CHERRY CREEK BASIN WATER QUALITY MASTER PLAN

TABLE OF CONTENTS

SECTION 1

EXECUTIVE SUMMARY

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 Cherry Creek Reservoir; however, it did not re-evaluate the technical basis for the 35 µg/L phosphorus standard. Since 1985, the Cherry Creek Basin Water Quality Authority (Authority) has conducted extensive water quality monitoring of Cherry Creek, its tributaries, the alluvium, pollutant reduction facilities (PRFs), and the Cherry Creek Reservoir (Reservoir). In 1996, the Authority commenced an update of historic modeling work and phosphorus estimates with over 12 years of data, and updating the original Master Plan.

As identified by Authority members, the four key objectives of the 1998 Master 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 Total Maximum Daily Load (TMDL).

- Identify and prioritize the implementation of activities and efforts necessary to achieve water quality objectives.

LEGAL AND REGULATORY FRAMEWORK

The Authority promotes 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.

The Cherry Creek Control Regulation, adopted by the Water Quality Control Commission (WQCC) in 1985, set forth the basic elements of the TMDL and the Master Plan. The 1985 TMDL determined that the maximum allowable load to the Reservoir is 14,270 pounds of phosphorus per year and allocated the load among point and nonpoint sources.

WATERSHED CHARACTERIZATION

Geography and Hydrology

Key features of the Cherry Creek watershed include the following:

- Cherry Creek drains an area of approximately 245,000 acres, or 384 square miles, in Arapahoe and Douglas counties.
- The watershed is made up of 31 sub-basins, with Cherry Creek Reservoir, an 850-acre lake, at the terminus of the watershed.
- Cherry Creek Reservoir was originally built for flood control, and is owned and operated by the U.S. Army Corps of Engineers (COE).
- The reservoir and land surrounding the reservoir, 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 significant alluvial aquifer. Flows in these creeks are intermittent. Other tributaries only have visible flow after storm events.
- 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. This affects runoff characteristics in the basin. Changes in the historic pumping pattern in the alluvium have altered Cherry Creek in various segments from a losing to a gaining stream. An analysis of gage data shows that Cherry Creek continues to be a losing stream for many of its segments.

Future Growth in the Watershed

Land Uses and Population Characteristics. A comparison of current and projected land uses (Denver Regional Council Of Government, 1998) in the Cherry Creek Basin (Basin) indicates that approximately 80-percent of the Basin will remain undeveloped in the next 20 years. The Denver Regional Council Of Government's (DRCOG) population projections for the Basin were 30,997, increasing to 62,534 by the year 2020. *(Note: Need to confirm that DRCOG land use data provided is consistent with population projections.)* Future growth in the area will result in increased water demands and wastewater treatment plant flows.

Wastewater Treatment Facilities. Seven wastewater treatment plants in the basin currently either provide secondary treatment followed by land application or advanced wastewater treatment (AWT) with direct discharge into Cherry Creek. With increases in population, the capacities of the existing wastewater treatment plants will increase and new facilities will be necessary in the future (Table 1-1).

Table 1-1. Wastewater Flow Projections

Service Area	Current Discharge,mgd	2008, mgd	2018, mgd
Castle Rock[1]	0.43[1]	1.32	3.02
Pinery	0.50	1.30	2.00
Parker	1.25	2.57	4.07
Stonegate	0.40	0.76	1.50
Arapahoe	0.70	1.04	1.28
Cottonwood	0.24	0.62	1.00
Meridian	0.05	0.80	1.50
Inverness	0.34	0.84	0.91
New Development	0.00	1.56	3.93

[1] Castle Rock includes Wastewater Treatment Facilities at Cherry Creek, McMurdo, Mitchell, and Newlin Gulch.

Municipal Water Sources. Municipal water sources in the Cherry Creek Basin are the alluvial and deep nontributary aquifers. There are five principal municipal water supply entities in the upper Cherry Creek Basin that utilize Cherry Creek alluvial aquifer wells. These entities, Arapahoe Water and Wastewater Authority, City of Aurora, Cottonwood Water and Sanitation District, Parker Water and Sanitation District, and the Pinery Water and Sanitation District, pump over 6,000 acre-feet annually. Future pumping from these municipalities will exceed 10,000 acre-feet annually.

Existing Conditions in the Watershed

Water Quality. The Authority conducts a comprehensive watershed monitoring program of surface and groundwater flows and quality. Monitoring of surface water and groundwater quality in the upper Cherry Creek watershed was initiated in August 1994 and continues to date (Halepaska, 1998). The water quality data collected to date indicate the following:

- Phosphorus concentrations are relatively constant throughout the Cherry Creek mainstem and the underlying alluvial aquifer, ranging between 150 µg/L and 250 µg/L. The principal variability in phosphorus loading to the Reservoir is related to flow variability.

- Ammonia -nitrogen concentrations have consistently been at, or below, detection limits (0.2 mg/L).

- 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.

- Chloride and sulfate concentrations have been increasing over time, which can be attributed to advanced wastewater treatment processes.

- There are significant total coliform counts throughout the study reach, including upstream of Castlwood Canyon.

Flows and Loads to the Reservoir. The Authority monitors flows and loads to the reservoir using stations on Cherry Creek, Cottonwood Creek, and Shop Creek (the three main surface inflows), along with estimates of direct precipitation and net alluvial inflow. The COE calculates inflow to Cherry Creek Reservoir as a function of measured values such as change in storage, outflow, and evaporation.

Flows in to the reservoir average 7,171 acre-feet annually. On an annual basis, total phosphorus loads into the reservoir have averaged approximately 6,600 pounds. Cherry Creek and its alluvium are responsible for approximately 69-percent of the total loads, with approximately 16-percent from Cottonwood Creek, 13-percent from direct precipitation, and 2-percent from Shop Creek.

Cherry Creek Watershed Model

Empirical data and simple water quality models have been applied to the Cherry Creek watershed to help provide a scientific basis for the 1998 Master Plan. The model is a tool to quantify potential water quality changes to the basin in the future. Conceptually, the Watershed Model for the Cherry Creek Basin is a composite of two separate models: 1) the Cherry Creek Stormflow Model, and 2) the Cherry Creek Baseflow Model. The Stormflow Model includes two sub-components, which describe a) watershed loading to the creek, consisting of nonpoint stormwater runoff and b) transport of those loading downstream to the reservoir. The Baseflow Model accounts for the constituent loads delivered to Cherry Creek Reservoir during baseflow conditions by integrating surface and alluvial waters.

Cherry Creek Stormflow Model. Nonpoint sources of phosphorus were evaluated through the application of a spreadsheet model, using the Simple Method to estimate loading to Cherry Creek from the surrounding watershed, based on rainfall/runoff and event mean concentrations for various land uses. Instream delivery ratios (IDRs) were also applied to account for the fact that a large portion of the phosphorus load generated within the Basin is not transported downstream to the Reservoir.

Cherry Creek Baseflow Model. The Baseflow Model accounts for phosphorus loads delivered to the Reservoir from the Cherry Creek mainstem, Cottonwood Creek and Shop Creek during baseflow conditions by integrating surface and alluvial waters. The Cherry Creek Baseflow Model is empirically based for the current condition and takes into account measured values in the Cherry Creek mainstem and alluvial waters, wastewater treatment plant discharges and alluvial pumping. Baseflow conditions were evaluated through application of monthly water quality and flow data collected by Halepaska and Associates along the Cherry Creek mainstem 1995 – 1997. Baseflow IDRs were developed to account for flow and chemical conditions that reduce the phosphorus delivery to the reservoir.

Model Results. Current condition estimates predicted by the 1998 Cherry Creek Watershed Model indicate nonpoint source loading of total phosphorus at approximately 8,100 pounds/year. This modeled value is in the range of data collected by the Cherry Creek Basin Authority 1995, 1996 and 1997 but generally higher than measured values. Extrapolating to the future condition, the model reflects a total phosphorus loading of approximately 11,200 pounds, or a 38-percent increase. This corresponds to a streamflow volume increase of 37-percent.

The current condition of the model was used to look at relative percent increases with respect to absolute values. Therefore, measured current condition loads were used and extended to the future condition using the 38-percent relative increase predicted by the model. Assuming a 38-percent increase in measured loads going into the Reservoir results in an approximate phosphorus load of 7,768 pounds for the future condition. Continued water quality monitoring will be applied to refine model predictions.

CHERRY CREEK RESERVOIR

Conditions in the Reservoir

The data collected during 1992-1997 indicate that the lake supports a seasonal average phosphorus value of approximately 50.0 – 60.0 µg/L, and the phosphorus content of the lake has typically been within this range over the period of record. Over this same time period, seasonal mean chlorophyll a values have averaged 15.7 µg/L.

Chlorophyll a/Phosphorus Standards for Cherry Creek Reservoir

For the purpose of setting standards for Cherry Creek Reservoir, the following is recommended:

- Cherry Creek Reservoir maintains a goal of 15 µg/L chlorophyll a, in terms of a rolling 5-year average of seasonal means.

- The phosphorus standard would be 60 µg/L, based on a 5-year rolling average of seasonal mean values.

- Within any 5-year period, if two consecutive seasonal means for phosphorus are greater than 77 µg/L, the standard will be considered to have been exceeded. If three consecutive seasonal phosphorus means are greater than 77 µg/L, or if any 5-year rolling average is greater than 60 µg/L, the Reservoir will be considered to be out of compliance with the standard, and the Authority would undertake corrective actions to bring the reservoir into compliance.

Allowable Loading to Reservoir

Based on the analysis of the reservoir response to external loads, the importance of internal loads to summer in-lake phosphorus concentrations, and the review of existing models describing this relationship, it is expected that the increased streamflows and loads predicted for future conditions would not result in a measurable change in average phosphorus concentrations in Cherry Creek Reservoir. Of the loading models examined for use in Cherry Creek Reservoir, the model proposed by Nurnberg (1998) which is a function of inflow/outflow and in-lake phosphorus concentrations, provides the best fit to observed values.

With future predicted increases in streamflow of 37-percent, the Nurnberg equation predicts an average allowable total load of approximately 9,775 lbs. This calculated load is predicted to meet the in-lake standard of 60 µg/L.

IMPLEMENTING THE PLAN

TMDL Allocation

The TMDL includes a margin of safety, wasteload allocation for point sources, and a load allocation for nonpoint and natural background sources. The 1998 wasteload allocation was determined by designating existing Wastewater Treatment Facilities (WWTFs), defining future needs, and apportioning the phosphorus among dischargers incorporating the effects of location and delivery ratios to the Reservoir (Table 1-2).

Table 1-2. Wasteload Allocation

Discharger	Allowable Load to Reservoir, Pounds
Castle Rock	165
Pinery	110
Parker	297
Stonegate	187
Arapahoe	160
Cottonwood	125
Meridian	94
Inverness	57
New Development	306
Total	**1,500**

A comparison between the 1985 and 1998 TMDL shows a reduction from 14,270 pounds to 9,800 pounds, respectively (Table 1-3). There is a shift in allocation categories from the original TMDL, in that the “background/returns” allocation includes future background loading from surface water, groundwater, septic systems, and delayed stormwater returns. There are allocations for point and nonpoint (background and storm event flow) sources, precipitation on the reservoir, and an emergency allocation. As indicated with the 1998 TMDL, annual loads from identified sources are estimated to total 8,800 pounds for the future 2018 condition. Approximately 1,000 pounds would remain unused, as a margin of safety.

Table 1-3. Comparison of 1998 and 1985 Cherry Creek TMDL

Allocation Category	1998 TMDL Pounds	Percent	1985 TMDL	
			Pounds	Percent
Background/Returns (gw, sw, ISDSs, and stormwater returns)	3,768	39	930	6.5
WWTFs		15	2,360	17
Existing WWTFs	1,194			
New Development WWTFs	306			
Storm Event Flow	2,686	28	10,290	72
Trading Pool Credit	-461			
Precipitation	848	9	690	4.5
Emergency	459	5		
Total Annual Load	8,800			
Margin of Safety	1,000	10		
Maximum Allowable Load (TMDL)	**9,800**		**14,270**	

SECTION 2

OVERVIEW

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 Cherry Creek Reservoir; however, it did not re-evaluate the technical basis for the 35 µg/L phosphorus standard. Since 1985, the Authority has conducted extensive water quality monitoring of Cherry Creek, its tributaries, the alluvium, nonpoint source projects (PRFs), and the Reservoir.

Background

In 1996, the Authority commenced an update of historic modeling work and phosphorus estimates with over 12 years of data, and an update of the original Master Plan. 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.

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 Authority's updated mission statement reflects this emphasis and direction:

> "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, water supplies, and other beneficial uses."

As re-affirmed by the 1997 survey of Reservoir users, the major uses of the Reservoir, recreation and fisheries, continue to be protected. The classified uses within Cherry Creek, water supply and agricultural uses, are also protected as evidenced by Cherry Creek meeting the water quality standards promulgated by the WQCC.

Objectives

As identified by Authority members, the four key objectives of the 1998 Master Plan are to:

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

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

The 1998 Cherry Creek Watershed Model provides a characterization of phosphorous loading, to Cherry Creek and the Reservoir, resulting from point and nonpoint sources from current and future development conditions. The primary focus of the 1998 Watershed Model is phosphorus. However, this model can address other constituents such as nitrogen and total suspended solids.

Additionally, a comprehensive groundwater and surface water quality monitoring program was initiated in 1994 to characterize water quality in the watershed and to identify trends. The water quality data and model are applied to support a number of evaluations within the watershed, including re-evaluation of the 1985 phosphorus TMDL allocation, identification of sub-basins with the greatest potential for phosphorous loadings, and development of priority areas for phosphorus controls.

- 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 to the Reservoir and its watershed or appropriately predict phosphorus or chlorophyll a loads. A more predictive model is necessary to relate predicted changes in loads from the watershed under future conditions to possible in-lake phosphorus concentrations. There is a wealth of sound and viable data about the Reservoir and its watershed that fully supports reconsideration of the standards and TMDL. The Authority has collected and analyzed more than twelve years of data on the phosphorus/chlorophyll a relationship in the Reservoir and phosphorus loading to the Reservoir and its watershed. Data collected over the past decade strongly suggests that the assumptions about the relationship between chlorophyll a and phosphorus contained in the original plan do not correspond with what is observed in the Reservoir.

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

Based on total allowable loading to the Reservoir and modeling, reallocate the phosphorus load among various categories. The TMDL process results in the determination of: 1) the amount of a specific pollutant that a segment can receive without exceeding the water quality standard (the TMDL), and 2) the apportionment to the different contributing sources of the pollutant loading (the allocation). The TMDL includes a margin of safety, wasteload allocation (for point sources), and a load allocation for nonpoint sources and natural background.

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 Cherry Creek Basin Water Quality Management Plan (DRCOG, 1985). Phosphorus loadings were projected for the years 1990, 2000, and 2010 for three sources: point, nonpoint, and background stormwater runoff sources[1]. Projected nonpoint source loadings did not reflect any reductions in loading from nonpoint source controls in the basin. It was assumed that all

[1] Background sources are defined in the 1985 Master Plan to include only precipitation, net groundwater, and baseflow and do not include point sources, nonpoint sources, septic systems, or industrial sources.

phosphorus generated in the watershed was delivered to the Reservoir, which does not account for the fact that Cherry Creek is a losing stream through most of the upper reaches. More recent studies provide a basis to refine this initial assumption.

The combination of point, nonpoint, and background sources of phosphorus were used to define the annual phosphorus load to the Reservoir, once again, assuming no losses of phosphorus generated from the watershed and subsequently delivered to the Reservoir. The Jones-Bachman in-lake phosphorus model was applied to relate in-lake phosphorus concentrations to total estimated annual loads. The model was the basis for setting a maximum load of 14,270 pounds that could enter the Reservoir annually to maintain the 35 µg/L total phosphorus standard. To maintain a maximum annual load of 14,270 pounds, a basinwide goal of 50-percent phosphorus reduction for nonpoint sources was established. Table 2-1 summarizes the original 1985 TMDL and allocation. Data and information collected in the Cherry Creek Basin since 1986 strongly suggest reconsideration of the original TMDL.

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
Septic Systems	450
Industrial Sources	50
Background	1,170
Critical Load (TMDL)	**14,270**

- Identify and prioritize the implementation of activities and efforts necessary to achieve water quality objectives. Such activities include:

➢ Implementing facilities that provide protection beyond best management practices (BMPs), such as PRFs, will create an additional barrier from nonpoint source impacts. Development of a PRF operations and maintenance plan will ensure that technical measures continue to serve their purpose.

➢ Implementation of the model Cherry Creek Stormwater Regulation and Conceptual Stormwater Plan will provide methods to implement, monitor, and enforce BMPs to control nonpoint source pollution during and after construction.

➢ Continuing the comprehensive water quality monitoring program for the watershed and Reservoir will assure that water quality objectives are being met in Cherry Creek and the Reservoir.

SECTION 3

LEGAL AND REGULATORY FRAMEWORK

The Authority is the designated 208 Management Agency for the Basin. The Authority initially operated pursuant to a contractual agreement between the affected jurisdictions: two counties, four cities, and seven special districts within the Basin. However, given the costs and issues related to the activities that needed to be undertaken to protect the Reservoir as well as the Basin, the Authority determined that it needed special powers and authorization to function effectively. The Authority was created by the Colorado legislature in 1988 (Colorado Revised Statutes, Section 25-8.5-101, et seq.). The Authority operates pursuant to that special legislation, which created and authorized the Authority to undertake water quality capital projects, initiate and maintain sampling programs to evaluate ongoing water quality, recommend controls for water quality, and charge fees and assessments to support its programs.

SECTION 4

CHERRY CREEK WATERSHED CHARACTERIZATION

The 1998 Master Plan update is a watershed plan. The Cherry Creek Watershed is a very intricate and complex system. Although water quality in the Reservoir continues to be a major focus, this Plan also addresses water quality throughout the watershed, including the streams, alluvial groundwater, and their interrelationships and Reservoir affects.

GEOGRAPHY AND HYDROLOGY

Cherry Creek Reservoir was originally built for flood control, and is owned and operated by the COE. The Reservoir, which has a surface area of approximately 850 acres, and land surrounding the Reservoir, 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. The Reservoir and surrounding state park serve as an important urban recreational site, providing opportunities for a variety of activities, including sport fishing, boating, swimming, bicycling, bird watching, and wildlife habitat (Authority, 1997).

Cherry Creek drains an area of approximately 245,000 acres, or 384 square miles, in Arapahoe and Douglas counties. The watershed is made up of 31 sub-basins, with the Reservoir, an 850 acre lake, at the terminus of the watershed. The basin drains northward, from elevations reaching approximately 7,700 feet along the southern perimeter in Douglas 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. A map of the watershed is provided on Figure 4-1.

Cherry Creek and Cottonwood Creek are the major surface water streams within the basin, each having its own significant alluvial aquifer. Although water flows continuously through the aquifer, 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 1956-1969. 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 1956-1996. The average inflow into the Reservoir, measured by Chadwick Ecological averaged 7,171 acre-feet/year (1992–1997).

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 1951-1996.

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. This affects runoff characteristics in the basin. Similarly, changes in the historic pumping pattern in the alluvium have altered Cherry Creek in various segments from a losing to a gaining stream. An analysis of gage data shows that Cherry Creek is a losing stream for many of its segments (Authority, 1989).

The Cherry Creek alluvium is deposited in a valley incised into the Denver 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. The cross-section indicates that the paleochannel is up to 110 feet thick and that the aquifer can be subdivided into four geological units. In general, all of these units exhibit a fining upward sequence with the coarsest, most permeable material at the base of the unit and the finer less permeable material at the top of the unit (Authority, 1989).

The Cherry Creek dam is an earth fill dam. Beneath the dam, over most of its length, all the unconsolidated material was excavated down to bedrock and replaced with impermeable material, to form a cutoff trench. 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).

