc. The floc reacts with phosphorus to form a compound, which is insoluble in water (under the condition found in Cherry Creek Reservoir) and generally not available for algae growth. As the floc settles, some particulate phosphorus is also removed by collecting suspended particles in the water column, leaving the lake clearer immediately after application. On the lake bottom, the floc forms a layer blocking release of phosphorus from the sediment.

- In-Stream Injection

  This project consists of injection of a micro-flocc alum solution into Cherry Creek just upstream of the perimeter road (Figure 6-7 in Appendix M). See in-lake application for description of how alum controls phosphorus.

- CCSP Wetlands

  The project is located within Cherry Creek State Park at the upstream end, where the creek has a long, left-hand bend (Figures 6-1 and 6-2 in Appendix M). Water is diverted from the Creek using a shallow well and distributed to a 37-acre wetland field by irrigation pipes and lateral distribution ditches.

- ACCWWA Pond L-3 Retrofit

  This project consists of modifying the existing ACWWA stormwater detention pond L-3 located upstream of Caley Avenue on Lone Tree Creek (Figures 6-13 and 6-14 in Appendix M). The detention pond was constructed as a dry detention basin with some wetlands in the bottom to mitigate for construction impacts. Modifications would create a constructed wetland basin, in accordance with Volume 3 (UDFCD, 1999).

- Cherry Creek Stream Stabilization

  This project consists of stabilizing the stream channel and bed from Arapahoe Road to the Douglas/Arapahoe County line, in accordance with the approved master plan (Figures 6-9 and 6-10 in Appendix M). Facilities include construction of approximately 10,700 feet heavy and light riprap revetments to hold the main channel banks in place.

- Piney Creek Stream Stabilization

  This project consists of stabilizing the stream channel and bed from the confluence with Cherry Creek to the upstream limits, including tributaries (Figures 6-11 and 6-12 in Appendix M). Requirements for stream stabilization are identified in the approved master plan. The total length of the project is 17.4 miles, but for the master plan, it is assumed that 1/3 of the total length would be stabilized by the year 2020.

- Newlin Gulch Stream Stabilization

  This project consists of stabilizing the stream channel and bed from the confluence with Cherry Creek to Jordan Road crossing. Requirements for stream stabilization are identified in the approved master plan. The total length of the project is 4,200 feet.

- Other Projects

  In addition to those projects described above, several additional projects were evaluated for phosphorus removal and cost specifically at the request of the City of Greenwood Village. These projects, which were identified in Appendix M, include other large detention facilities, additional stream bank stabilization, filtration, and enhanced treatment using calcium precipitation. Preliminary costs were identified and phosphorus reduction capabilities estimated, including effects of in-stream delivery ratios. These projects represent other facilities that the Authority should include in its priority list at some future date.

5.2.2.2.3 Watershed Based Trading Program

The Phosphorus Trading Program allows point source dischargers to receive credit for new or increased phosphorus WLAs in exchange for phosphorus load reductions from PRFs.

The Phosphorus Trading Program allows point source dischargers to receive credit for new or increased phosphorus WLAs in exchange for phosphorus load reductions from PRFs (Appendix O). The Trading Program provides for two types of trades, (1) Authority Pool trades and (2) In-Kind trades. Only PRFs that remove phosphorus beyond minimum BMPs will qualify for trading.

Authority Pool trades are premised upon a Trading Pool of discharge credits from Authority controlled nonpoint source projects. The Trading Pool has 461 pounds from the four largest and most well established nonpoint source projects - Shop Creek, Cottonwood Creek, East Shoreline and Quincy Outfall.