FUTURE GROWTH IN THE WATERSHED

Land Uses and Population Characteristics

The northern portion of the watershed has been urbanizing over the past ten years, especially in the sub-basins immediately adjacent to the Reservoir. Developed land uses include low, medium and high density residential areas, large lot subdivisions, and office, commercial and light industrial parks. Traditional agricultural and agribusiness uses are still present, but mostly in the southern half of the watershed (Authority, 1997). Although the watershed is dominated by agricultural/open space lands, the areas nearest the Reservoir and along the major drainages have become urbanized. As shown on Figure 4-2, a relatively large percentage of the basin remains undeveloped in comparison to residential, commercial, and industrial 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.

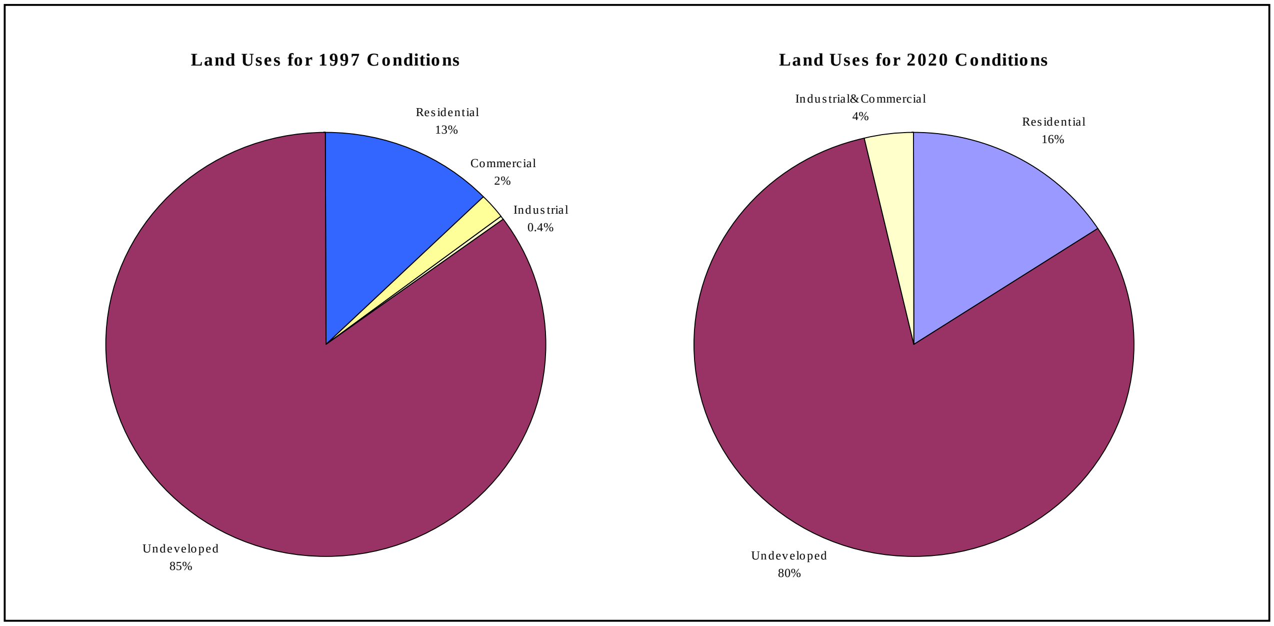

Figure 4-2. Comparison of Land Uses for 1997 & 2020 Condition.

Population Projections

Projections of population and employment were developed for each WWTF area for the planning years 2000, 2005, 2010, 2015 and 2020. Table 4-1 summarizes population projections for the Cherry Creek Basin service area. These projections are from DRCOG's adopted regional population and employment forecasts. The population numbers are based on Traffic Analysis Zones, which are loosely based on employment, number of houses and land use. The populations are given for wastewater service area. The forecasts were developed from the 1990 census data and subsequently updated through the ongoing planning process. The estimated basin population is 30,997, increasing to 62,534 by the year 2020. *(Note: Need to confirm that DRCOG land use data provided is consistent with population projections in the basin)*

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
Newlin Gulch*	455	482	557	676	864	1,176
Cherry Creek*	7,320	7,433	8,146	9,066	10,275	11,903
Denver SE	20	21	47	145	669	3,854
Inverness	87	87	85	85	90	155
Meridian	166	171	222	301	416	582
Parker	13,131	13,921	15,467	17,484	20,357	25,393
Rampart Range*	253	264	386	573	949	2,003
Stonegate	3,009	3,249	3,474	3,744	4,159	5,228
Totals	**30,997**	**32,539**	**35,905**	**40,475**	**47,539**	**62,534**

*No growth expected for these facilities. Numbers given are from (unpublished) 1998 Clean Water Plan.

Municipal Water Sources

Municipal water sources in the Cherry Creek Basin are the alluvial and deep nontributary aquifers. There are five principal municipal water supply entities in the upper Cherry Creek Basin that utilize Cherry Creek alluvial aquifer wells. These entities, Arapahoe Water and Wastewater Authority, City of Aurora, Cottonwood Water and Sanitation District, Parker Water and Sanitation District, and the Pinery Water and Sanitation District, pump over 6,000 acre-feet annually. Future pumping from these municipalities will exceed 10,000 acre-feet annually. The protection of the alluvial aquifer for drinking water supplies is an important water quality concern reflected in this update.

Wastewater Treatment Facilities

Seven wastewater treatment plants currently provide advanced wastewater treatment, including treatment of phosphorus to very low levels. Wastewater treatment plants either provide secondary treatment followed by land application or AWT with direct discharge into Cherry Creek to fulfill water augmentation requirements and beneficial reuse or land application (Table 4-2). Parker and Lincoln Park designed and built AWT facilities in 1995 and initiated direct discharge to Cherry Creek in 1996. Arapahoe Water and Wastewater Authority and Inverness, which land-apply their effluent, are currently designing AWT facilities.

Table 4-2. Treatment Plants, Processes, and Effluent Disposal Methods in the Cherry Creek Basin (CCBWQA, 1997).

Service Area	Treatment Process	Disposal Method
Arapahoe Water and Wastewater Authority/Cottonwood Water & Sanitation District	Secondary	Rapid Infiltration Basin & Land Application
Pinery Water & Sanitation District (f/k/a) Denver Southeast Water & Sanitation District	AWT	Rapid Infiltration Basin
Inverness Water & Sanitation District	Secondary	Land Application
Meridian Water & Sanitation District	AWT	Land Application
Parker Water & Sanitation District	AWT Secondary	Direct Discharge Land Application
Lincoln Park Metropolitan District (f/k/a) Stonegate Center Metropolitan District	AWT Secondary	Direct Discharge Land Application

Individual or commercial establishments not in proximity to municipal wastewater treatment facilities treat wastewater with septic systems. As described later in this report, studies are currently underway to assess potential impact on water quality from these systems in the Cherry Creek Basin and ultimately to Cherry Creek Reservoir.

Water Quality Monitoring

The Authority conducts a comprehensive watershed water quality monitoring program. Sampling of the influent streams is designed to provide data that allows calculations of nutrient loading to the Reservoir. Sampling of alluvial flows provides a baseflow characterization of groundwater quality. Monitoring of surface water and groundwater quality in the upper Cherry Creek watershed, as described in Appendix A, was initiated in August 1994 and continues to date (Halepaska, 1998). Ten surface water monitoring stations and nine groundwater monitoring stations were established for the Phase I Baseline Study (Figure 4-3). Table 4-3 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.

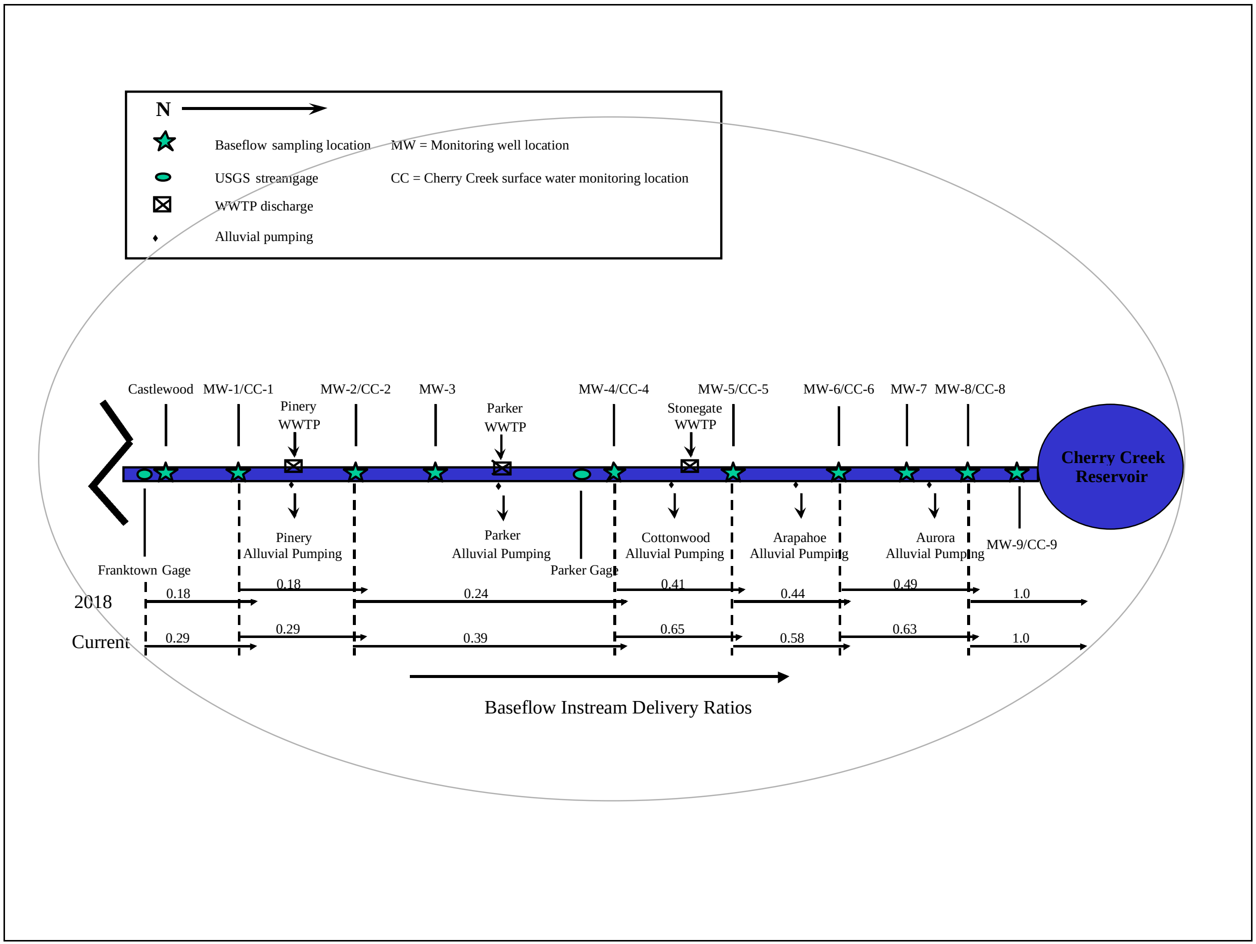

Figure 4-3. Baseflow Instream Delivery Ratios for the Cherry Creek Basin.

Table 4-3. 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]	
Quarterly Sediment Sampling:[2]	
Ammonia	Total Phosphorus
Semi-Annual Sampling:[1]	
Gross Alpha	Copper[4]
Arsenic[4]	Mercury[4]
Barium[4]	Selenium[4]
Cadmium[4]	Silver[4]
Chromium[4]	
Annual Sampling:[1]	
Chloroform	Mercury[4]
Barium[4]	Selenium[4]
Cadmium[4]	Silver[4]
Chromium[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.

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 (Figure 4-4). 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. 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 to the Reservoir is related to greater flows. Even at higher flows during spring runoff, phosphorus concentrations do not increase above background 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

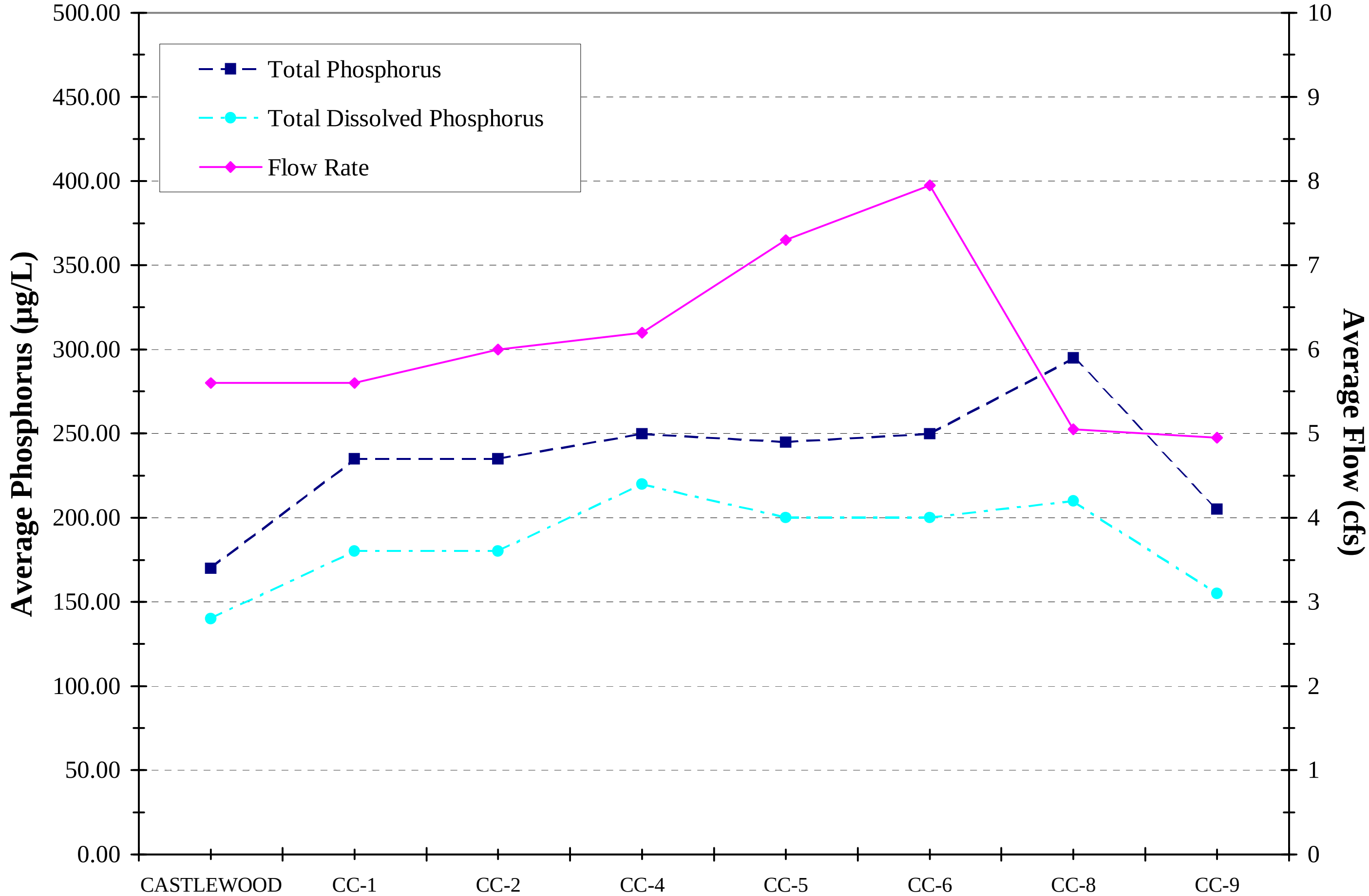

Figure 4-4. Average Total and Dissolved Phosphorus Concentration and Flow vs. Location (John C. Halepaska and Associates, Inc., 3/30/98)

pumped from the Cherry Creek alluvial aquifer by the municipal water entities is replaced by advanced wastewater treatment 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.

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. While Cherry Creek is listed as an ammonia-impaired reach, 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.

Both sulfate and chloride indicate concentration trends that may be indicative of impacts from wastewater discharges. The increase in sulfate appears to be related to the addition of aluminum sulfate as part of the advanced wastewater treatment process to reduce phosphorus concentrations in the effluent. While concentrations of both constituents are below current drinking water standards of 250 mg/L, 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 mainstem. Basin dischargers are currently evaluating both constituents in the wastewater treatment process and alternative chemicals for phosphorus removal.

Elevated levels of specific metal ions, such as iron and manganese, and observed gross alpha activity are thought to be related to naturally-occurring phenomena, and are not related to anthropogenic activities in the Basin. These exceedences are indicative of natural geologic conditions in the Basin, where iron and manganese are more widespread throughout the basin and gross alpha is more sporadic.

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- to 15-percent of the total coliform counts and the presence of high total coliforms at Castlewood Canyon (above the direct dischargers in the Basin).

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 some direct dischargers to ultraviolet disinfection, rather than chlorination, will serve to further reduce the potential for the formation of trihalomethanes (THMs) in the disinfection process.

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 Colorado Water Quality Control Division (WQCD) and the DRCOG have concluded that the Reservoir is generally phosphorus limited (WQCD 1983, DRCOG 1985).

Monitoring Activities for Derivation of Phosphorus Loads. Phosphorus loading has been determined by the Authority for several primary sources since monitoring began, including the influent streams Shop Creek, Cherry Creek, and Cottonwood Creek, as well as from direct precipitation (Figure 4-3). 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 5-10 storms spread out through the summer. To provide matching comparisons with the analysis of phosphorus and chlorophyll a data in the Reservoir, the analysis of phosphorus loads is based on the 1992-1997 monitoring period.

Currently, alluvial flows in the Cherry Creek mainstem are monitored by Halepaska & Associates for locations upstream and downstream of the Reservoir. 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. In addition, rainfall was 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. Flow data are available from the COE and USGS gauging station located just downstream of the Reservoir. Baseflow water quality sampling was conducted during the summer to allow calculations of loads leaving the Reservoir.

Final Calculations of Reservoir Inflows and Phosphorus Loads. 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. As outlined above, the Authority monitors inflow and loads to the Reservoir using stations on Cherry Creek, Cottonwood Creek, and Shop Creek (the three main surface inflows), along with estimates of direct precipitation and net alluvial inflow. Due to differences in the two methods for determining inflow, an exact match is not expected. Therefore, Authority flow values were normalized to match COE inflows and combined with the direct precipitation and net alluvial inflow to estimate total phosphorus loading to the Reservoir.

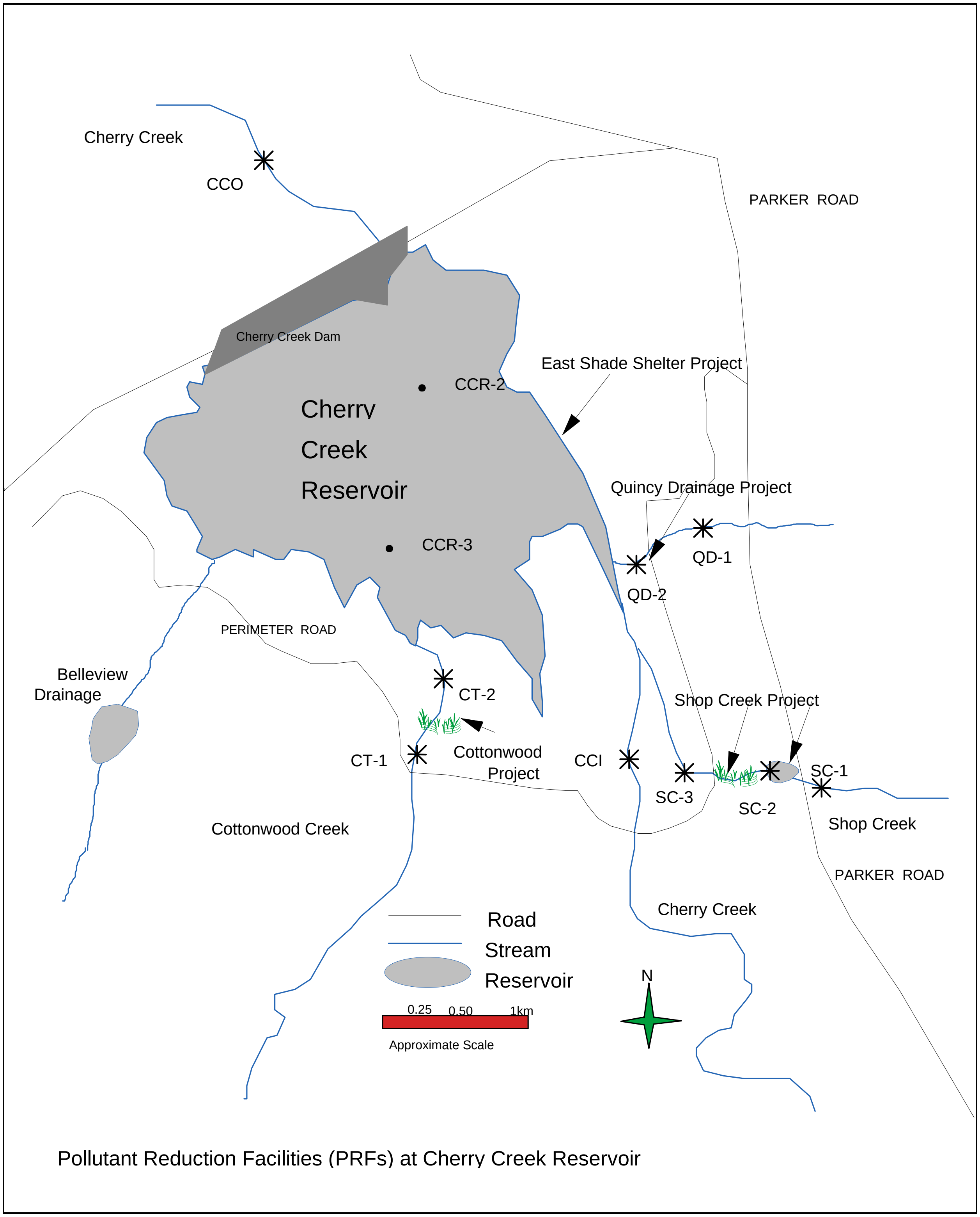

Figure 4-5. Location of Sampling Locations and PRFs in the Cherry Creek Basin.

Phosphorus Loads from Streams and Precipitation. Annual loading of phosphorus to the Reservoir have been determined since 1987. These values are summarized for the 1992-1997 water years to match the in-reservoir analysis above, as normalized to COE inflow calculations.

As shown on Figure 4-5, there are four primary sources of phosphorus loads to the Reservoir: 1) Shop Creek (as monitored at Site 3), 2) the Cherry Creek mainstem inflow (as surface flows at Site CC10 and net alluvial inflow), 3) Cottonwood Creek inflow (as CT1 from 1996-1995 and CT2 from 1996-1997), and 4) direct precipitation (Table 4-4). On an annual basis, total phosphorus loads into the Reservoir have ranged from over 10,000 pounds to roughly 5,000 pounds, with a six-year average of approximately 6,600 pounds (Table 4-4). On average, Cherry Creek and its alluvium are responsible for 69-percent of the total loads, with approximately 16-percent from Cottonwood Creek, 13-percent from direct precipitation, and only 2-percent from Shop Creek.

Table 4-4. Estimated phosphorus loading (pounds/year) into Cherry Creek Reservoir, 1992-1997

Source of Data	1992	1993	1994	1995	1996	1997	Mean
Shop Creek 3	124	162	112	128	119	141	131
Cherry Creek	5,493	2,982	3,938	4,962	4,082	2,853	4,052
Cottonwood Creek	958	411	228	3,320	588	714	1,036
Subtotal for Streamflows	**6,575**	**3,555**	**4,278**	**8,410**	**4,789**	**3,708**	**5,219**
Cherry Creek Alluvium	555*	555*	470	597	635	520	555
Direct Precipitation	921	680	563	1,262	735	928	848
Total Load	**8,051**	**4,790**	**5,311**	**10,269**	**6,159**	**5,156**	**6,622**
Cherry Creek Outflow	1,317	774	950	1,975	1,109	996	1,187
Net Load	**6,734**	**4,016**	**4,361**	**8,294**	**5,050**	**4,160**	**5,435**

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

Phosphorus Loadings 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 thought 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 and the activities and facilities related to urbanization (e.g. overland stripping for subdivision development, paving and associated stormwater runoff associated with subdivision development and installation of septic tanks/leach fields for large lot developments) that produce nonpoint discharges are minimal. Therefore, it is believed that phosphorus loading data at Castlewood Canyon are representative of background conditions in the upper Cherry Creek Basin and that inputs downstream of Castlewood Canyon to the Reservoir are more related to urbanization along the Cherry Creek corridor.

Using this premise, Halepaska and Associates (1997) 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 (Appendix B).

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) and an estimation can be made of the biologic assimilation of phosphorus and/or additional pumping in the study reach (e.g., irrigation 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 4-5, for the period 1995 through 1997, cumulative annual phosphorus loadings 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. While total phosphorus concentrations remained relatively consistent throughout this 3-year period, flows were much higher in 1995 than in 1996 or 1997.

Table 4-5. 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

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. In 1995, there was a net total phosphorus load increase from the upstream end of the study reach to the downstream end of the study reach of 1,831 pounds, 2,491 pounds, and 2,203 pounds, for the years 1995, 1996, and 1997, respectively. While the net increases in phosphorus loads from the upstream end of the study reach to the downstream end of the study reach were fairly consistent, there were larger variations (both increases and decreases) in total phosphorus loads at intermediate stations in the study reach.

FUTURE CONDITIONS IN THE WATERSHED

Cherry Creek Watershed Model

Empirical data and simple water quality models, as described in Appendix C, have been applied to the Cherry Creek watershed to help provide a scientific basis for the 1998 Master Plan. Specifically, the 1998 Cherry Creek Watershed Model provides a characterization of phosphorus loading to Cherry Creek and the Reservoir resulting from point and nonpoint sources from two development conditions - current (1997) and future (2018). To date, the primary focus of the modeling has been on phosphorus, but this model could address other constituents in the future. The 1998 Watershed Model can be applied to support a number of evaluations within the watershed, including;

- Estimation of current and future loading in the watershed,
- Re-evaluation of the 1985 phosphorus TMDL allocation,
- Identification of sub-basins with the greatest potential for phosphorus loading, and
- Development of priority areas for phosphorus controls.

The Watershed Model can also be combined with models for the Reservoir to provide a comprehensive picture of water quality within the Cherry Creek Basin.

Conceptually, the Watershed Model for the Cherry Creek Basin is a composite of two separate models: 1) the Cherry Creek Stormflow Model, and 2) the Cherry Creek Baseflow Model. The Stormflow Model includes two sub-components, which describe a) watershed loading to the creek, consisting of nonpoint stormwater runoff and b) transport of those loading downstream to the Reservoir[1]. The Baseflow Model accounts for the constituent loads delivered to the Reservoir during baseflow conditions by integrating surface and alluvial waters. As noted earlier, baseflows also include short term delayed return flows from stormwater[2]. The total phosphorus loading to the Reservoir can be estimated as the sum of loading from the baseflow and stormflow components.

The 1998 Cherry Creek Watershed Model describes total loading to Cherry Creek Reservoir as:

(Stormflow Loading)(Stormflow Instream Delivery Ratio) + (Baseflow Loading)(Baseflow 1DR)
= Total Loading to Cherry Creek Reservoir

Cherry Creek Stormflow Model. Nonpoint source stormwater runoff is a significant source of phosphorus loading to Cherry Creek and the Reservoir. The two sub-components of the Cherry Creek Stormflow Model, loading and transport, are described below.

<u>Stormwater Runoff Loading Sub-component</u>. Nonpoint sources of phosphorus were evaluated through the application of a spreadsheet model, using the Simple Method to estimate loading to Cherry Creek from the surrounding watershed, based on rainfall/runoff and event

[1] The stormflow component is referred to as “storm event flow” in the TMDL allocation.
[2] The baseflow component is referred to as “baseflow/returns” in the TMDL allocation.

mean concentrations for various land uses. Originally in 1985, a generalized stormwater runoff model was applied to the Cherry Creek watershed. The model was improved with the addition of site-specific refinements to better represent actual conditions unique to Cherry Creek, such as runoff coefficients and land use data from the DRCOG. Site-specific refinements may be improved with future data from the basin.

Transport Model Sub-component (IDRs). Because of the soil and alluvial characteristics of the Cherry Creek watershed, much of the flow generated in the upper portions of Cherry Creek is not ultimately transported downstream to the Reservoir. To reflect this effect in the Stormflow Model, stormflow IDRs were developed and applied. Cherry Creek was divided into three segments, as follows.

- Segment 3 - Upstream end to Franktown gage
- Segment 2 - Franktown gage to Parker gage
- Segment 1 - Parker gage to Reservoir

In nonpoint source modeling, a delivery ratio is a dimensionless ratio of the actual observed load divided by the load theoretically possible. The stormflow IDR accounts for constituent losses during travel along the main channel to a location of concern. For this study, the location of concern is the Reservoir. The reasons for the discrepancy between these numbers may include chemical or biological changes to the load or the physical removal of the load. The Cherry Creek Stormflow Model assumes that a portion of storm runoff volume (and therefore the pollutant load) is lost en route to the main stream channel. This loss in runoff volume is accounted for through the coefficients of runoff. However, a stormflow IDR is required to account for stormflow load losses as flows are transported through Cherry Creek and the alluvium to the Reservoir.

As described in more detail in Appendix C, stormflow IDRs were developed based on analysis of rainfall runoff relationships in the Cherry Creek Basin. The evaluation indicated that 74-percent of the flows generated from storm events occurring within the upper two segments of Cherry Creek do not ultimately reach the Reservoir. Conversely, only 26-percent of the flows generated from storm events actually make their way to the Reservoir. Alluvial pumping by Aurora, Arapahoe, Cottonwood and others have significant impacts on surface flows in Segment 1 of Cherry Creek. An instream delivery ratio of 26-percent for Segment 1 reflects this condition. Stormflow IDRs for Segments 2 and 3 were calculated to be 7 percent.

Direct flow areas within Segment 1, such as the 725-acre Shop Creek sub-basin, were given an instream delivery ratio of 50 percent. This is based on an evaluation of flow response to precipitation events in the area during the period 1993 - 1996. Shop Creek streamflows have been monitored at the gage at South Parker Road by a variety of entities like the Authority (Jones & CEC, 1998), the USGS, and City of Aurora (Rocky Mountain Consultants, 1996).

Summary of Cherry Creek Stormflow Model Results. The Stormflow Model was applied to estimate loading for current and future conditions. (Table 4-6). The Stormflow Model, coupled with stormflow IDRs applied to three segments of Cherry Creek, indicate that a total of approximately 4,090 pounds of phosphorus from nonpoint source runoff would be delivered to the Reservoir as the result of storm events annually for the current condition. The future loading estimate was approximately 45-percent greater, or 5,937 pounds. For comparison, the 1985 modeling performed by DRCOG estimated loading of approximately 21,531 pounds for the year 2000 and 43,909 pounds for the year 2010. The vast difference in the 1998 Cherry Creek Model versus the 1985 DRCOG model is that DRCOG assumed that all phosphorus generated within the watershed was transported to the Reservoir. Supporting water quality data collected by the Cherry Creek Basin Authority disproves this assumption. Data indicate that on an annual basis total phosphorus loads into the Reservoir have ranged from over 5,000 pounds to 10,000 pounds, with a six year average of approximately 6,600 pounds (this includes phosphorus load from precipitation on the Reservoir). Over the same time period, phosphorus loads in the Reservoir outflow have averaged approximately 1,200 pounds, resulting in an average "net" loading to the Reservoir of roughly 5,400 pounds (Jones and CEC, 1998).

Table 4-6. Summary of Current and Future Predicted Stormflow Phosphorus Loads Transported to Cherry Creek Reservoir

Modeled Condition	Segment of Cherry Creek	Load from sub-basins, pounds	Delivery Ratio	Load to Reservoir, pounds
Current	Segment 3	1,080	0.07	76
Current	Segment 2	5,441	0.07	381
Current	Segment 1	10,935	0.26	2,843
Current	Direct Flow Areas	1,580	0.50	790
Total Current Load		**19,036**		**4,090**
Future	Segment 3	2,270	0.07	159
Future	Segment 2	5,193	0.07	364
Future	Segment 1	14,824	0.26	3,854
Future	Direct Flow Areas	3,120	0.50	1,560
Total Future Load		**25,407**		**5,937**

Cherry Creek Baseflow Model. The Cherry Creek Baseflow Model for phosphorus loading to the Reservoir accounts for phosphorus loads delivered to the Reservoir from the Cherry Creek mainstem, Cottonwood Creek and Shop Creek during baseflow conditions by integrating surface and alluvial waters. Baseflow loads consist of background phosphorus loads in surface water and groundwater plus point source discharges. Baseflow loads are delivered to the Reservoir reflecting rates of changes of total phosphorus measured in each segment and unique characteristics observed in the Upper Cherry Creek Basin, such as extensive alluvial pumping. Cherry Creek was divided into several segments, in a manner similar to the Stormflow Model, using instream water quality monitoring stations as control points to describe the flux of constituents in each segment (Figure 4-3). (Halepaska, 1997)

Baseflow conditions were evaluated through application of monthly water quality and flow data collected by Halepaska and Associates along the Cherry Creek mainstem for three sampling seasons, 1995, 1996 and 1997. The "Phase 1 Baseline Water Quality Data Collection Study, conducted by J.C. Halepaska and Associates" (Baseline Study), characterizes baseflow loading conditions for the mainstem. The Cherry Creek Baseflow Model is empirically based for the current condition and takes into account measured values in the Cherry Creek mainstem and alluvial waters, wastewater treatment plant (WWTF) discharges and alluvial well pumping. By monitoring surface and groundwater conditions, it is assumed that the baseflow phosphorus loads at these control points are completely known. As mentioned above, a mass balance analysis was used as the basis for calculating phosphorus gains and losses that occur between segments.

Baseflow Instream Delivery Ratios**.** As described in detail in Appendix C, baseflow IDRs were developed to account for flow and chemical conditions that reduce the phosphorus delivery to the Reservoir. Specific removal mechanisms include alluvial pumping, biological assimilation, chemical interactions within the soils and alluvium, and basic hydrologic characteristics of the Cherry Creek basin that make it a "losing" stream. Extrapolating to the future condition required data on projected discharges and alluvial pumping. Data provided by Cherry Creek Basin entities on future projected flows and pumping were the basis for determining baseflow IDRs for the future condition. Baseflow IDRs will be verified annually with the baseflow monitoring program. Figure 4-3 summarizes current and future baseflow IDRs.

Summary of Baseflow Model Results. Baseflow phosphorus loading estimates to the Reservoir increase approximately 30-percent for the future condition from 4,046 pounds and 5,268 pounds, respectively (Table 4-7). Point sources are well defined and make up a very small portion of the total baseflow phosphorus loading to the Reservoir. For the current condition, the loading estimate to the Reservoir is calculated by taking the median values of measurements made by Halepaska and Chadwick Ecological Consultants from 1995 - 1997 for the Cherry Creek mainstem just upstream of the Reservoir, Shop Creek and Cottonwood Creek. Loading contributions from Quincy and Bellview drainage's are considered negligible, because the flows are ephemeral.

Table 4-7. Summary of Predicted Baseflow Phosphorus Loading to Cherry Creek Reservoir

Modeled Condition	From Cherry Creek Mainstem, pounds	From Cottonwood Creek, pounds	From Shop Creek, Pounds	Total, pounds
Current	3,771[1]	185[2]	90	4,046
Future	5,043	135[3]	90	5,268

[1] From data measured by Halepaska and Assoc. (Median of 1995-1997 data)
[2] From data measured by Chadwick Ecological Consultants (Median of 1995 -1997 data * .3)
[3] In the future, Arapahoe Water and Wastewater Authority discharges to Happy Canyon Creek, not Cottonwood Creek.

Extrapolating to the future condition required data on projected discharges and alluvial pumping. The loading estimate for the future condition is based on alluvial pumping and discharge assumptions summarized in Table 6 of Appendix C. As noted, one such change in the future will be Arapahoe Water and Wastewater Authority's (Arapahoe's) point of direct discharge. Arapahoe will direct discharge to Happy Canyon Creek, a tributary of Cherry Creek, not Cottonwood Creek. The modeled loading estimate for the future condition is 5,268 pounds.

Additional alluvial pumping data and information will be verified annually to refine the future modeled condition.

Model Results. The Cherry Creek Watershed model is a tool to quantify potential water quality changes to the basin in the future. Table 4-8 summarizes the 1998 Cherry Creek Watershed Model predictions of annual phosphorus loading to the Reservoir. The modeled values do not include loading from precipitation on the Reservoir.

Table 4-8. Summary of 1998 Cherry Creek Watershed Model Predictions of Annual Phosphorus Loading to Cherry Creek Reservoir

Annual Phosphorus Load	Current Condition, pounds	Future Condition, pounds
Baseflow Load	4,046	5,268
- Point Source Load	278	1,500
- Background Load (surface water + groundwater)	3,768	3,768
Stormflow Load	4,090	5,937
Total Load	**8,136**	**11,205**

Current condition estimates predicted by the 1998 Cherry Creek Watershed Model indicate nonpoint source loading of total phosphorus at approximately 8,100 pounds/year. This modeled value is in the range of data collected by the Cherry Creek Basin Authority 1995, 1996 and 1997 but generally higher than measured values. Extrapolating to the future condition, the model reflects a total phosphorus loading of approximately 11,200 pounds, or a 38-percent increase. This corresponds to a streamflow volume increase of 37-percent.

The stormflow load estimated by the Cherry Creek Watershed Model based on land use patterns in the Reservoir watershed for the current and future conditions were compared to the nonpoint source loads estimated by DRCOG in the 1985 Master Plan (Figure 4-6). The 1985 methodology for estimating nonpoint source loads assumed that all generated loads reached the Reservoir without taking into account the phosphorus reduction mechanisms in Cherry Creek, such as well pumping, evapotranspiration, soil moisture, and chemical interactions within the soil and alluvium.