Dischargers who wish to purchase credits from the Trading Pool must demonstrate:

- The allocation requested complies with the allocation criteria, including the treatment levels, delivery ratios and return flow factors.
- The allocation is necessary to serve increases in wastewater flows projected through 2010.
- The allocation promotes consolidation of WWTPs or supports a WWTP for an area that cannot efficiently and economically be served by existing WWTPs.
- Allocating the WLA now is appropriate given the timing and schedule for the facilities.
- The allocation will not preclude other dischargers within the watershed from securing increased allocations necessary to provide service through 2010.Immediate need for the credits, such as historic growth, per capita projections, and total projected flows.
- WWTP expansion is or will be within Master Plan.
- Status of implementation of stormwater ordinance.

Appendix O, “Phosphorus Trading Guidelines”, provides more detail on the trading program.

5.2.2.2.4 Other Possible In-lake Control Strategies

Initial in-lake controls should concentrate on controlling phosphorus release and cycling within the lake, since the Expert Panel appears to have a desire to bring the lake into a phosphorus-limiting condition. The Authority is evaluating other lake management options, such as bio-manipulation of biota by eliminating zooplankton-eating fish or addition of predator species. This is an indirect, more labor-intensive approach to minimize chlorophyll, whose benefit is somewhat supported by published data. To be effective, this management strategy would need to be used annually.

5.2.2.2.5 Other Possible Watershed Control Strategies

Total phosphorus concentration in groundwater averages from 0.15 mg/L to 0.25 mg/L, depending on location in the watershed (Appendix B). Discharges from WWTP are required to have total phosphorus concentrations no greater than 0.05 mg/L for direct discharges and 0.2 mg/L for land application (see Section 5.3 below). Water that is pumped from the alluvium then discharged to the watershed through a WWTP will contain less phosphorus and, therefore, total phosphorus loads to the Reservoir will be reduced by pumping and treatment.

Currently, this reduction in phosphorus loads by water providers is recognized and accounted for in the calculation and application of the in-stream delivery ratios for load allocations (WLA/IDR see Section 4). Provided the WLA/IDRs are maintained at current levels, future increases in alluvial pumping, followed by discharge through a WWTP can be considered a PRF, since phosphorus loads in the watershed will be reduced.

Municipal pumping from the alluvium has averaged around 5,400 acre-feet per year (Section 4.1.2) with some projections of future pumping reaching 10,000 acre-feet per year. Assuming return flows from the Pinery WSD, which averaged 36 percent, are representative of the watershed, then for every 1,000 acre-feet of water pumped from the alluvium, approximately 360 acre-feet of water is returned to the stream system. If the return flows are pumped at 0.2 mg/L phosphorus and discharged at 0.05 mg/L phosphorus, the load reduction (at the point of discharge) would be approximately 150 pounds of phosphorus per year.

The load reduction to the Reservoir would be the product of the appropriate WLA/IDR and the pounds of phosphorus at the point of discharge. For example, if the Cottonwood WSD increases its pumping by 1,000 acre-feet per year, the reduction in phosphorus load to the Reservoir would be approximately 80 pounds (i.e.: 150 pounds times WLA/IDR of 53 percent). If the Pinery WSD increases its pumping by 1,000 acre-feet per year, the reduction in phosphorus load to the Reservoir would be approximately 43 pounds (i.e.: 150 pounds times WLA/IDR of 29 percent).

5.3 Managing Point Sources

All WWTFs provide advanced phosphorus removal either through tertiary treatment or secondary/tertiary treatment followed by land application. Permitted phosphorus concentration of land application is 0.2 mg/L. This revised proposal recommends a more stringent phosphorus concentration for direct dischargers of 0.05 mg/L.

The Colorado Discharge Permit System (CDPS) permits for basin discharges require monitoring of phosphorus discharged, regardless of disposal method. In addition to monitoring phosphorus and operating within annual poundage requirements, direct discharges are also required to sample Cherry Creek and the alluvium up gradient and down gradient of their discharge points. Dischargers that land apply effluent monitor and measure phosphorus loading with the use of lysimeters.