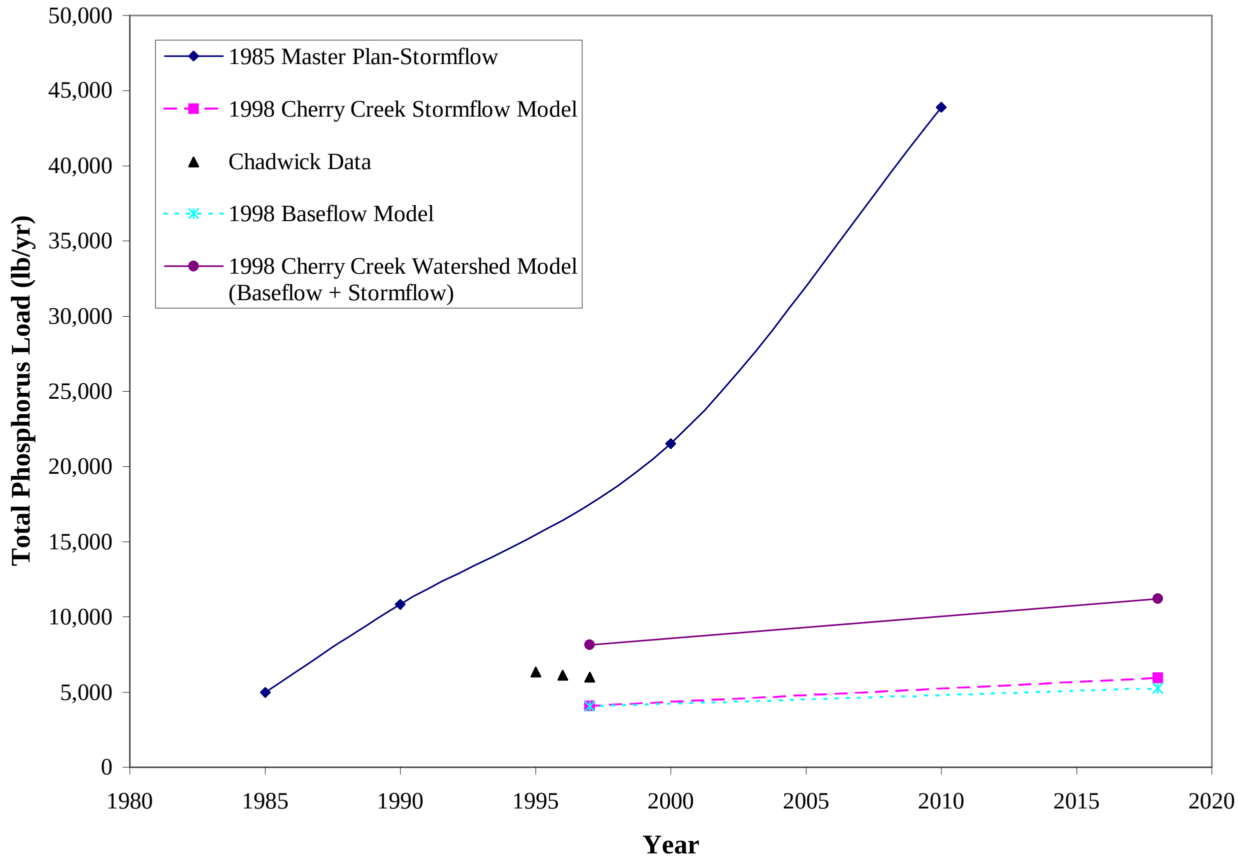

Figure 4-6. Comparison of measured and predicted phosphorus loading to the Cherry Creek Reservoir.

Comparison of the Cherry Creek Watershed Model to Measured Values. The benefit of the Cherry Creek Watershed model is in predicting changes in loading in the future. These changes are expressed in terms of the percent difference in the baseflow and stormflow loads between current and future conditions.

Annual average streamflow loading of phosphorus, as measured by Chadwick and normalized to COE calculations, is 5,774 pounds. Chadwick values were normalized to match COE inflows by first subtracting monthly estimates of direct precipitation and net alluvial inflow from the COE values, then determining the proportion each stream (Cherry Creek, Cottonwood Creek, and Shop Creek) contributed to the remaining monthly inflows using Chadwick streamflow values. The percentages were multiplied by the inflow measured by the COE (minus precipitation and alluvial flow) to adjust the estimate of load from each stream's inflow to the Reservoir.

The watershed model current condition was used to look at the relative percent increase with respect to absolute values. Therefore, the current measured loading was used and extended to the future condition using the 38% relative increase (Table 4-9). As shown, the current condition of the model was reset to match the measured values of Chadwick. Based on the watershed modeling, the magnitude increase in loading for the baseflow and storm event flow is 30-percent and 45-percent, respectively. Based on these magnitudes of increase, future conditions could be calibrated. As shown, baseflow conditions in the future total 5,268 pounds. The storm event flow totals 2,500 pounds. Assuming a 38-percent increase in measured loads going into the Reservoir, as predicted by the model, results in an approximate streamflow load of 7,768 pounds for the future condition. Continued water quality monitoring will refine predictions.

Table 4-9. Adjustment of the Watershed Model

Load Condition	Load, pounds			Flow, acre-feet		
	Current Condition	Future Condition	Percent Change[4]	Current Condition	Future Condition	Percent Change
Average Streamflow Load to the Reservoir (pounds)[1]	5,774	7,768	138%	9,857	13,465	137%
Baseflow/Storm Returns[2]	4,046	5,268	130%	6,993	9,269	133%
Storm Event Flow[3]	1,728	2,500	145%	2,864	4,196	147%

1) Average measured load to the Reservoir for current condition minus average load from precipitation (6,622 pounds – 848 pounds).
2) For current condition, measured values from Halepaska and Chadwick.
3) Average streamflow load to Reservoir minus measured baseflow.
4) Percent change based on 1998 Watershed model magnitude of change in loading from current to future condition.

SECTION 5

THE CHERRY CREEK RESERVOIR

The Authority has collected more than 12 years of data on the phosphorus and chlorophyll a relationship in the Reservoir and on phosphorus loading to the Reservoir. Data collected over the past decade strongly indicate that the assumptions about the chlorophyll a/phosphorus relationship in the first plan do not correspond with what is in the Reservoir.

RESERVOIR MONITORING– CURRENT CONDITION

The Reservoir monitoring program began as early as 1975, with sampling conducted by the COE. Another monitoring program (1984-86), conducted by the USGS, sampled roughly on a bi-weekly 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, Reservoir monitoring consisted of bi-monthly sampling, primarily throughout the May-September growing season. To provide additional information on seasonal cycles in the Reservoir, weekly sampling was conducted during the 1993-1997 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, have also been collected. The Colorado Division of Wildlife has collected fish population data. Figure 4-5 identifies sampling sites on the Reservoir and tributaries on State Parks property.

The COE has monitored total phosphorus in the Reservoir since 1975 and their data show the mean exceeded the existing 35 µg/L standard each year (Appendix D). In 1982, the year on which the phosphorus standard was based, the COE measured an average of 53 µg/L ($n = 4$ sample dates) during May-September, and their seasonal averages have ranged between 40 and 130 µg/L. From 1975-1984, the COE data had average phosphorus levels of 79.6 µg/L, an average of 84 µg/L from 1985 to 1991, and 86µg/L from 1992-1997. These mean values are not significantly different ($p < 0.05$), indicating that there have been no changes in phosphorus levels in the Reservoir over time. Other consultants and agencies who have monitored total phosphorus in the Reservoir have noted similar exceedances from the 35 µg/L standard each year, with an overall average of 59 µg/L, during May-September (Table 5-1) (Jones and CEC, 1998).

Earlier data collected by the U.S. EPA in 1975 had a mean phosphorus value of 52 µg/L, while the Colorado Water Quality Control Division (WQCD), which sampled in 1982 and 1983, had a mean phosphorus level of 29 µg/L and 103 µg/L, respectively. Combined, these historical data show a wide range in values, with few reported values meeting the current standard of 35 µg/L.

Since 1992, the University of Missouri (MU) has measured phosphorus in the Reservoir. This data collected is the most reliable information on conditions within the Reservoir. The data collected during 1992-1997 indicate that the lake supports a seasonal average phosphorus value of approximately 50-60 µg/L, and the phosphorus content of the lake has typically been within this range over the 1992-1997 period. Over this same time period, seasonal mean chlorophyll a values have averaged 15.7 µg/L.

Table 5-1. Mean Total Phosphorus (TP) on Cherry Creek Reservoir, May to September (From Jones/Chadwick, 1998)

	COE		USGS/ISI/ASI		MU	
	n	TP (µg/L)	N	TP (µg/L)	n	TP (µg/L)
1975	2	125	-	-	-	-
1976	2	55	-	-	-	-
1977	1	130	-	-	-	-
1978	1	40	-	-	-	-
1979	3	63	-	-	-	-
1980	3	73	-	-	-	-
1981	3	50	-	-	-	-
1982	4	53	-	-	-	-
1983	3	110	-	-	-	-
1984	4	110	3	57	-	-
1985	4	103	11	57	-	-
1986	4	130	10	48	-	-
1987	5	72	9	88	-	-
1988	4	68	10	70	-	-
1989	4	85	9	46	-	-
1990	4	80	10	55	-	-
1991	5	60	8	59	-	-
1992	3	97	9	48	6	54
1993	4	60			9	54
1994	4	75			8	54
1995	3	100			22	46
1996	4	65			21	54
1997					22	86
Average		**82**		**59**		**58**

FUTURE CONDITIONS IN THE RESERVOIR

In-Lake Modeling

Evaluating Chlorophyll a and Phosphorus Standards for Cherry Creek Reservoir. Using the MU data 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(chlorophyll a) = 1.15 log(total phosphorus) - 0.89.

Using the Jones-Bachmann equation, the goal of 15 µg/L chlorophyll a for the Reservoir would require that the lake contain an average of 35 µg/L total phosphorus, which is the source of the standard in the original Cherry Creek Reservoir Control Regulation. The Jones-Bachmann model does not fit what we have measured in the Reservoir, and as a practical matter, the Jones-Bachmann chlorophyll a/phosphorus model was used to back calculate a phosphorus standard for the Reservoir, which was heavily weighted towards natural lakes and did not include data from the Reservoir. Using the Cherry Creek Reservoir-specific regression equation based on individual points from 1992-1997, 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), where both chlorophyll a and phosphorus are seasonal means expressed as the average within the photic zone. 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 D). 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 TP value of 58 to 60 µg/L. The model by Jones *et al*. (1989), based on lakes in Nepal, shows a TP 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 5-2).

Table 5-2. Chlorophyll a-phosphorus models (Jones and CEC, 1998)

If Chl = 15 µg/L, then:			
Jones and Bachman	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.

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 an inappropriate phosphorus standard.

STATISTICAL EVALUATION OF SEASONAL MEAN TOTAL PHOSPHORUS IN CHERRY CREEK RESERVOIR

Dr. Mark Kaiser, Department of Statistics, Iowa State University, used a nonparametric bootstrap technique to estimate a seasonal mean value of total phosphorus and a 95-percent confidence interval for the Reservoir (Kaiser 1998) (Appendix E). The confidence interval provides information on the level of variability expected in a seasonal mean total phosphorus value for this lake. This information is needed to set a total phosphorus standard and monitor conditions over time so that we can evaluate whether a true "change" has occurred in total phosphorus levels. If estimates of the seasonal mean were to be consistently greater than the standard by an amount larger than expected, based on our estimated of inherent variability (using the 95-percent confidence interval), then we would infer that conditions had changed. However, if the amount of variability in the seasonal mean in within the expected range, the lake would be considered essentially unchanged.

The estimated seasonal mean total phosphorus was 59.6 µg/L. Among the 100,000 individual bootstrap estimates of the seasonal mean, the median value was 59.25 µg/L, and individual estimates ranged from 38 to 89.65 µg/L (Kaiser 1998). The upper endpoint of a one-sided 95-percent confidence interval was 77 µg/L. Therefore, the seasonal mean total phosphorus in the Reservoir during 1992-1997 was about 60 µg/L, with approximately 95-percent confidence that the true value was no greater than 77 µg/L.

The bootstrap procedure was also applied to the total phosphorus data collected by the COE during 1975-1984. The estimated seasonal mean total phosphorus for this period was 78.2 µg/L, the median value was 76.2 µg/L, and individual estimates ranged from 36 to 159 µg/L. These values are larger than estimates for 1992-1997 (based on MU data). It is reasonable to conclude from this analysis that total phosphorus has not increased from 1970s to the 1990s.

The bootstrap analysis of MU chlorophyll a data during 1992-1997 (May to September) found the seasonal mean value was 13.9 µg/L, the median was 13.8 µg/L, and individual values ranged from 6.2 to 25.8 µg/L. The upper 95-percent confidence interval endpoint was 20.2 µg/L. This outcome suggests that the true mean chlorophyll a value in the Reservoir during 1992-1997 was about 13.9 µg/L, with 95-percent confidence that this value was no greater than 20.2 µg/L.

Based on the bootstrap analysis, the seasonal mean total phosphorus in the Reservoir over the period 1992-1997 was about 60 µg/L (with approximately 95-percent confidence that this value is no greater than 77 µg/L). If the estimate of the true seasonal mean is used as the standard (60 µg/L), it follows that it would be unlikely that the annual seasonal mean would consistently exceed 77 µg/L unless there was a change in the lake.

Chlorophyll a/Phosphorus Standards for Cherry Creek Reservoir

Data collected over the past 12 years strongly suggest that the assumptions about the relationship between chlorophyll a and phosphorus contained in the original Master Plan (using the Jones-Bachmann model) do not provide a good fit for the Reservoir. The original goal of 15 µg/L chlorophyll a during the summer closely matches the observed in-lake concentrations averaged over time, and this value seems like a reasonable goal for the Reservoir. However, the use of the Jones-Bachmann relationship to develop a phosphorus standard to maintain the goal of 15 µg/L of chlorophyll a is not appropriate for this reservoir. Empirical data on chlorophyll a and phosphorus in the Reservoir show that the goal of 15 µg/L chlorophyll a is achieved with an in-lake mean phosphorus value of approximately 60 µg/L. A published "shallow" lake model from the OECD (1982) project provides a better fit with the Reservoir and provides a suitable replacement for the Jones-Bachmann model.

The original goal of protecting the trophic status of the Reservoir by maintaining a seasonal average chlorophyll a level of 15 µg/L seems reasonable, and represents conditions within the Reservoir. Monitoring data shows that in terms of a long-term average, this level is achievable, although it may be exceeded during any one year. As such, use of a rolling average is appropriate when determining a chlorophyll a goal for the Reservoir. This rolling average should be based on seasonal means during May through September to best reflect the period of recreational use of the Reservoir.

A recommended approach for the Reservoir would be a goal for chlorophyll a levels based on a 5-year rolling average chlorophyll a value of 15 µg/L (based on twice monthly measurements from May to September, averaged across seasons). Given present conditions within the lake, using the analysis of Dr. Kaiser, it would be expected that average chlorophyll a values will exceed 20 µg/L in some years, but it is unlikely that this value would be exceeded in consecutive seasons.

Using the OECD chlorophyll a-phosphorus model, an average chlorophyll a of 15 µg/L can be achieved with an average total phosphorus value of 60 µg/L. This value matches the long-term average phosphorus concentration in Dr. Kaiser's analysis of the Reservoir data. That analysis also suggests that seasonal mean phosphorus values for any individual year can exceed 77 µg/L (Kaiser 1998), and not represent an increase in total phosphorus levels in the Reservoir.

For the purpose of setting standards for the lake, it is recommended that the Reservoir maintain a goal of 15 µg/L chlorophyll a, in terms of a rolling 5-year average of seasonal means, computed from two observations gathered in each of the months from May to September. To achieve this goal, the phosphorus standard would be 60 µg/L, based on a 5-year rolling average of seasonal mean values, and computed from two observations gathered in each of the months from May to September. Within any 5-year period, if two consecutive seasonal means for phosphorus are greater than 77 µg/L, the standard will be considered to have been exceeded. If three consecutive seasonal phosphorus means are greater than 77 µg/L, or if any 5-year rolling average is greater than 60 µg/L, the Reservoir will be considered to be out of compliance with the standard, and the Authority would undertake corrective actions to bring the Reservoir into compliance.

REVIEW OF ORIGINAL PHOSPHORUS LOADING VS. IN-LAKE PHOSPHORUS MODEL DEVELOPMENT

The Clean Lakes Study (CLS) (CWQCD 1983) collected data from November 1981 to October 1982 in order to: 1) determine the physical, chemical, and biological water quality characteristics of the Reservoir; 2) determine the eutrophication related impacts from nutrient loading; and 3) assess the relationship of various nutrient control options to the future water quality of the Reservoir (CWQCD 1983). DRCOG used the CLS data with the Vollenweider model (1969) to predict total phosphorus loading of 14,270 pounds to meet the goal of in-lake phosphorus of 35 µg/L.

An initial analysis of phosphorus loads for the Reservoir attempted to recalculate the annual phosphorus load using the data provided in the DRCOG (1985) report (Jones and CEC, 1998). Using the Vollenweider equation from the CLS and the data reported by DRCOG, in order to obtain a phosphorus loading of 14,270 pounds to meet an in-lake phosphorus concentration of 35 µg/L, the inflow to the Reservoir would have to be 26,500 AF, four times the average inflow of 6,561 AF measured between the years of 1992 and 1997 (COE, unpublished data). Using this average inflow to the Reservoir, the goal of 35 µg/L in-lake phosphorus would result in an in-lake phosphorus load of 12,296 pounds (not 14,270 pounds), whereas the load of 14,270 pounds would result in an in-lake phosphorus of 41 µg/L.

Review of Alternative Loading Models for Cherry Creek Reservoir

In general, many of the existing loading models do not describe the relationship between external inputs (loads) and in-lake phosphorus values in the Reservoir. Using the input-output model of Jones and Bachmann (1976) with a sedimentation coefficient of 0.65, the external phosphorus loads averaged over 1992-97 would be expected to result in an in-lake phosphorus value of 135 µg/L. This estimate is some 2.3 times larger than the in-lake average phosphorus value of 58 µg/L. A general phosphorus loading model proposed by the OECD (1982) predicted in-lake phosphorus of 225 µg/L. This prediction is nearly 4 times the observed mean. A different phosphorus loading model based on phosphorus concentration in the inflow proposed by OECD (1982) predicted phosphorus content of Cherry Creek would be 82.4 µg/L, much closer to the observed mean value of 58 µg/L than several of the other empirical models.

One reason these general lake models do not fit the Reservoir is that, like many reservoirs, it seems to have a high rate of phosphorus sedimentation. During 1992-97 the phosphorus content of inflow from all external sources averaged 283 µg/L; meaning the mean phosphorus content of the lake water (58 µg/L) is only 20-percent of the inflow concentration. Rapid sedimentation of particulate phosphorus carried into reservoirs has been feature of phosphorus modeling and this has resulted in reservoirs being treated as a distinct from natural lakes (Jones and Bachmann, 1976).

Agreement between model predictions and observed phosphorus values improve when phosphorus loading models developed specifically for reservoirs are applied to Cherry Creek, or when models are adapted to conditions within this waterbody. The best "fit" appears to be provided by a model proposed by Nurnberg (1998), which is:

$$TP = (L/q_s) \times (1-R),$$

where TP is in-lake phosphorus, L is loading, q_s is the ratio of outflows to lake area, and R is a retention coefficient (in this case 0.87).

However, while these models provide reasonable predictions of the measured *average* P content of the lake during 1992-1997, the models are not sensitive to conditions within individual years. For example, during 1992-1996, seasonal mean lake phosphorus values ranged between 46 and 54 µg/L even though there was a 2-fold difference in external P loads during this period (range approximately 5,000 pounds in 1993 to over 10,000 pounds in 1995). And, despite a moderate input in 1997 (5,200 pounds), the in-lake P value was 86 µg/L, some 40-percent larger than the average during 1992-1997. This lack of response to variation in loads during individual years is not necessarily a function of the available loading models, but rather suggests that in-lake phosphorus values in Cherry Creek are responding to other factors in addition to external inputs.

Factors Potentially Affecting Response of Cherry Creek Reservoir to Phosphorus Loading

Internal loading of phosphorus is likely important in determining in-lake phosphorus values and appears to dampen the relation with external loads from specific years (Appendix F). Lake morphology is a key factor in determining the role of internal processes on summertime phosphorus concentrations in lake. In the Reservoir, the ratio of mean depth to the square root of surface area (an indication of the propensity for mixing) strongly suggests that internal loading can influence phosphorus levels. Lakes of this type stratify for brief periods and then undergo complete mixing of the water column. During stratification, phosphorus is released from the sediments by desorption of phosphorus from organic complexes and mineralization of phosphorus associated with organic material in the sediments.

The migration of phosphorus-laden algal cells from the lake bottom into the water column also is a likely mechanism for the translocation of phosphorus from the sediments by biogenic processes. In fact, summer increases in phosphorus in the Reservoir are often associated with the appearance of algal taxa, which germinate on the sediments (Jones and CEC, 1998).

Additional evidence from the literature suggests that phosphorus may be released from anoxic sediments into the water column under conditions of high pH and temperature by microbial breakdown of sediment organic matter or by direct release from sediment micro-organisms and subsequent release on a mirozone level. Aerobic release is also important when a large portion of the sediment is above the thermocline, as is the case for the Reservoir. The literature also notes the importance of secretion of nutrients by fish in the internal loading in a lake.

Another source of phosphorus to the deep water layer would be from nutrient rich inflow entering the Reservoir from tributary inflows, which if cooler, will plunge into the deeper layers of the lake as an underflow. Subsequently this phosphorus is mixed into the water column, and the process is considered internal loading.

Monitoring over the past six years shows that the phosphorus content of the Reservoir undergoes a seasonal pattern that is consistent in its general form but varies somewhat in absolute amounts and timing from year to year. Phosphorus values typically are between 45 and 60 µg/L during April and May, while in June they decline to about 30 µg/L. This decline is known as the "clear water phase" in many temperate lakes and is a time when grazing by zooplankton lowers algal biomass and water clarity improves. Sharp increase in phosphorus values follows in late June or July and values of 50 to >75 µg/L are measured in the lake during the July - September period, regardless of external inputs to the Reservoir during this period. This increase in phosphorus is likely a result of internal loading.

Phosphorus Loading and Cherry Creek Reservoir -- Seasonal Analysis

A descriptive model of phosphorus loading was developed to better represent seasonal in-lake phosphorus conditions within the Reservoir. The first step in this approach was to use the phosphorus loading during the October-May period to predict an in-lake phosphorus value during spring. If the models noted above are used, average predicted spring phosphorus values ranged from 48 to 74 µg/L (actual value 52.5 µg/L). Again, predictions using the formula by Nurnberg (1998) provided a close match between predicted (54 µg/L) and observed values (52.5 µg/L). It appears that empirical loading models based on loading and hydrology can provide a reasonable estimate of conditions within the lake prior to summer stratification.

A second step in this approach was to treat conditions in Cherry Creek during June as a period of transition. The decline in phosphorus to a seasonal low value of around 30 µg/L in June represents a decrease of some 30- to 45-percent in the phosphorus content of the lake relative to spring. This is probably an example of rapid sedimentation of phosphorus, most likely particulate forms.

The third step in this approach was to model the increase in phosphorus within the lake from June to the July-September period. Starting with how much phosphorus was in the lake in early summer (i.e., June) -- the point when it was at its seasonal low value, the amount of phosphorus entering the lake from external sources is determined, as well as the amount of phosphorus that left the lake in the outflow during this time period. With this information, internal phosphorus loads were arrived at by difference.

Typically the average phosphorus content of Cherry Creek during July-September is double the seasonal low in June. The calculations show that during the 1992-1996 5-year period, internal processes added an average of 291 Kg of phosphorus to the lake , which amounts to an average increase of 23 µg/L within the water column. This increase attributed to internal loading is 1.4 times that attributed to the external input during this same period (approximately 16 µg/L). This pattern was different in 1997. In July-September 1997, approximately 689 Kg phosphorus was attributed to internal loading; this was about 8.5 times the net external load and equates to an increase of about 54 µg/L of phosphorus within the lake water (or twice the average increase observed in 1992-1996). External inputs during July-September amounted to 270 Kg, equating to about 21 µg/L within the lake water. There is clear evidence that in 1997 the Reservoir underwent thermal stratification early in the season and upon subsequent mixing the lake was internally loaded with phosphorus (Jones and CEC, 1998).

Importance of Internal Loading

The analysis of internal loads suggests that during 1992-1996 internal processes added some 290 Kg of phosphorus to the lake annually, which amounts to about 10-percent to the annual phosphorus budget from external sources. This amount is equivalent to an increase within the water column during this time period of 23 µg/L phosphorus. Calculations suggest that internal loading in 1997 was about 2.3-times larger than internal inputs during 1992-1996. Approximately 689 Kg of phosphorus entered the lake water from internal sources and accounted for an increase of 54 µg/L. These internal processes occur within the time frame of the seasonal lake monitoring and likely affect the response of the lake to external annual phosphorus loads.

The data suggest that in a typical year, internal loading would be expected to match that observed during 1992-1996 and that the lake water will contain some 50 to 60 µg/L phosphorus as a seasonal mean (May to September) as a result. This is substantiated by the statistical evaluation of seasonal mean total phosphorus in the Reservoir (Kaiser, 1998). Occasionally, however, weather patterns will favor internal loading of the magnitude measured in 1997 and it is probable that in-lake phosphorus values will exceed 70 µg/L during those years.

Predictions of In-lake Response to Phosphorus Loading

Based on this analysis, it appears that existing published models of phosphorus loading for reservoirs can predict average in-lake phosphorus values for the Reservoir. However, these models are not responsive to specific year-to-year values (i.e. they only predict an average response). In addition, it is apparent that internal loading is an important feature in the Reservoir and can control seasonal mean in-lake phosphorus concentration during individual years.

While the phenomenon of internal loading is well known to the limnological literature, it is a phenomenon that is difficult to model. As such, determining an appropriate predictive model for external phosphorus loads to maintain a specific in-lake phosphorus goal is difficult. Nonetheless, it is necessary to use a predictive model to relate predicted changes in loads from the watershed under future conditions to possible in-lake phosphorus concentrations.

Of the models examined for use in the Reservoir, the model proposed by Nurnburg (1998) provided the best “fit” to the observed values. For this Master Plan update, a goal of in-lake phosphorus is proposed at 60 µg/L. Using the Nurnburg equation with the current lake conditions, for an in-lake goal of 60 µg/L, the average load should be approximately 6,840 pounds per year. The 1992-1997 average total phosphorus load into the Reservoir is estimated at 6,622 pounds, closely matching this prediction.

Modeling of future conditions has predicted an approximately 38-percent increase in loads from streamflows resulting primarily from an predicted increase or 37-percent in the volume of streamflows (Brown and Caldwell, 1998). This would result in an overall increase in total loads of roughly 8,600 lbs per year. This predicted future loading is well within the range of total loads observed over the past 6 years; loads which have resulted in an average summer in-lake phosphorus value of 58 µg/L.

Calculation of Allowable Loads Based on Future Conditions

With future predicted increases in streamflow of 37-percent, a new q_s for the Nurnberg equation was calculated for each water year (based on 1992-1997 data adjusted to the predicted future flows) and the expected load (L) was calculated to meet the in-lake goal of 60 µg/L. These were averaged over the six years, resulting in an average predicted allowable total load of approximately 9,775 lbs. If average loads from precipitation and alluvial inflows are subtracted (which would not be expected to change), this would result in an allowable streamflow load of approximately 8,370 lbs for future conditions. This represents a roughly 50-percent increase over current streamflow loads of 5,200 lbs.

Based on the analysis of the Reservoir response to external loads, the importance of internal loads to summer in-lake phosphorus concentrations, and the review of existing models describing this relationship, it is expected that the increased streamflows and loads predicted for future conditions would not result in a measurable change in average phosphorus concentrations in the Reservoir. Also, with increased streamflows and given that the Reservoir serves as a flood control reservoir, any increase inflows would, in necessity, result in increased outflows, otherwise flood control would be in jeopardy.

SECTION 6

MANAGING THE WATERSHED FOR WATER QUALITY

The ultimate goal of point and nonpoint source management in the Reservoir watershed is to reduce the quantity of pollutants that enter the Reservoir and to maintain watershed health. Nonpoint source management will be achieved by implementing facilities that provide protection beyond baseline BMPs, implementing the Cherry Creek Stormwater Regulation, and continuing comprehensive water quality monitoring in the watershed and the Reservoir to ensure that water quality objectives are being met.

MANAGING NONPOINT SOURCES

To protect the health of the Reservoir, a TMDL of 14,270 pounds of phosphorus per year (lb/yr) was originally established in 1985. Analysis of 12 years of water quality monitoring data and modeling in the 1998 Master Plan update suggests a TMDL of 9,800 pounds. The amount of this phosphorus TMDL that is allocated to nonpoint sources is 7,302 lb/yr. To ensure that nonpoint source loads remain below this allocation, BMPs are to be implemented throughout the watershed.

However, ensuring good quality water throughout the Reservoir watershed requires that nonpoint source management efforts go beyond controlling just phosphorus. 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.

POLLUTANT REDUCTION FACILITIES (PRFS)

As described in Appendix G, "Controls to Reduce Watershed Loading", a wide range of controls are applied to reduce pollutant loading from nonpoint sources within the Reservoir watershed. As a first level of control, baseline BMPs are applied throughout the watershed, both during construction and on a permanent basis. 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 proposed for incorporation into a watershed-based Trading Program within the Cherry Creek watershed.

PRFs are considered to be the second line of defense after baseline BMPs. PRFs go beyond baseline BMPs and were established with the expressed goal of reducing phosphorus and other pollutants. 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.
- To provide water quality protection in a sub-watershed that lacks adequate baseline BMPs due to present levels of development.
- To protect sensitive environmental areas within the Reservoir watershed, while enhancing water quality protection.

Characteristics of PRFs

PRFs can be a single or series of facilities to protect the water quality of Cherry Creek and Cherry Creek Reservoir, which go beyond baseline BMP requirements. Some examples of facilities that qualify as PRFs include: a facility that provides for extended detention of captured runoff (drain time of 12 hours or more of upstream water quality capture volume (WQCV), as defined in the Urban Drainage Flood Control District's (UDFCD) Volume 3), a facility that provides a constructed wetland with a surface area greater than 0.1 acre, a property used to maintain a buffer for environmentally sensitive areas, or a structure that stabilizes an existing erosion problem area and prevents future erosion along streambanks or the reservoir's shoreline.

Description of Existing PRFs

The Authority has constructed and is operating, maintaining, and monitoring four major PRFs in the Cherry Creek watershed, as shown in Figure 6: Shop Creek (1990), Quincy Outfall (1996), Cottonwood Creek (1997), and East Side Shade Shelter (1996). These initial PRFs, which are described below, are included in Phase I of the Trading Program.

Shop Creek. The purpose of the Shop Creek PRF is to slow stormflows and baseflows from its 725-acre drainage area, allowing suspended particles to settle out. As a result, 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 added. While this cyclical phenomenon has been documented for individual sampling events, the Shop Creek PRF has always shown an annual net removal of phosphorus.

Cottonwood Creek. The Cottonwood Creek PRF is essentially the same type of facility as the Shop Creek PRF with the purpose of slowing stormflows and baseflows. 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—7,500 acres. A second modification from the Shop Creek design is that the Cottonwood Creek PRF is followed only by a single wetland for polishing, due to its proximity to the Reservoir.

Quincy Drainage. The purpose of the Quincy Drainage PRF is to contain baseflows and slow stormflows by allowing rapid infiltration into the sandy soils at the terminus of this 530-acre drainage. Captured runoff quickly infiltrates into the sandy alluvium when 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 baseflow conditions. Outflow during precipitation/runoff events has been very limited, based on existing data.

East Side Shade Shelter. The East Side Shade Shelter PRF differs from the other three PRFs in its design and purpose. The East Side Shade Shelter PRF was constructed as a demonstration project to determine the effectiveness of shoreline stabilization projects. The project is located on the Reservoir shore immediately adjacent to a covered picnic area within Cherry Creek State Park. Adjacent to the picnic area is a paved parking lot that has historically drained directly into the Reservoir. The improvements involved controlling pedestrian access, rerouting erosive storm drainage, grading the steep bank, and stabilizing the toe of the bank with a rock toe and willow plantings. The East Side Shade Shelter PRF improvements have provided for water quality enhancement by repairing existing bank erosion, controlling pedestrian access, and infiltrating parking lot runoff. In addition, the improvements created an amenity for park users.

The four PRF projects provide a number of benefits, including detaining and filtering baseflows and stormflows, stabilizing the stream corridor, and enhancing the riparian zone with wetlands.

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 verify phosphorus and other pollutant removal capabilities. Additional information about the PRF effectiveness calculations is included in Appendix G.

STORMWATER QUALITY MANAGEMENT

A Stormwater Quality Conceptual Plan (Appendix H) was developed to ensure quality water throughout the watershed. The Conceptual Plan requires that efforts go beyond controlling phosphorus alone. Other constituents include sediment, nitrogen, and metals. Recommended measures also provide a net environmental benefit by improving riparian health and wildlife habitat.

The Cherry Creek Basin Water Quality Management Plan (1989 Plan) identified several measures for nonpoint source control. These measures included: (a) model best-management practices ordinance, (b) establishment of a disturbed land fee, (c) construction of pollutant reduction facilities in priority sub-basins, and (d) creation of the Authority to implement and regulate the programs. Whereas, each of these measures were implemented or initiated, this Conceptual Plan identifies more specific measures based on other factors, including:

- Nonpoint source watershed model,
- An assessment of development trends,
- Identification of environmentally sensitive areas, and
- Adoption of the Cherry Creek Stormwater Quality Model Regulation.

Nonpoint Source Watershed Model

The 1998 model supports identification of sub-basins with the greatest potential for nonpoint phosphorus loads and designation of priority areas for phosphorus controls. As shown on Figure 7, specific sub-basins have been identified as having the highest priority based on IDRs:

- **Reservoir Direct Flow Areas**. These areas continue to be the primary focus for the Authority due to the storm runoff that drains directly into the Reservoir with limited potential for load reduction during transport. In addition, substantial development has occurred within these sub-basins and additional development continues, particularly in direct flow areas (DFAs) No. 1 and No. 5.

- **Segment 1 from the Reservoir to the Parker Gage**. This reach includes sub-basins with the greatest area of development and, therefore, the largest phosphorus load potential. Cottonwood Creek commercial development and Piney Creek residential development both contribute large annual loads to the Reservoir, approximately 1,000 pounds each. In addition, the stormflow IDRs in this reach is the highest, resulting in greater loads delivered to the Reservoir by Cherry Creek from sub-basins draining directly to the Creek.

- **Segment 2 from the Parker Gage to the Franktown Gage**. The stormflow IDR within this reach is about one third of that in Segment 1, the annual load contribution from Sulphur Gulch (i.e.: 350 pounds) suggests that control measures are needed sooner than other sub-basins in this segment.

Development Trends

The sub-basins with the greatest areas of development continue to be the highest priority in Segment 1. However, as the result of the Authority's role in review of land use changes and observations in the watershed, other important trends have been identified.

There are a number of developments in the watershed which are providing large detention areas that control sub-basins from 100 acres up to several hundred acres. Many of these detention ponds include water quality control features and the ponds, which were designed based on all tributary areas contributing to the detention pond. In addition, since environmentally sensitive developments have become good business practice, some developments include measures along the drainageways that further enhance storm water quality, as well as providing an aesthetic environment that increases property values. These trends provide opportunities for PRFs through retro-fit projects for existing sites and cooperative projects for developing sites.

Environmentally Sensitive Areas

Some locations within the Reservoir watershed are more sensitive to impacts from stormwater runoff. For example, wetlands, riparian habitats, and groundwater recharge areas can be affected by urban runoff and, therefore, require additional protection than afforded by baseline BMPs. New development is within environmentally sensitive areas are required to further enhance water quality protection beyond minimum levels by providing for infiltration of storm runoff using such measures as grass swales, grass buffer strips or wetland channels.

Currently, environmentally sensitive areas include the Cherry Creek alluvium area and jurisdictional wetlands outside of the alluvium. Identification of sensitive areas is an ongoing process and additional areas may be included in the future.

Model Stormwater Quality Regulation

In June 1997, members of the Cherry Creek Basin land use agencies and the Authority formed the Stormwater Quality Committee to improve stormwater quality management within Cherry Creek Basin. The committee developed a model Stormwater Quality Regulation (Appendix I) for land use agencies to adopt in their own respective programs. The purpose of the model Stormwater Quality Regulation (Regulation) is to control the quality of stormwater runoff from private and public property and to reduce the loads of sediments and nutrients reaching Cherry Creek and Cherry Creek Reservoir. The standards and controls set forth in the model regulation are necessary to reduce and maintain nonpoint source phosphorus below the load allocation.

The Authority and the agencies responsible for land use and nonpoint source control throughout the Reservoir watershed worked together to develop a model regulation that is flexible and can be incorporated into each jurisdiction’s existing drainage requirements. The model regulation establishes minimum requirements for construction and permanent stormwater quality BMPs and identifies special requirements for land disturbances related to industrial and agricultural land use and in environmentally sensitive areas.

The model regulation includes the following minimum requirements for construction:

- Phase construction
- Reduce stormwater runoff flow to non-erosive velocities
- Protect Drainageways from erosion and sediment damage
- Control Sediment Before it Leaves Construction Site
- Stabilize Soils
- Revegetate disturbed soils

The model 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. The goal of the model regulation BMPs is to provide greater than 50-percent phosphorus reduction in the basin. The model regulation also encourages regional water quality facilities that can be more cost-effective and can be integrated into open space, parks, and golf courses. Industrial facilities must meet the minimum requirements for permanent BMPs and also satisfy the following additional special requirements designed to prevent or reduce the amount of pollutants generated or released from and industrial development:

- Implement source reduction practices
- Reduce exposure of materials with stormwater
- Provide an emergency response plan for spills and leaks

A program to monitor and enforce BMP implementation is also addressed by the model regulation. Land use agencies are being requested to adopt this model Regulation into their respective programs. A copy of the model Stormwater Regulation is provided in Appendix I.

ALLUVIAL WATER QUALITY PROTECTION

The alluvial groundwater has been classified for drinking water supply and agricultural uses. Most of the dischargers in the Cherry Creek Basin rely on the Cherry Creek alluvium as a source of water supply. As such, alluvial water quality protection is a concern for the Authority and member entities. The Colorado Department of Health and Environment’s Colorado Wellhead Protection Program provides a framework for protecting groundwater drinking sources, such as delineating wellhead protection areas, identifying potential contaminants, and developing management approaches and contingency plans. Land use agencies within the watershed take primary responsibility for implementing their own wellhead protection programs, however, the Authority serves as a resource, with its comprehensive groundwater monitoring programs in place.

MANAGING POINT SOURCES

All wastewater treatment facilities provide advanced phosphorus removal either throughout tertiary treatment or secondary/tertiary treatment followed by land application. Permitted phosphorus concentration for direct dischargers is based on at total phosphorus effluent quality of 100 µg/L or better at the design capacity of the treatment plant. Permitted phosphorus concentration of land application is 200 µg/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.

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.

WASTELOAD ALLOCATION

The DRCOG Clean Lakes Study (1983) recommended the adoption of annual phosphorus allocations for each wastewater treatment plant in the Cherry Creek Basin, as well as loading from nonpoint and other sources, in terms of pounds of phosphorus per year. These allocations were adopted by the Water Quality Control Commission as part of the Cherry Creek Control Regulation in 1985. The pounds of phosphorus allocated to each plant were anticipated to be adequate for the plant's 1985 capacity plus the next increment of plant expansion. This 1998 Master Plan warrants modification to the original wasteload and load allocations, taking into account water quality data from the watershed and Reservoir, modeling, updated allowable loading to the Reservoir and future needs of dischargers.

The 1998 wasteload allocation was determined by designating existing WWTFs, defining future needs (plant expansions and discharge projections), and apportioning the phosphorus among dischargers. The WLA also takes into consideration allocation for new development in the basin, such as prospective development by Rangeview Metropolitan District and Happy Canyon Ranch. The WQCD requires that WLAs both be equitable to existing and future discharges, and meet water quality standards for the predicted 20-year planning period. The wasteload allocation assumes a recommended effluent limit of 100 µg/L for phosphorus for direct dischargers to Cherry Creek and its tributaries and 200 µg/L for land application.

Wastewater Flow Projections

With increases in population, the capacities of the existing wastewater treatment plants will need to increase and new facilities will be necessary. Wastewater flow projections were obtained from the local governments and are based on employment and population projections by service areas. Table 6-1 summarizes current discharge and projected wastewater flows.