5.3.1 Service Areas

Existing and potential service areas for existing districts are shown in Appendix J. As proposed, developments requesting to be removed from the existing service area would require a major amendment to the Cherry Creek Master Plan. Potential service areas for each WWTF may overlap with other facility service areas. A minor amendment to the Plan is required to annex to an existing WWTF.

5.3.2 Wasteload Allocation

The 2000 WLA was determined by designating existing WWTFs, defining future allocations, and apportioning the phosphorus among dischargers.

The 2000 WLA was determined by designating existing WWTFs, defining future allocations (plant expansions and discharge projections), and apportioning the phosphorus among dischargers. The WLA also takes into consideration major new developments in the basin, such as prospective development by Rangeview Metropolitan District and the Canyons. WLAs must be equitable to existing and future discharges, and meet water quality standards for the predicted 20-year planning period. Therefore, the 2000 WLA is 2,280 pounds.

As wastewater flows increase, dischargers will be required to reduce phosphorus concentrations from 0.2 mg/L total phosphorus to 0.05 mg/L total phosphorus to comply with their load allocations. Future allocations of 1,411 pounds may be allocated to any existing discharger for expansions or new facilities or facilities serving new areas. Allocations from the future allocation pool must also be based on 0.05 mg/L total phosphorus for direct dischargers and land disposal and 0.1 mg/L total phosphorus for land application. As shown in Table 5-3, current allocations are comprised of existing discharges totaling 869 pounds. Future WLAs of 1,411 pounds include expansions of existing facilities, new development, industry and mining. The WLA assumes a more stringent effluent limit of 0.05 mg/L for phosphorus for direct dischargers to Cherry Creek and its tributaries and 0.2 mg/L for land application.

Table 5-3. Current Total Phosphorus Allocations

Dischargers	Total Annual Phosphorus Load to Reservoir
ACWWA / Cottonwood W&SD	285
Pinery W&SD	90
Inverness W&SD	120
Meridian W&SD	114
Parker W&SD	177
Stonegate Center W&SD	82
Direct TV	2
Current Allocations	869
Future Allocations [1]	1411
Total Wasteload Allocation	2280 pounds

[1] Includes expansions of existing WWTPs, new facilities such as Castle Rock, Aurora, The Canyons, Rampart Range and Rangeview, ISDS, new industry, or mining discharges.

5.4 Monitoring and Enforcement

5.4.1 Point Sources

Incorporating the phosphorus allocation into discharge permits is the vehicle by which the WQCD can enforce the phosphorus control program and have the guarantee that a discharger is in compliance with the basin-wide allocation program. The NPDES permits for Basin dischargers require monitoring of phosphorus discharged, regardless of disposal method. Phosphorus contributions by the individual plant operators are reported to the WQCD and the Authority.

Land application facilities applying effluent at agronomic rates have consistently achieved "zero" discharge. Land application facilities monitor phosphorus loading with the use of lysimeters. Many land application facilities also demonstrate down-gradient capture capacity (such as detention/retention facilities followed by wetlands), thereby providing additional water quality protection.

5.4.2 Nonpoint Sources

Due to the broad scope of nonpoint sources in the Cherry Creek basin, several programs have been in progress, including reservoir and watershed monitoring, regulations for stormwater controls, monitoring of ISDS's, and public education/outreach programs.

5.4.2.1 Annual Watershed and Reservoir Monitoring

Monitoring programs will continue to ensure that water quality standards and allowable loads are not exceeded. Data collected will also be used to further verify IDRs and refine models used for the Reservoir and watershed. The monitoring program for the Cherry Creek mainstem upstream of the Reservoir is summarized in Appendix B.

5.4.2.2 Drinking Water Quality Protection

To protect drinking water quality, several constituents have been monitored for trends and recommendation is to continue monitoring. These constituents are discussed below.