Table 6-1. Wastewater Flow Projections

Service Area	Current Discharge, mgd	2008, mgd	2018, mgd
Castle Rock[1]	0.43[1]	1.32	3.02
Pinery	0.50	1.30	2.00
Parker[2]	1.25	2.57	4.07
Stonegate	0.40	0.76	1.50
Arapahoe	0.70	1.04	1.28
Cottonwood	0.24	0.62	1.00
Meridian	0.05	0.80	1.50
Inverness	0.34	0.84	0.91
New Development	0.00	1.56	3.93

[1] Castle Rock includes WWTFs at Cherry Creek, McMurdo, Mitchell, and Newlin Gulch. Castle Rock currently discharges to Plum Creek.
[2] Includes the North Parker WWTF and the South Parker WWTF.

Apportioning the Phosphorus Among Dischargers

As mentioned earlier in the plan, the total allowable load to the Reservoir is approximately 9,800 pounds per year. This is based on the in-lake phosphorus modeling and recommended in-lake phosphorus standard of 60 µg/L and chlorophyll a goal of 15 µg/L. The allocation evaluated future needs of the dischargers while staying well below the total allowable loading to the Reservoir.

As empirically shown, phosphorus contributions from wastewater treatment plant discharges are minimized before reaching the Reservoir by natural assimilation and infiltration throughout the reaches of Cherry Creek, hydrologic connection, and extensive groundwater use in the basin. The baseflow IDRs are appropriate to apply in the wasteload allocation to reflect actual reduction in phosphorus loading to the Reservoir due to chemical and flow conditions. The baseflow IDRs are derived by evaluating percent losses between segments due to hydrology and pumping in the basin. Figure 6-1 illustrates the baseflow delivery ratios that will be applied to dischargers in the Cherry Creek Basin. As indicated, phosphorus loading to the Reservoir by a WWTF depends on the location of the discharge in the basin and its corresponding baseflow IDR.

Additionally, with those dischargers that land apply effluent, land application return flow factors are applied to take into account the amount of phosphorus uptake by vegetation and assimilation of phosphorus prior to reaching the creek. A zone map of land application zones in the Cherry Creek Basin and general description of this study is provided in Appendix K. The Authority proposes using geologic conditions and distances from streams to evaluate the potential return flows to the stream system from land application areas. The basis of this work is in the State Engineer's Office groundwater return flow studies and evaluations. As shown, three land application return flow zones are proposed;

1) 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 recharge to the stream hydrology. In these areas, it is assumed that there would be 100-percent return flows at the point where the discharge enters the alluvial aquifer system. No attenuation of the effluent concentration is assumed as it flows downgradient in the alluvial aquifer.

2) In areas located adjacent to the alluvial systems where colluvial soil types are such that there will be some return flows to the stream system, but there will also be attenuation of flow due to retention of water in the unsaturated zone and water use by phreatophytes. In these areas, we are estimating that return flows to the stream system would be more on the order of 50-percent of the return flows immediately below the land application areas.

3) In areas outside these two zones (upland areas which either contain soils not conducive to water movement or that are large distances from the existing stream channels), it is assumed that there would still be a limited amount of return flow from these areas (estimated to be 25-percent as opposed to 0-percent used by the State Engineer).

The Authority will continue monitoring in the basin to verify these delivery ratios and return flow factors. The wasteload allocation is summarized in Table 6-2. As shown, of the total allowable load of 9,800 pounds, approximately 15-percent of the load, or 1,500 pounds, is allocated to point source discharges.

Table 6-2. Wasteload Allocation

Discharger	Allowable Load to Reservoir, Pounds
Castle Rock	165
Pinery	110
Parker	297
Stonegate	187
Arapahoe	160
Cottonwood	125
Meridian	94
Inverness	57
New Development	306
Total	**1,500**

The wasteload allocation for each discharger takes into account appropriate baseflow IDRs and land application return flow factors. An allocation of 306 pounds for new developments was also created to provide for future allocations to existing WWTFs to serve new areas, to new WWTFs, and to un-designated, un-listed new WWTFs. Those facilities that are undesignated will require a plan amendment before receiving an allocation. Additionally, there will be a preference for allocations to new areas that will be served by existing WWTFs.

WATERSHED-BASED PHOSPHORUS TRADING PROGRAM

The Phosphorus Trading Program allows point source dischargers to receive credit for new or increased phosphorus wasteload allocations in exchange for phosphorus load reductions from PRFs. The Trading Program provides for two types of trades: (1) Authority Pool trades and (2) In-Kind trades. Authority Pool trades are premised upon a Trading Pool of discharge credits from Authority controlled nonpoint source projects. The Authority has currently allocated a credit of 461 pounds to the trading pool from the four largest and most well established nonpoint source projects---Shop Creek, Cottonwood Creek, East Shoreline and Quincy Outfall. Only PRFs that remove phosphorus beyond minimum BMPs will qualify for trading. Dischargers who wish to purchase credits from the Trading Pool must demonstrate need for the credits, treatment efficiency of the applicant's facility, the facility's compliance with effluent limitations, reasonableness of the facility's plans for expansion and requested credits, net effect on water quality in the Basin, and consistency with the Control Regulation, Master Plan and Trading Guidelines. Appendix L, "Phosphorus Trading Guidelines", provides more detail on the trading program.

Potential In-Reservoir Control Strategies
(Section needs to be provided by Canton)

SECTION 7

IMPLEMENTING THE PLAN

One of the significant elements of the 1989 Master Plan update is to address implementation of the Cherry Creek TMDL. This section discusses the allocation of phosphorus loading to meet water quality standards in Cherry Creek Reservoir and long term monitoring and enforcement programs that ensure the water quality standards and allowable loading are not exceeded.

TMDL ALLOCATION

The Total Maximum Daily Load process is designed by the Federal Clean Water Act to ensure that all sources of pollutant loading are accounted for when devising strategies to meet water quality standards. The TMDL is an estimate of the greatest amount of phosphorus the Reservoir can receive without violating the phosphorus standard of 60 µg/L. Based on water quality monitoring and modeling, the annual pollutant loading to the Reservoir is 9,800 pounds per year.

Table 7-1 summarizes the allocation categories for allowable loading to the Reservoir. As shown, there are allocations for point and nonpoint (background and storm event flow sources), precipitation on the Reservoir and an emergency allocation. Annual loads total 8,800 pounds. Therefore, the difference between the TMDL and the annual load, or approximately 1,000 pounds, is designated as a margin of safety.

The “background/returns” allocation, totaling 3,768 pounds, includes future background loading from groundwater, surface water, and ISDSs. Baseflow loads are the sum of background and point sources. The “storm event flow” allocation of 2,686 pounds reflects future stormflow loading to the Reservoir (2,500 pounds) and the existence of the Shop Creek PRF and its phosphorus removal capabilities averaging 186 pounds. Since the stormflow model reflected a period when the Shop Creek PRF was fully established (1995 – 1997) and providing reductions in phosphorus loading, this phosphorus reduction must be taken into account and allocated in the “storm event flow” allocation. Nonpoint sources are included in both the “storm event flow” allocation and the “background/return” allocation. The “trading pool credit” reflects the four PRFs providing phosphorus reduction credits totaling 461 pounds, which was authorized in 1997 by the WQCC. The precipitation allocation is based on average precipitation loading on the Reservoir from 1992 – 1997, totaling 848 pounds. The emergency allocation of 459 pounds is identified in the Cherry Creek Control Regulation and retained specifically for temporary, emergency phosphorus allocations. Given a TMDL of 9,800 pounds and the annual load allocation of 8,800 pounds, a margin of safety is provided totaling approximately 10-percent of the total maximum load, or 1,000 pounds.

Table 7-1. Comparison of 1998 and 1985 Cherry Creek TMDL

Allocation Category	1998 TMDL Pounds	Percent	1985 TMDL Pounds	1985 TMDL Percent
Background/Returns (gw, sw, ISDSs, and stormwater returns)	3,768	39	930	6.5
WWTFs		15	2,360	17
Existing WWTFs	1,194			
New Development WWTFs	306			
Storm Event Flow	2,686	28	10,290	72
Trading Pool Credit	-461			
Precipitation	848	9	690	4.5
Emergency	459	5		
Total Annual Load	8,800			
Margin of Safety	1,000	10		
Maximum Allowable Load (TMDL)	**9,800**		**14,270**	

MONITORING AND ENFORCEMENT

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 downgradient capture capacity (such as detention/retention facilities followed by wetlands), thereby providing additional water quality protection.

Nonpoint Sources

Annual Watershed and Reservoir Monitoring. Monitoring programs will continue to ensure that water quality standards and allowable loading are not exceeded. Data collected will also be used to further verify IDRs and refine models used for the Reservoir and watershed.

Stormwater Quality Model Regulation. Jurisdictions in the watershed will be required to adopt stormwater quality ordinances, such as the stormwater quality control model regulation developed by the Authority. 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. The standards and controls set forth in the regulation are necessary to reduce and maintain nonpoint source phosphorus below the load allocation. As described above, this 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:

- **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 the watershed on a limited basis to verify that BMPs are implemented per approved plans.

FUTURE COOPERATIVE PROGRAMS AND CAPITAL IMPROVEMENT PROJECTS

Future PRF Locations

A detailed storm drainage-quality plan will be prepared to identify and site up to 10 potential PRFs for inclusion in a 5- or 10-year plan for the watershed. The detailed plan will focus on priority areas identified in our stormwater planning process;

- Segment 1 Direct Flow areas
- Cottonwood Creek or Piney Creek sub-basins
- Environmentally sensitive areas
- Sulphur Gulch
- Other areas deemed important by the Authority

Evaluation of potential PRF sites will include site inspection, property ownership from tax records, a preliminary site plan, a cost estimate, and rating for pollutant removal and cost-effectiveness.

Regional BMP Enhancement

There are projects being planned that include large regional BMPs, such as Challenger Park in the Town of Parker. Because of the size and number of large BMPs constructed by third parties there is an opportunity to enhance existing facilities to PRF status, thereby providing benefits to the owner and the Authority. PRFs must meet specific criteria and specifically go beyond 50-percent baseline BMPs. Enhancements could include improved maintenance access, construction of littoral zones, pre-treatment area, enlargement of WQCV, or downstream wetlands.

Stream Stabilization

Measurements of in-situ phosphorus content suggest that stream banks in Cherry Creek can contain as much as two pounds of phosphorus for every cubic yard of soil. For one mile of stream, the potential phosphorus contribution by erosion is from 1,000 to 2,000 pounds for each foot of horizontal bank erosion. Contributions from large watersheds, such as Cottonwood and Piney Creeks, are on the same order. Two stream stabilization projects are recommended:

- **Cherry Creek from Arapahoe Road to the County Line**. Stream bank stabilization is recommended in the 1985 Feasibility Study of Cherry Creek from Arapahoe Road to the county line and the current Corridor Outfall Systems plan (see above). This reach of Cherry Creek is a high priority. It is recommended the 1985 Plan be updated and an implementation plan and schedule be developed.

- **Cottonwood Creek below Peoria Street**. This stream segment is a component of the Lower Cottonwood Creek Water Quality Plan and a high priority in Segment 1. The project has been jointly funded project by public and private interests, however, it is currently stalled due to regional traffic issues with widening of Peoria Street.

ONGOING CHERRY CREEK BASIN STUDIES

As water quality issues in the Cherry Creek Basin have evolved, the Authority has taken proactive measures to study or evaluate these special topics of concern. Future special study issues may include addressing water quality impacts of highway development, agricultural loads, animal waste, and additional nonpoint source controls. Two ongoing studies, septic tanks/leach fields and public education, are generally described below.

Evaluation of Water Quality Impacts from Septic Tanks/Leach Fields

It is unknown what the actual contribution is from septic tanks/leach fields, particularly as a function of distance from the stream system. To evaluate the potential impact on water quality in the upper Cherry Creek Basin and ultimately to the Reservoir, the Authority has authorized a study to assess this issue. The study is not designed to evaluate the actual water quality discharging from individual sewage disposal systems (ISDSs), but is focused instead on the potential movement of discharges from ISDSs and whether phosphorus and nitrogen species are assimilated through geochemical or biochemical processes, or whether these species are transported downgradient into the mainstem Cherry Creek system (Halepaska, 1998).

As a test case, two drainages in the upper Cherry Creek Basin watershed were selected for the study due to heavy development in these watersheds using septic tanks and leach fields. These two drainages are Bayou Gulch and Baldwin Gulch. Four monitoring well locations have been 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 downgradient. Similarly, monitoring wells have been located in the Baldwin Gulch alluvial aquifer to monitor downgradient 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. When the phosphorus data from the Bayou Gulch and Baldwin Gulch monitoring wells are compared to similar time frame phosphorus data on the mainstem of Cherry Creek, the phosphorus concentrations are consistent with background phosphorus data, and there doesn't appear to be a water quality impact due to the concentrated use of ISDSs. Therefore, the initial conclusion regarding phosphorus impacts due to ISDSs is that they are not a source of nonpoint increases in phosphorus loads that are being observed in the Phase I Baseline Study.

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 ISDSs in this area.

Ongoing data collection efforts will help refine the impacts of these constituents from ISDS discharges on water quality in the watershed, and ultimately the Reservoir. More detail on the study is found in Appendix M.

Education/Public Information

The Authority has undertaken a public information program. Since 1996, the program has assisted in informing the general public about water quality in the Upper Cherry Creek Basin, 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. The public information program has also been responsible for designing signage in the park that describe water quality benefits of the PRFs, such as Shop Creek, on the Park property. This program will continue to identify future areas to further educate the public on water quality protection in the watershed.

INSTITUTIONAL ROLES

The Authority's Responsibility

Legal, institutional, managerial capabilities
Financial capabilities

Cooperative Partnerships

Land Use Agencies
Water Quality Control Division
Urban Drainage
State Parks

Required Approvals

DRCOG
WQCC
EPA

Appendix C
Cherry Creek Reservoir Watershed Modeling

INTRODUCTION

Empirical data and water quality models have been applied to the Cherry Creek Watershed to help provide a scientific basis for the Master Plan Update. Specifically, the models provide a characterization of constituent loadings to Cherry Creek and the Cherry Creek Reservoir resulting from point and nonpoint sources for two development conditions - current (1997) and future (2020). To date, the primary focus of the modeling has been on phosphorus, but these models could address other constituents (e.g., nitrogen and suspended solids) in the future. The watershed models can be applied to support a number of evaluations within the watershed, including:

- estimation of current and future loading in the watershed,
- re-evaluation of the 1985 phosphorus Total Maximum Daily Load (TMDL) allocation,
- identification of sub-basins with the greatest potential for phosphorus loadings, and
- development of priority areas for phosphorus controls.

The watershed models can also be linked to models for the Cherry Creek Reservoir to provide a comprehensive picture of water quality within the Cherry Creek Basin.

Historical Background

Annual phosphorus loads were previously modeled for the Cherry Creek basin as part of the Cherry Creek Basin Water Quality Management Plan [DRCOG, 1985]. Phosphorus loadings were projected for the years 1990, 2000, and 2010 for three sources; point, nonpoint, and background stormwater runoff sources[1]. As summarized in Table 1, modeling performed by the Denver Regional Council of Governments (DRCOG) estimated nonpoint loading from the watershed of approximately 10,835 pounds, 21,531 pounds and 43,909 pounds for the years 1990, 2000 and 2010, respectively. These projected nonpoint source loadings did not reflect any reductions in loading from nonpoint source controls in the basin. Also, it was assumed that <u>all</u> phosphorus generated in the watershed was delivered to the reservoir, which does not account for the fact that Cherry Creek is a losing stream through most of the upper reaches. More recent data and studies provide a basis to refine this initial assumption.

[1] Background sources are defined in the 1985 Master Plan to include only precipitation, net groundwater, and baseflow and do not include point sources, nonpoint sources, septic systems, or industrial sources.

Table 1. Summary of Historic Predictions of Annual Phosphorus Loading to Cherry Creek Reservoir [from DRCOG's Cherry Creek Basin Water Quality Management Plan, 1985]

Total Phosphorus Loads, lbs/yr	Year 1990	Year 2000	Year 2010
Point Source Load	657	2,310	4,210
Nonpoint Source Load	10,835	21,531	43,909
Background Load	1,170	1,170	1,170
Total Load	12,662	25,011	49,289

The combination of point, nonpoint, and background sources of phosphorus were used to define the annual phosphorus load to the reservoir, once again, assuming no losses of phosphorus generated from the watershed and subsequently delivered to the reservoir. The Canfield-Bachman in-lake phosphorus model was applied to relate in-lake phosphorus concentrations to total estimated annual loads. The model was the basis for setting a maximum load of 14,270 pounds that could enter the reservoir annually to maintain the 0.035 mg/L total phosphorus standard. To maintain a maximum annual load of 14,270 pounds, a basinwide goal of 50% phosphorus reduction for nonpoint sources was established.

1998 Cherry Creek Watershed Model Overview

In 1998, Brown and Caldwell has developed a conceptual watershed model for the Cherry Creek basin that includes two components: 1) the Cherry Creek Stormflow Model, and 2) the Cherry Creek Baseflow Model. The stormflow model includes two sub-components, which describe a) watershed loadings to the creek, consisting of nonpoint stormwater runoff and b) transport and delivery of those loadings downstream to the reservoir. The baseflow model accounts for the constituent loads delivered to Cherry Creek Reservoir during non-storm flow periods by integrating surface and alluvial ground water. Figure 1 illustrates the total phosphorus loading to the reservoir as estimated by the sum of loadings from the baseflow and stormflow components.

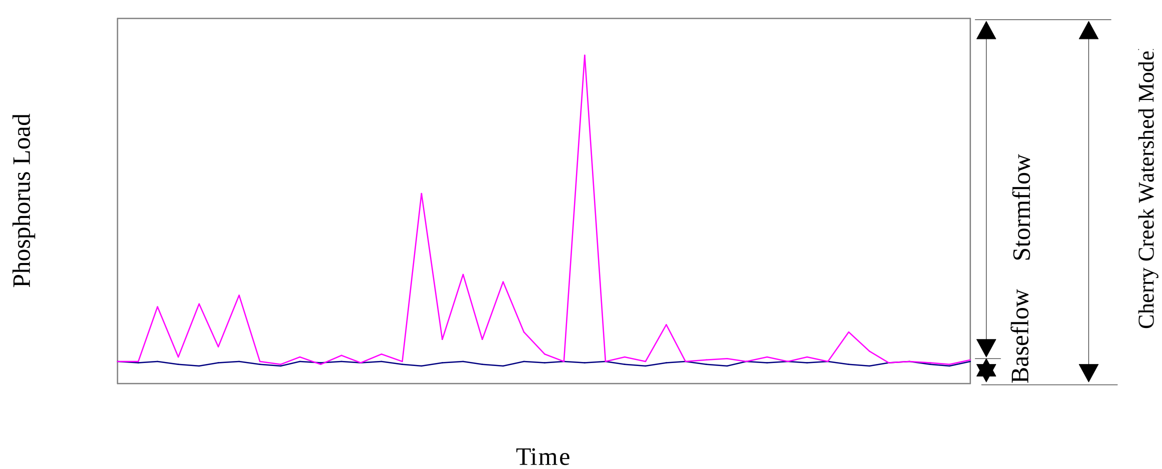

Figure 1. Conceptual Pollutant Load accounted for by Baseflow and Stormflow Components in the Cherry Creek Watershed Model.

CHERRY CREEK STORMFLOW MODEL

The Cherry Creek Stormflow Model accounts for constituent loads delivered to Cherry Creek Reservoir as a result of precipitation events in the watershed. Figure 2 conceptually illustrates the watershed model for stormflow (nonpoint source) constituent loading to Cherry Creek Reservoir. The two sub-components of the Cherry Creek Stormflow Model, loading and transport, are described in more detail below.