5.4.2.2.1 Nitrogen

While there appears to be a measurable input of nitrate-nitrogen concentrations (approximately 0.5 mg/L to 10 mg/L) in portions of the study reach, concentrations are still well below drinking water standards of 10 mg/L and the trend is not of consistently increasing concentrations. Nitrate-nitrogen concentrations should continue to be monitored to evaluate if the trends become more pronounced with time and to evaluate if concentrations are generally increasing at specific locations within the study reach.

5.4.2.2.2 Sulfate

While sulfate was not a principal concern related to protection of Cherry Creek Reservoir, it has been monitored in this water quality program as an indicator of impacts from wastewater discharges (Appendix B). A linear regression of sulfate concentrations indicates a significant increasing trend from the upstream end to the downstream end of the study reach. So while dischargers continue to reduce phosphorus loads with addition of aluminum sulfate, concentrations of sulfate rise due to the chemical addition in AWT processes. Authority members will continue to work towards an appropriate balance of phosphorus reduction that does not compromise sulfate concentrations in the watershed.

Sulfate concentrations are still below the drinking water standard (250 mg/L). However, concentration increases throughout the study reach (from 50 mg/L to 125 mg/L) warrant continued monitoring for this parameter, as well as evaluation of treatment methodologies to produce both acceptable phosphorus and sulfate concentrations in WWTP effluent.

5.4.2.2.3 Chloride

Chloride has been monitored in the baseline study for similar reasons as sulfate, as a potential indicator of impacts from direct discharges from WWTP as some dischargers use ferric chloride in their AWT processes to reduce phosphorus loads. There appears to be a trend of increased chloride concentrations in the study reach in surface water (from approximately 15 mg/L to 35 mg/L), although there is a corresponding decline in chloride concentration in ground water. While the chloride concentrations in the study reach do not currently indicate significant impact from wastewater discharges, chloride should be monitored to evaluate future trends as wastewater discharges increase and to find the delicate balance between phosphorus reduction and chloride concentration.

5.4.2.2.4 Coliforms

The baseline study has indicated the presence of total (141 to 1678 counts per 100 mL) and fecal coliforms in the surface water. However, there have been no measured total coliform counts in the ground water that are indicative of bacteria or virus movement through the soil matrix. The water quality data base from municipal water suppliers indicates that these supplies are not impacted by total coliform counts currently being observed in surface water. Given direct discharge effluent concentrations ranging from 2 to 22 counts per 100 mL, it is obvious that direct discharges provide only a minor component of the coliform counts in Cherry Creek. It is believed that the bulk of the coliform counts being observed are related to ranching operations south of Castlewood Canyon, as some of the highest counts occur at the furthest upstream monitoring station.

5.4.2.2.5 Metal Ions

Two metal ions which are secondary drinking water standards (i.e.: iron and manganese) have been identified at elevated concentrations in the watershed. These ions are typically found in clay minerals. When iron-bearing minerals, such as hematite, magnetite, siderite and pyrite are found in a saturated zone or sediments in a stream channel, iron can be transported either in a dissolved or suspended state. The presence of iron and manganese concentrations in the upper Cherry Creek watershed appears to be naturally-occurring phenomenon related to the presence of minerals in the soils, and is not related to any anthropogenic activity in the basin.

5.4.2.2.6 Gross Alpha Activity

Gross alpha activity is relatively consistent, with a slight increasing trend in surface water and a more variable trend in ground water. As is the case with metal ions, it is believed that the gross alpha activity measured at surface and ground water monitoring stations is related to naturally occurring elements and is not related to any anthropogenic activity in the basin.

5.4.2.2.7 Trihalomethanes

To date, no detectable levels of chloroform, used to evaluate the potential formation of trihalomethanes (THMs), have been observed in either the surface or ground water. All dischargers in the watershed currently implement or are proposing to change from chlorination to ultraviolet disinfection, which should further reduce potential formation of THMs.

5.4.2.3 Stormwater Quality Regulations

Jurisdictions in the watershed will be requested to adopt stormwater quality ordinances, such as the Stormwater Quality Control Model Regulation (Regulation) developed by the Authority (Appendix L). To date, the City of Greenwood Village and the City of Aurora have adopted the stormwater quality ordinance. The Regulation controls the quality of stormwater runoff from private and public property to reduce the loads of sediments and nutrients reaching Cherry Creek and the Reservoir with particular restrictions to stream preservation areas in the watershed. The standards and controls set forth in the Regulation are necessary to reduce and maintain phosphorus from nonpoint and stormwater sources below the load allocation. As previously described, the Regulation requires that all permanent BMPs provide a water quality capture volume designed to capture and treat, at a minimum, the 80th percentile of small and frequent storms.

Land use agencies within the watershed take primary responsibility of controlling nonpoint sources through their own programs, however the Authority provides BMP monitoring and enforcement within the Reservoir watershed as follows.

- Stream Preservation Areas. Additional BMPs, over and beyond permanent BMPs, are required for all land disturbances within Stream Preservation Areas. Stream Preservation Areas include the Reservoir, direct flow areas to the Reservoir, all of Cherry Creek State Park, drainage and discharge to the park within 100 feet of the park boundary, lands overlying the Cherry Creek alluvium and all lands within 100 yr. flood plain.

- Construction Erosion and Sedimentation Control. Representatives of the Authority will monitor construction sites on a limited basis to identify and report violations of the erosion and sediment control plan to the local jurisdiction.

- BMP Performance. Specific BMPs will be monitored to determine or verify their pollutant removal effectiveness. These data can be used to refine design requirements, verify trading requirements, and test new BMP technology

- BMP Implementation. Representatives of the Authority will monitor BMP implementation through reviews of development drainage reports, as a referral agency for each land use jurisdiction. Some monitoring will occur in the watershed on a limited basis to verify that BMPs are implemented per approved plans.

The Authority will assist local land-use jurisdictions with presentations of Regulations to their appropriate boards and councils to facilitate review and adoption.

5.4.2.4 Water Quality Impacts from ISDS and Leach Fields

The Authority does not allow for construction of ISDS in stream preservation areas, due to potential water quality impacts.

The Authority does not allow for construction of ISDS's in stream preservation areas, due to potential water quality impacts. In 1997, the Authority evaluated the potential impact of ISDS's on water quality in the upper Cherry Creek Basin and ultimately to the Reservoir. The Authority conducted the study to:

- Identify potential movement of discharges from ISDS's,

- Determine whether phosphorus and nitrogen species are assimilated through geochemical or biochemical processes, and

- Determine whether these species are transported down-gradient into the mainstem Cherry Creek system (Halepaska, 1998).

Bayou Gulch and Baldwin Gulch, located in the upper Cherry Creek watershed, were selected for the study. These sub-basins were selected due to reliance by development on ISDS's and leach fields for wastewater treatment. Four monitoring well locations were selected in Bayou Gulch to evaluate water quality effects from two separate areas, and then to evaluate water quality changes in the alluvial aquifer as discharges mix with native water and move down-gradient. Similarly, monitoring wells have been located in the Baldwin Gulch alluvial aquifer to monitor down-gradient water-quality impacts from leach fields.

The monitoring wells were installed in mid-August 1997 and initial samples were collected in conjunction with the August 1997 Phase I sampling. Comparing phosphorus data from the Bayou Gulch and Baldwin Gulch monitoring wells to data collected on the mainstem of Cherry Creek, phosphorus concentrations are consistent with background phosphorus data.

Similarly, nitrate-nitrogen data for the Bayou Gulch monitoring wells show a trend of elevated concentrations at the upstream monitoring wells (BG-1 through BG-3), while background concentrations have been observed at the furthest downgradient monitoring well (BG-4). This is likely related to dilution, and possibly nitrogen uptake, as there is a high water table in this area. Conversely, nitrate-nitrogen concentrations in Baldwin Gulch are relatively elevated in the data obtained to date from BD-2. It appears that some of the nonpoint nitrate-nitrogen load identified in the mass balances may be attributable to ISDS's in this area.