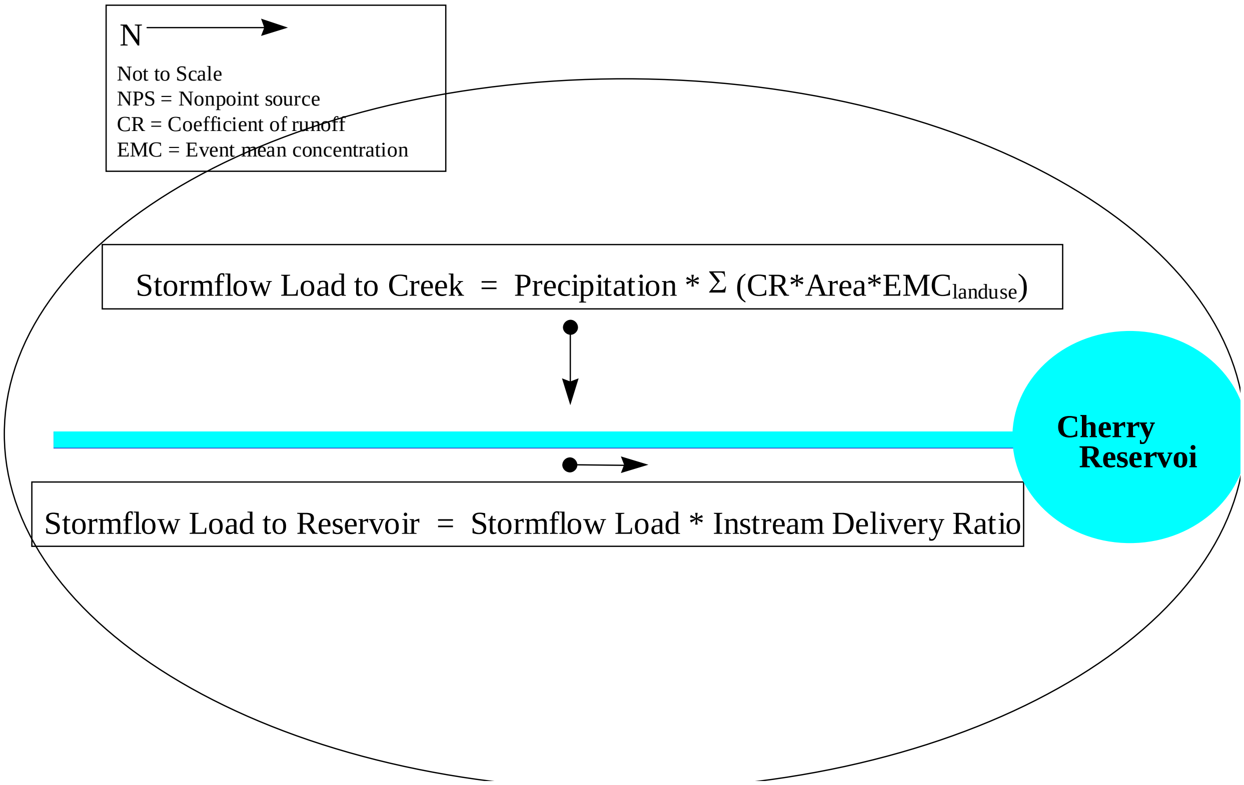

Figure 2. Watershed Model for Stormflow Constituent Loading to Cherry Creek Reservoir.

Stormwater Runoff Loading Sub-component

Nonpoint sources of phosphorus were evaluated through the application of a spreadsheet model, using the Simple Method (Metropolitan Washington Council of Governments (MWCOG), 1983b) to estimate loadings to Cherry Creek from the surrounding watershed. The Simple Method calculates loads based on two primary components—hydrology and water quality. The hydrology component uses simple rainfall/runoff relationships to estimate the amount of precipitation that becomes runoff. Factors affecting runoff volume include the quantity of rainfall and physical characteristics of the land. The water quality model component uses average constituent concentration in storm runoff to estimate the pollutant load from a storm event. Currently, in the Cherry Creek Reservoir watershed, total phosphorus is the primary constituent of concern. Both water quality and quantity are affected by human activity (land use) and various natural physical characteristics of the land, including soil type, vegetative cover, soil moisture, and slope. The variables used to calculate runoff volume and water quality are discussed in more detail below.

Hydrology. The Cherry Creek Stormflow Model assumes that the amount of water that becomes runoff is a function of three variables: precipitation, surface area, and a coefficient of runoff. For purposes of this analysis, precipitation includes only rainfall and not snowfall. Although a rapid snowmelt event could produce runoff, snowfall was assumed to contribute to runoff over a longer period than rainfall and, therefore would be included in the baseflow component. The selection of precipitation events to use for the analysis is discussed in detail later.

The coefficient of runoff (CR) is the ratio between the total amount of rainfall and the amount of precipitation that becomes runoff. The coefficient is dependent on land use, as characterized by impervious area. A high value represents a largely impervious surface that converts most rainfall into runoff, such as a parking lot. A low value represents a surface that retains or intercepts most rainfall and yields little runoff, such as a vegetated undeveloped area.

Water Quality. To quantify constituent concentrations in stormwater runoff, samples are taken during a runoff event and composited to account for variations in concentrations during the runoff period. The average concentration during the storm event is referred to as the event mean concentration or EMC.

$$EMC = \frac{\text{Total Load (mg)}}{\text{Total Flow Volume (L)}}$$

Stormflow Loads. Both runoff volume and EMC's are directly related to land use. For this reason, the load contributed from each land use type is calculated separately and totaled for the basin, so that

$$\text{Total Stormflow Load} = \text{Precipitation} * \Sigma(CR * Area * EMC)_{\text{by land use area}}$$

Where:

Total Stormflow Load = mass/year
Precipitation = inches/year
CR = coefficient of runoff, unitless
EMC = event mean concentration, mass per unit of volume

Model Inputs

The Cherry Creek Stormflow Model requires the following information:

- acreage of a specified basin or sub-basin;
- land use of basin or sub-basin, such as open space (or undeveloped), residential, commercial, and industrial;

- average annual rainfall for the basin, in inches;

- coefficient of runoff (CR) for each land use type, unitless; and

- event mean concentration (EMC) for each constituent of concern for each land use type, mg/L.

An overview of each component is presented below, with greater detail in Attachment A.

Sub-basin Delineation. The acreage of each land use for each sub-basin within the Cherry Creek Reservoir watershed was provided by DRCOG using its geographic information system and database for MetroVision 2020. The 31 sub-basins described in the original Cherry Creek Basin Master Plan (1985) were delineated onto United States Geological Survey (USGS) 1:24,000-scale topographical maps for the purposes of this evaluation. The Cherry Creek Master Plan and Urban Drainage and Flood Control District (UDFCD) mylar overlays depicting the sub-basins were used as references in the delineation process. Where the USGS' topography was revised to reflect altered stream channels, sub-basin delineation's were likewise revised.

When all sub-basins were delineated onto the USGS topographic maps, the subbasins were digitized into a GIS using the ARC/INFO™ GIS software. ARC/INFO™ is a product of Environmental Systems Research Institute (ESRI). Existing digital GIS data were imported to the sub-basin coverage for the outline of Cherry Creek Reservoir and the Shop Creek basin. These data were acquired from the USGS 1:24,000-scale Digital Line Graph (DLG) data sets and the City of Aurora, respectively. Each of the sub-basins are represented with the identification number assigned in the original 1985 Cherry Creek Master Plan. There are 31 sub-basins, including the body of Cherry Creek Reservoir. The GIS coverage is in the Central Colorado State Plane, 1927 datum projection. The basin GIS data were also converted into the ArcView™ (ESRI) Shapefile format. Figure 3 illustrates the resulting sub-basin delineation of the Cherry Creek Reservoir watershed.

The sub-basin GIS coverage (both formats) was then provided to DRCOG for land use percentage processing. Four categories of land use were used for the model —residential, commercial, industrial, and undeveloped. Final review of the 1997 land use acreage data from DRCOG revealed a shortfall of approximately 20,000 acres as compared to a total of approximately 247,000 acres for the entire watershed. It is believed that part of this is because DRCOG does not assign land uses to land area that falls within El Paso and Elbert counties. A percent weighting procedure was used to account for the difference in acreage (see Attachment A, 'Revised Table 1b'). The sub-basin areas in the revised land use table were used for the watershed loading model. Final review of the 2020 land use acreage data revealed a shortfall of approximately 40,000 acres for the entire watershed. Similar weighting procedures were used to revise the 2020 estimates.

Cliff Map

Watershed Land Uses. The Cherry Creek Stormflow Model was specifically applied to estimate current and future loading to the watershed using land use data from the DRCOG. Conditions were modeled for the years 1997 and 2020 to predict how changes in nonpoint source loads might impact Cherry Creek Reservoir. Comparisons of undeveloped acreage between current and future conditions indicates an 11,000 acre difference. The watershed land use acreage expected for the 2020 condition is illustrated in Figure 4. As shown, a relatively large portion of the basin remains undeveloped in comparison to residential, commercial, and industrial for the 2020 condition. 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 Cherry Creek basin.

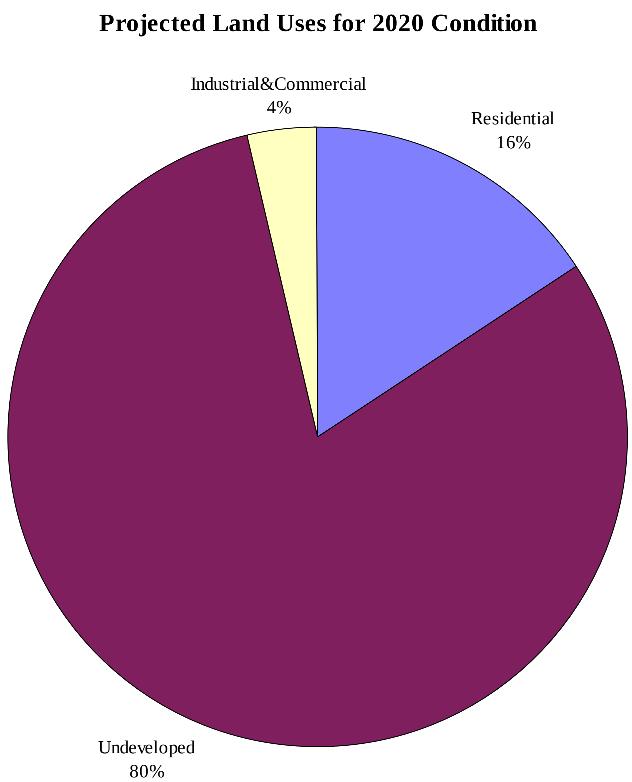

Figure 4. Land uses for 2020 condition.

Stormwater Runoff Hydrology

Site-specific model refinements were required to account for several unique features of the Cherry Creek watershed, such as the undeveloped nature of the basin and the highly pervious soils of the watershed. The site-specific model inputs included refinements to incipient rainfall events, number of storm events, and runoff coefficients. A summary of the Cherry Creek Stormwater Model inputs is provided below in Table 2. Greater detail for each input is provided below.

Table 2. Summary of Cherry Creek Stormwater Model Inputs

Input Parameter	Land Use			
	Undeveloped	Residential	Commercial	Industrial
Average Annual Rainfall	16.54	16.54	16.54	16.54
Incipient Rainfall Amount to result in runoff	0.43 inches	0.1 inches	0.1 inches	0.1 inches
Average Annual Number of Storm Events	11	39	39	39
Runoff Coefficient	0.017	0.15	0.65	0.67
Event Mean Concentration Total Phosphorus	0.40 mg/l	0.65 mg/l	0.42 mg/l	0.43 mg/l

Incipient Rainfall Events. Data from weather stations and stream gaging stations around the basin were used to quantify the reservoir's response to rainfall events. Weather data from station sites at Cherry Creek Dam, Castle Rock and Elbert were examined. These stations are located in the northern, west-central and south-eastern portions of the basin. Weather events were screened to include only days when more than 0.1 inches of precipitation was recorded at each station. This was used to support the assumption that on these days the rain was not localized but falling across the entire basin. Records from the months of December, January and February were excluded to reduce the chance that the form of precipitation was snow and would not result in immediate runoff. With the remaining records, the average of the three station values was used to represent the average rainfall within the basin.

Daily flow records from the USGS gaging stations at Franktown and Parker were used to study Cherry Creek's response to precipitation. When precipitation events occurred, flow data from the previous, present and following days were examined. Flow from the previous day was assumed to be baseflow. This value was subtracted from the daily flow of the current and following days. The sum of these differences was considered to be the creek's response to the event. Flow records were examined to determine how long storm runoff in Cherry Creek would occur after the day of the event. By comparing the flows for one and two days after the event to the previous day flow rate, it was determined that the storm runoff in Cherry Creek would occur for about two days after the event. This result was consistent with crude estimates of flow velocity in the Creek and time of travel to the gage.

The first analysis focused on the period between 1966 and 1980 and the area south of the USGS Franktown gage. The Parker gage was not installed until 1991, so it was not used for this evaluation. The period 1966-1980 was selected to support an assumption that all land south of the gage was relatively undeveloped. Furthermore, significant pumping, diversions, and discharges above the Parker gage were considered to be negligible for that time period.

Figure 5 shows the change in flow in response to precipitation. The solid line represents a linear regression of these points. The dashed line shows the response that would be expected using a CR of 0.04 (a published regional value for undeveloped land) for the watershed area above the gage. The line intercepts the axis at 0.5 inches. In other words, on average a basinwide rainfall event greater than 0.5 inches is needed to produce a change in flow at the Franktown gage. Furthermore, using the hydrologic equation outlined above, the respective CR for undeveloped land would be 0.011. As shown, this regression is not statistically significant (p value = 0.1079). Therefore, additional flow and precipitation data were evaluated.

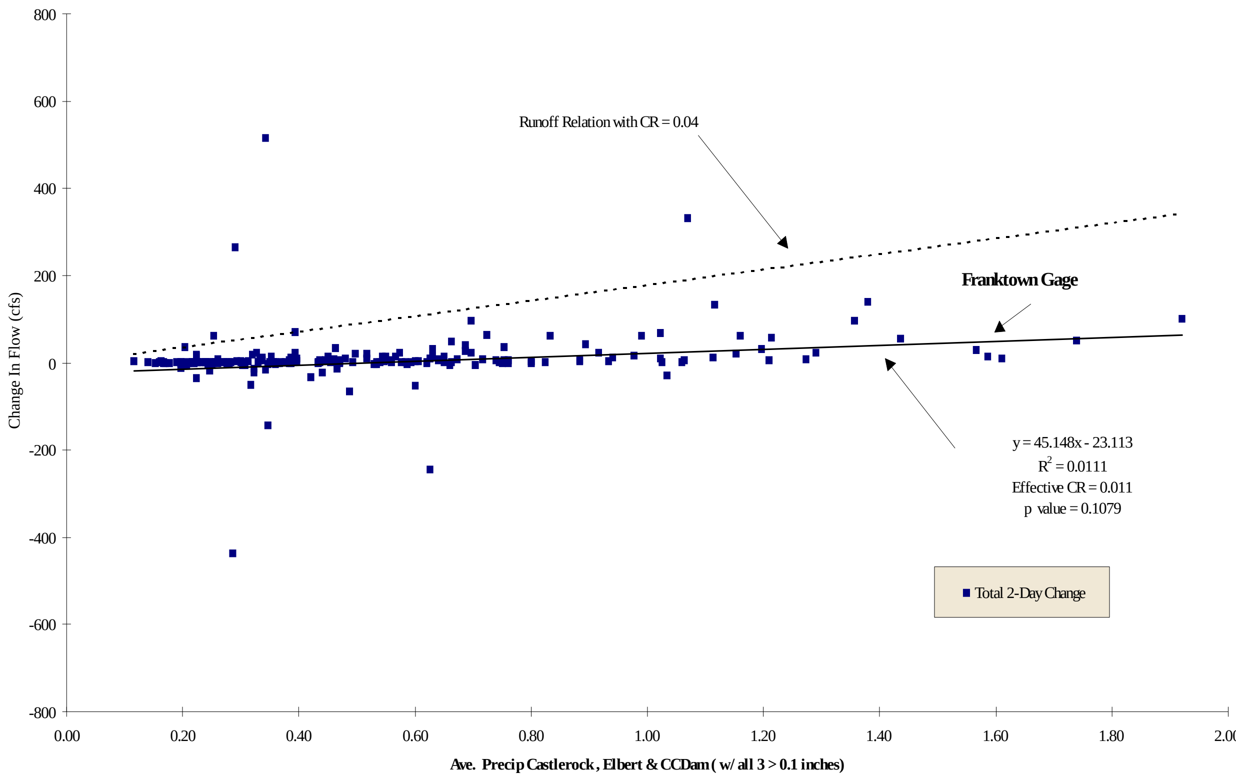

Figure 5. Relationship of Instream Flow and Rainfall (1966-1980)

Next, daily flow records from the USGS gaging stations at Franktown and Parker (1991 - 1996) were used to study Cherry Creek's response to precipitation. During this period of time the USGS Parker gage was in operation in addition to the Franktown gage. The Elbert weather station ceased operation in 1980. Changes in flow in response to precipitation were again evaluated. The area south of Franktown was assumed to have remained largely undeveloped. The area between Parker and Franktown had significant amounts of pumping and other human activities occurring during this time frame. Data from the Parker gage was included to examine the movement of flow through this creek reach.

Figure 6 illustrates the results of this analysis. Changes in surface flows at the Parker gage exhibit a limited relationship to precipitation, while greater changes in surface flow occur at the Franktown gage. The intercept of the regression of data collected at the Franktown gage intercepts the axis at 0.4 inches and has a slope which corresponds to a runoff coefficient of 0.017. This relationship is statistically significant (P value = 0.70). A key point to note for this analysis is that the intercept and the slope are reasonably close to the analysis performed on the older data. This observation supports and confirms that a minimum of 0.4 inches in rainfall is required to produce stormwater runoff within the Cherry Creek watershed. This value is significantly greater than the 0.1 inches generally assumed for incipient rainfall events in urbanized areas (Driscoll, 1989).

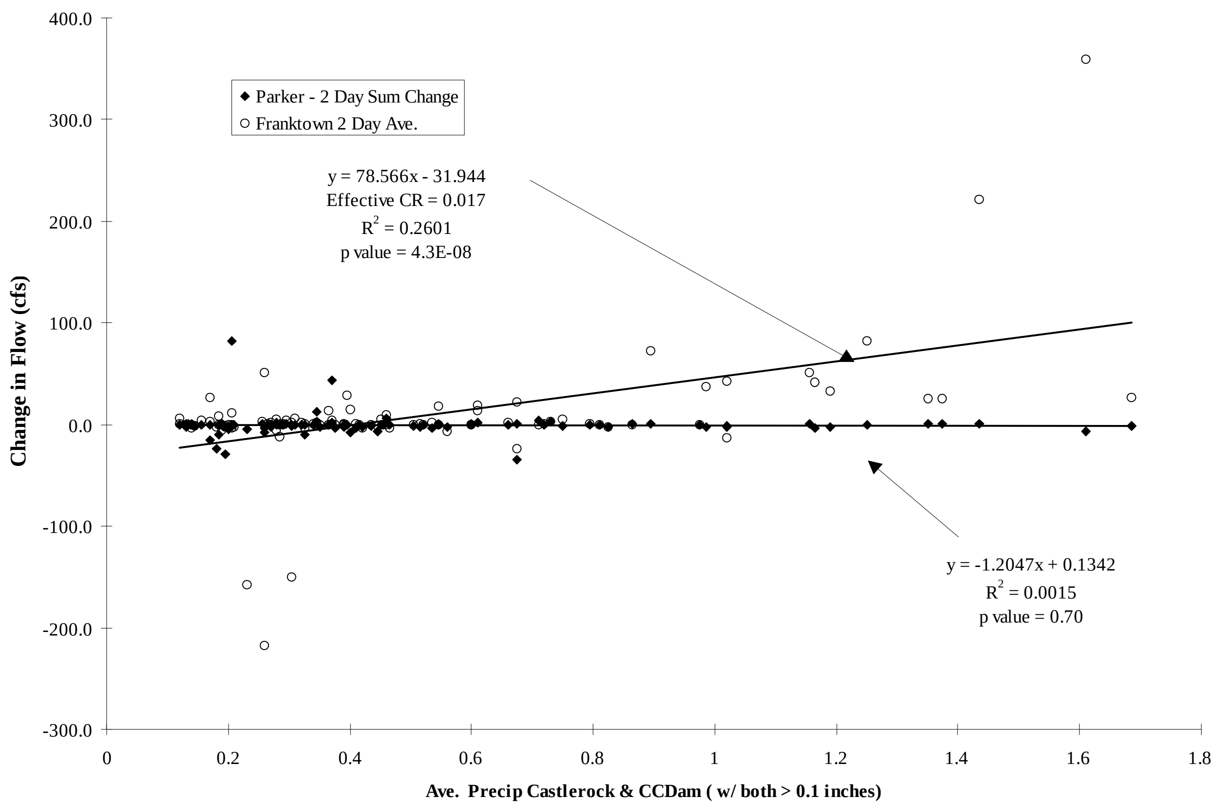

Figure 6. Relationship of instream flow and rainfall (1991-1996).