More detail on the study is found in Appendix Q

5.4.2.5 Public Education and Outreach

The Authority has undertaken a public information program. Since 1996, the program has been involved in the following activities:

- Participated in information programs for general public about water quality in the Upper Cherry Creek Basin, such as through signage of projects in the Cherry Creek State Park.
- Conducted a one-day symposium: Stewardship of the Cherry Creek Watershed and its Reservoir on October 15, 1999. Topics covered included watershed dynamics, impacts and issues, stakeholder activity panel, and other related front-range issues.
- Conducted a User Survey which evaluated park users opinions about the Reservoir water quality.
- Published newsletters and brochures for those that live or recreate in the basin.
- Awarded a grant through the Water Environment Research Foundation (WERF) that demonstrated the environmental benefits of watershed based trading. Through this grant the Cherry Creek watershed has received national recognition.
- Conducted an Authority board sponsored workshop on the Master Plan update that included ex-officio members and the public.
- Provided outreach to interested environmental groups, such as the Sierra Club.

The education and outreach program will continue to identify future areas to further educate the public on water quality protection in the watershed.

5.4.2.6 Operations and Maintenance

Each pollutant reduction facility must continue to remove phosphorus over a long period. Therefore, economy and ease of maintenance are important considerations when planning and designing a PRF. Future PRF will be designed with the following objectives:

- Maintain physical integrity and proper hydraulic function of the structure.
- Provide access for maintenance equipment.
- Avoid creating nuisances, such as insect infestation and odors.
- Include features that promote safety and convenience of the public.
- Address aesthetic and recreation requirements.

The Authority is currently developing a detailed operations and maintenance plan for existing and future PRF, which will identify specific activities, frequency of maintenance, capital replacement requirements, and costs for budgeting purposes.

5.5 Future Cooperative Programs and Capital Improvement Projects

The Authority supports the enhancement of BMPs by additional features through a cooperative enhancement program, some of which could be classified as PRFs after modification.

Because development in the Cherry Creek basin is occurring in relatively large tracts (i.e.: greater than 100 acres and often several hundred acres), baseline BMP requirements often result in relatively large facilities. Some of these facilities are located in areas where performance could be enhanced by additional BMP features, such as adding wetland channels downstream of a detention site. The Authority would like to take advantage of these opportunities through a cooperative enhancement program, some of which could be classified as PRFs after modification.

The Authority is also investigating benefits of increased alluvial pumping on phosphorus loads delivered to the Reservoir. Pumping from the alluvium directly effects runoff volume (and phosphorus loads) delivered to the Reservoir, both of which can have an effect on Reservoir water quality (see Section 5.2.2.2.5).

5.5.1 Future PRF Locations

Currently, the primary focus for siting PRF facilities is to locate them within the immediate Reservoir impact area, partly due to the phosphorus reduction benefits demonstrated by the in-stream delivery ratios (Section 4). However, the Authority's water quality goals extend throughout the watershed, as demonstrated by the extent of potential PRF sites investigated in the upper Segments of Cherry Creek (Figure 4-1 in Appendix M). Because cost sharing can significantly reduce the cost-per-pound of phosphorus removed for a PRF, large BMP projects represent cost effective opportunities for enhancement to PRF status. Several of the projects included in the list of potential PRFs were identified with this objective in mind. It is anticipated that the Authority would continue to monitor development activity through its referral review process and identify potential projects that could be enhanced.

5.5.2 Cooperative BMP Enhancement Program

BMP enhancements could include improved maintenance access, construction of littoral zones, pre-treatment area, enlargement of WQCV, downstream wetlands, or other technology to remove phosphorus from stormwater.

Because of the size and number of large BMPs constructed by third parties as part of growth in the watershed, there is an opportunity to enhance existing facilities to PRF status, thereby providing benefits to the owner and the Authority. Enhancements could include improved maintenance access, construction of littoral zones, pre-treatment area, enlargement of water quality capture volume (WQCV), downstream wetlands, or other technology to remove phosphorus from stormwater. To be considered for enhancement, the BMP must be:

- Constructed to minimum BMP standards per Regulations
- Meet requirements for maintenance by the UDFCD

- Meet Authority requirements for PRFs
- Control all tributary area with a watershed of 130 acres or more.

Priority for consideration would include higher IDR, stream preservation areas, and other criteria deemed appropriate by the Authority. Incentives to participate in the enhancement program could include assumption of operations and maintenance costs by the Authority, co-funding of enhancements by the Authority, and phosphorus trading credits. The following process is recommended to pursue these opportunities:

- The Authority establishes technical guidelines for developer incentives to upgrade facilities to PRF status, such as size and methods to estimate performance.
- Conduct meeting(s) between Authority representatives and the developer's engineers to determine technical merits of upgrading the BMP.
- Provided the project has technical merit, present a formal agreement to the Authority for a cooperative program to upgrade the facility.

5.5.3 TMDL Implementation

There is reasonable assurance that the TMDL will be implemented...

- *The Authority's commencement of implementation activities prior to TMDL approval*
- *The specificity of the Best Efforts Plan*
- *The funding and schedules for implementation*

There is reasonable assurance that the TMDL will be implemented, as evidenced by: (1) the Authority's commencement of implementation activities prior to TMDL approval, (2) the specificity of the Best Efforts Plan including prioritization of projects, and (3) the funding and schedules for implementation.

The WLA implementation will occur as follows.

- By 2010, all direct dischargers in the watershed will reduce phosphorus concentrations of 0.2 mg/L to 0.05 mg/L. Reductions of direct dischargers' phosphorus concentrations will be incorporated in discharge permits. Compliance with the 0.05 mg/L phosphorus concentration can be attained with the facilities of all existing direct dischargers and new or expanded WWTFs will be required to construct facilities which can attain the 0.05 mg/L phosphorus concentration.
- Dischargers shall not exceed their WLAs specified for their facility. No discharges currently would exceed their WLAs under the new TMDL and because of the state-of-the-art treatment facilities, all facilities are capable of continuing to achieve their WLAs at permitted flows.
- In order to standardize all discharge permits amongst dischargers, the Authority will work towards basin wide permitting in the Cherry Creek watershed. Common language will be incorporated into all discharge permits outlining the methods and equations for calculating and reporting phosphorus loads.

The internal allocation and load allocation implementation will occur as follows.

- Stormwater quality regulations will be adopted by the Authority and existing Authority members within the next 18 months. The Authority adopted and has been implementing the Stormwater Quality Requirements in its review of watershed projects. Aurora and Greenwood Village have presently adopted the stormwater regulations and the Authority will provide support to other land use agencies on the adoption and implementation of the regulations. An education program for BMP inspection and enforcement should be developed.

- PRFs capable of removing approximately 1,557 pounds of phosphorus annually should be implemented within the next 3 to 10 years, and further PRFs capable of removing an additional 1,200 pounds annually should be implemented by 2010. The Authority's Capital Improvement Plan considered the phosphorus reduction effectiveness and costs for more than 40 projects within the watershed. The Best Efforts Plan provides for the construction of the highest priority PRFs to achieve phosphorus reductions.
- In-lake management should be initially implemented within 3 years. The Authority has identified in-lake control strategies and is working with the representatives of the state parks, wildlife and water quality agencies to select in-lake controls and secure necessary approvals. Programs for education, monitoring and feedback will be developed.
- The Authority has commenced the planning and funding for the PRFs, in-lake management and stormwater quality requirements adoption and implementation. The Authority intends to use funds from its annual revenues and supplementary monies from grants, loans and agency cost-sharing arrangements to finance TMDL implementation.

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