Number of Storm Events. The U.S. EPA's statistical analysis of rainfall data in the United States indicates that the mean size for a precipitation event in the Denver region is 0.43 inches. The mean number of events is 39 for storms producing 0.1 inches or greater rainfall (Driscoll, 1989). The resulting mean annual storm precipitation total for events is therefore 16.54 inches per year (in/yr).

However, as indicated in Figure 6, the Cherry Creek basin is unique, as precipitation events less that 0.43 inches do not result in runoff from undeveloped land that would be reflected in increased flows in Cherry Creek. The rainfall gage at Cherry Creek Dam, which has a period of record from 1951 to 1996, indicates an average of 11 storm events greater than 0.43 inches and 8 storm events greater than 0.5 inches. Therefore, for the Cherry Creek Stormwater Model, the number of runoff-producing storms used for undeveloped lands was conservatively set at 11 events per year, rather than 39. Because the mean size storm event for the Denver area, regardless of whether runoff results, remains 0.43 inches, the mean annual precipitation that results in storm runoff from undeveloped land is 4.73 inches, rather than 16.5 inches per year (11 events at 0.43 inches = 4.73 inches).

Site-specific Runoff Coefficients. The coefficient of runoff for commercial and industrial land uses originated from the U.S. EPA's National Urban Runoff Program (NURP) (1983). These coefficients have been used by several agencies in the Denver metropolitan area to calculate nonpoint source pollutant loads. For example, the City of Aurora, City of Denver, and the City of Lakewood filed a joint stormwater National Permit Discharge Elimination System (NPDES) permit in 1997 using the following CR values to calculate their stormflow loads; industrial (0.67), commercial (0.65), residential (0.31), and undeveloped (0.04).

These same values, 0.67 and 0.65 for industrial and commercial lands, respectively, are used in the Cherry Creek Stormflow Model.

As discussed earlier, by studying the rainfall and stream flow responses at the Parker and Franktown gages, the CR for undeveloped areas was less than generally assumed for the Denver area. Instead of the 0.04 suggested by the NURP (EPA, 1983) studies, the actual CR was found to be 0.017. In addition, residential development in the Cherry Creek Basin is less dense than residential areas examined in the NURP study and NPDES stormwater permit (approximately 20% impervious versus 40% or greater). Therefore, a residential CR of 0.15 was used instead of 0.31, which accounts for a lower average impervious density and a lower runoff coefficient for the pervious surfaces. The incipient rainfall event of 0.1 inches and the 39 storm events per year were used for residential land use.

Event Mean Concentrations. The EMC values for the four land uses used by this model for total phosphorus were obtained from a 1993 stormwater characterization study performed in the Denver metropolitan area by the Urban Drainage and Flood Control District (UDFCD) [Doerfer and Urbonas, 1993]. These EMC's are "citywide average EMC" values that represent data from developed areas. The joint stormwater permit filed by the cities of Aurora, Denver, and Lakewood in 1997 used the same EMC values. The EMC's for undeveloped, residential, commercial and industrial land uses are 0.4 mg/L, 0.65 mg/L, 0.42 mg/L, and 0.43 mg/L, respectively.

In order to verify the applicability of the NURP and Denver area EMC's to the Cherry Creek Basin, composited stormflows measured at Shop Creek and Cottonwood Creek [Cherry Creek Basin Water Quality Authority, 1996] were evaluated. These values were compared with the UDFCD values. Figure 7 shows that the "Estimate Used" from the UDFCD study closely compares with the median values of measured stormflow concentrations for Cottonwood and Shop Creek.

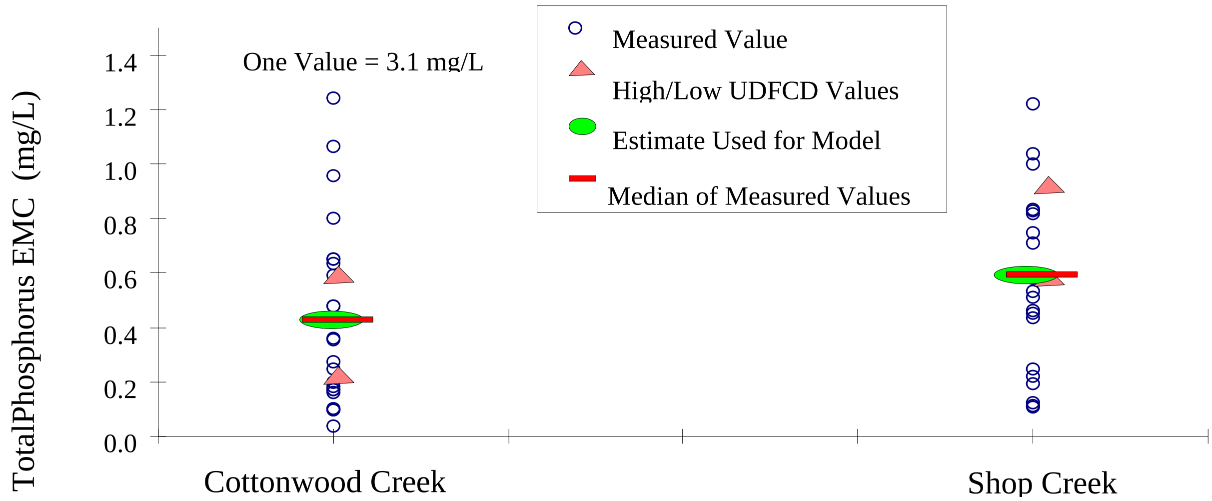

Figure 7. Comparison of Regional EMC's to Cottonwood Creek and Shop Creek Runoff

Transport Model Sub-Component

Because of the soil and alluvial characteristics of the Cherry Creek watershed, much of the flow generated in the upper portions of Cherry Creek does not reach the reservoir by surface flow. An analysis of the gage data shows that Cherry Creek is a "losing" stream, which means that surface flow in the creek decreases in the downstream direction. To reflect this effect in the stormflow model, stormflow instream delivery ratios (IDR's) were developed and applied to the stormflow model runoff results. Cherry Creek was divided into three segments, from the reservoir upstream as follows.

- Segment 1 - Cherry Creek below the Parker gage
- Segment 2 - Cherry Creek between the Franktown gage and Parker gage
- Segment 3 - Cherry Creek above the Franktown gage

Stormflow Instream Delivery Ratio

In nonpoint source modeling, a delivery ratio is a dimensionless ratio of the actual observed load divided by the load theoretically possible. The stormflow IDR accounts for constituent losses during travel along the main channel to a location of concern. For this study, the location of concern is the Cherry Creek Reservoir. The reasons for the discrepancy between these numbers may include chemical or biological changes to the load or the physical removal of the load. The Cherry Creek Stormflow Model assumes that a portion of storm runoff volume (and therefore the pollutant load) is lost en route to the main stream channel. This loss in runoff volume is accounted for through the coefficients of runoff. However, a stormflow IDR is required to account for stormflow load losses as flows are transported through Cherry Creek and the alluvium to Cherry Creek Reservoir.

Figure 6 indicates that while runoff from precipitation events greater than 0.4 inches changes flows in Cherry Creek at the Franktown stream gage, these same storms do not affect the stream gage at Parker. Runoff data from 1991 through 1996 provide evidence that runoff and associated pollutants from storms as large as 1.6 inches in the upper watershed (i.e., south of Parker) do not affect Cherry Creek downstream of Parker. An additional analysis of a period of time extending from April 1962 to October 1969 was examined. This period of time was chosen because precipitation data was available from three areas in the basin -- Cherry Creek Dam, Castle Rock, and Elbert. Within this period, Cherry Creek generally experienced decreases in flow between the USGS Franktown gage and the USGS Melvin gage. Focusing on storm events (greater than 0.1" of precipitation at all three weather stations), decreases occurred 74% of the time (conversely, flow increases occurred only 26% of the time). Aside from the stormflow IDR, this is significant for several reasons. The drainage area contributing to flows at the Melvin gage is approximately three times larger than the drainage area at Franktown. Given a basinwide storm, one would expect flows at the Melvin gage to increase in proportion to the contributing area. The fact that this reach of Cherry Creek can often absorb these flows during periods is telling as to the alluvial characteristics of the Cherry Creek basin and the low runoff coefficient of the surrounding lands.

The rainfall runoff analyses also support what we have observed in the basin from a water development standpoint. Namely, alluvial pumping has significant impacts on surface flows in Cherry Creek just upstream of the reservoir. Pumping by Aurora, Arapahoe Water and Sanitation District, and Cottonwood Water and Sanitation District for drinking water purposes, decrease flows in Cherry Creek noticeably from June through October, when portions of the stream are dry. Static water level data collected from a series of piezometers over the past five years have shown that a depression in the shallow groundwater table upstream of the reservoir develops when well diversions exceed surface water flows. The depression fills when runoff starts and streamflow naturally enters the groundwater system through the streambed and recharges the shallow aquifer. [Bishop-Brogden and Associates, 1996]. Due to these alluvial characteristics and well pumping, the likelihood of stormflow being conveyed from Franktown to Parker and from Parker to the Reservoir is not substantial.

The stormflow IDRs were based on the rainfall runoff analyses described above. Therefore, with respect to phosphorus loads moving from segment 1 to the Reservoir, the stormflow IDR was estimated at 26%. This ratio was developed to reflect unique conditions upstream of the Reservoir in Segment 1 and the low percentage of time that storm events in the basin actually result in increased flows above the reservoir. The stormflow IDR for Segment 2 was calculated to 7% (26%*26%). Similarly, the stormflow IDR for the uppermost segment, Segment 3, was 7% (26%*26%*100%).

Direct flow areas within Segment 1, such as the 725-acre Shop Creek sub-basin, were given an instream delivery ratio of 50 percent. This is based on an evaluation of flow response to precipitation events in the area during the period 1993 - 1996. Shop Creek streamflows have been monitored at the gage at South Parker Road by a variety of entities like the Authority (Jones & CEC, 1998), the USGS, and City of Aurora (Rocky Mountain Consultants, 1996).

Cherry Creek Stormflow Model Results

A summary of present and future stormflow phosphorus loads, delivery ratios and transported loadings to Cherry Creek reservoir is provided in Table 3.

Table 3. Summary of Current and Future Predicted Stormflow Phosphorus Loads Transported to Cherry Creek Reservoir

Modeled Condition	Segment of Cherry Creek	Load from sub-basins (pounds)	Delivery Ratio	Load to Reservoir (pounds)
Current	Segment 3	1,080	0.07	76
Current	Segment 2	5,441	0.07	381
Current	Segment 1	10,935	0.26	2,843
Current	Direct Flow Areas	1,580	0.50	790
	Total	19,036		4,090
Future	Segment 3	2,270	0.07	159
Future	Segment 2	5,193	0.07	364
Future	Segment 1	14,824	0.26	3,854
Future	Direct Flow Areas	3,120	0.50	1,560
	Total	25,407		5,937

The Cherry Creek Stormflow Model, coupled with stormflow IDRs applied to three segments of Cherry Creek, indicate annual phosphorus loadings of approximately 4,090 pounds and 5,937 pounds for the current and future condition, respectively.[2] This reflects the amount of phosphorus from nonpoint source loads that would be delivered to Cherry Creek Reservoir as a result of storm events for the 1997 and 2020 development conditions. Detailed model output is provided in Attachment B.

CHERRY CREEK BASEFLOW MODEL

The Cherry Creek Baseflow Model for phosphorus loading to Cherry Creek Reservoir accounts for constituent loads delivered to the Reservoir from the Cherry Creek mainstem during baseflow[3] conditions by integrating surface and alluvial waters. Baseflow loads consist of background[4] phosphorus loads in surface water and ground water plus point source discharges. Baseflow loads delivered to the reservoir reflect rates of changes of total phosphorus measured in each segment and unique characteristics observed in the Cherry Creek basin, such as extensive alluvial pumping.

[2] Within this report, loadings are expressed to the nearest pound. Loadings referenced within this document vary over several orders of magnitude. In all cases, the number of significant figures expressed is not meant to imply a level of precision. These values are completely expressed in order to better illustrate the methodology and to allow for better quality control and review.
[3] Baseflows include background sources plus point sources.
[4] Background sources for the 1998 Watershed Model are defined to include background sources in groundwater and surface water, such as septic systems, industrial sources, and unknown loads. Background sources do not include precipitation.

Cherry Creek was divided into several segments, in a manner similar to the Stormflow Model, using instream water quality monitoring stations as control points to describe the flux of constituents in each segment. Figure 8 is a line diagram of Cherry Creek showing relative locations of sampling stations, monitoring wells, USGS gaging stations, WWTF point discharges and pumping station.

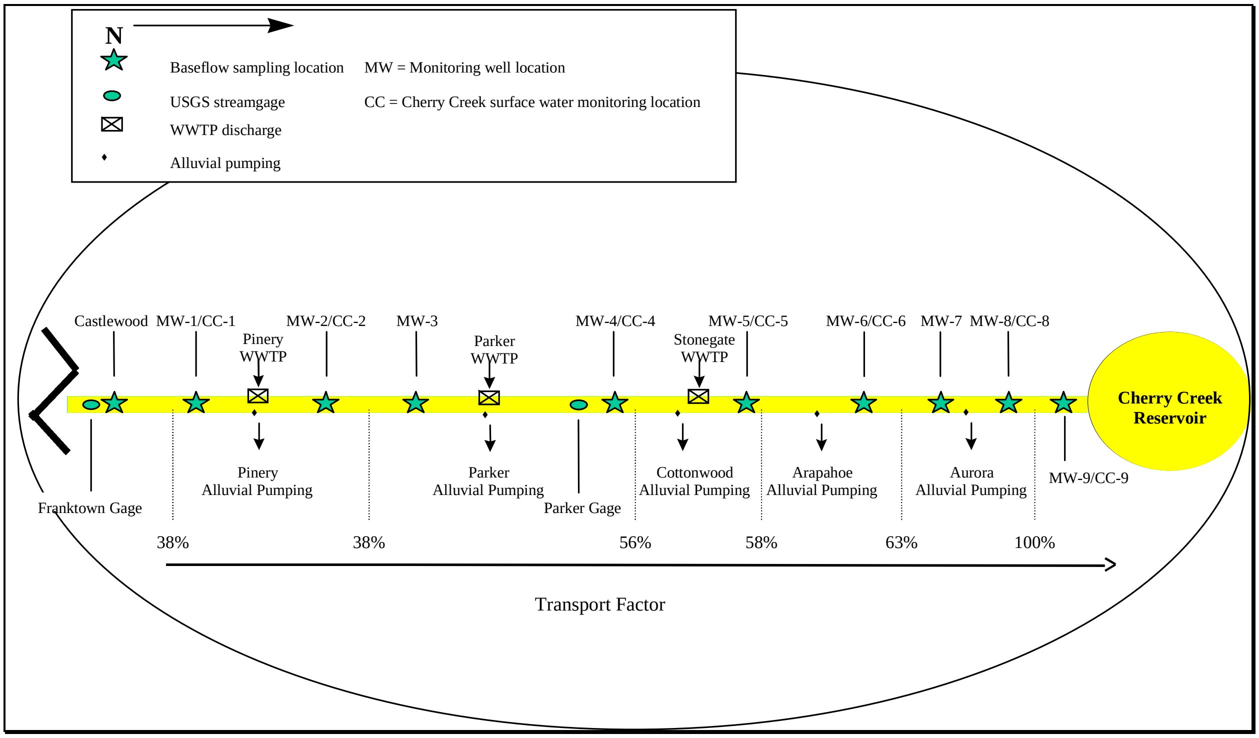

Figure 8. Conceptual Watershed Model for Baseflow Loading to Cherry Creek and the Cherry Creek Reservoir.

Model Framework

Baseflow conditions were evaluated through application of monthly water quality and flow data collected by Halepaska and Associates along the Cherry Creek mainstem for three sampling seasons, 1995, 1996 and 1997. The "Phase 1 Baseline Water Quality Data Collection Study", (Baseline Study) conducted by J.C. Halepaska and Associates (Halepaska), characterizes baseflow loading conditions for the mainstem. The Cherry Creek Baseflow Model is empirically based and takes into account measured values in the Cherry Creek mainstem and alluvial waters, wastewater treatment facility (WWTF) discharges and alluvial well pumping. By monitoring surface and groundwater conditions, it is assumed that the baseflow phosphorus loads at these control points is known. A mass balance analysis was used as the basis for calculating phosphorus gains and losses that occur between segments. As opposed to the stormflow IDRs that account solely for flow conditions, the baseflow IDR's developed for the Baseflow Model account for two conditions that reduce the phosphorus delivery to the reservoir - flow and chemistry.

Baseflow Model Inputs - Current Condition

Baseflow Model inputs are generally described below.

Groundwater and Surface Water Quality. Monthly total phosphorus was measured at 8 surface water stations and 9 alluvial ground water stations as part of the Halepaska's Baseline Study. These data were critical input to the Cherry Creek Baseflow model. Phosphorus gains or losses were based on rate of change of total phosphorus measured at each of the stations. These values were calculated using Halepaska's measurements from 1995, 1996 and 1997.

Attachment C depicts the ground water and surface water quality data collected by Halepaska and Associates during the three sampling seasons. As shown, seasonal variations are observed for surface water phosphorus concentrations, ranging from 0.05 mg/L to 0.25 mg/L, but little variation is seen from year to year from the annual average of 0.20 mg/L.

Surface Water Flow and Alluvial Underflows. Surface water flows were measured at the eight stations used in the Baseline Study. As described in the Halepaska report, alluvial underflow were estimated at the nine groundwater stations using Darcy's Equation, where

*Underflow = K * i * A*

where, K = Hydraulic conductivity
i = Hydraulic gradient
A = Cross section saturated area.

Point Source Discharges. Wastewater treatment facilities that discharge directly to Cherry Creek were accounted for in the Baseflow Model. These WWTFs include Pinery Water and Sanitation District, Parker Water and Sanitation District, and Stonegate Center Metropolitan District. The NPDES permits require dischargers to monitor and quantify the concentration and total pounds of phosphorus discharged. Monthly data from these monitoring reports were used as inputs into the Cherry Creek Baseflow Model.

Alluvial Well Pumping. Five municipal water supply entities in the upper Cherry Creek Basin utilize Cherry Creek alluvial wells – Arapahoe Water and Wastewater Authority, City of Aurora, Cottonwood Water and Sanitation District, Parker Water and Sanitation District, and the Pinery Water and Sanitation District. At present, over 4000 acre-feet of alluvial water is pumped annually from these wells for potable water purposes. Halepaska estimated annual phosphorus removed from the Cherry Creek alluvium due to well pumping by using average measured phosphorus concentrations for each of these pumping areas from the Phase 1 baseline groundwater quality database and volume of annual pumping of alluvial wells from each entity. Average phosphorus removed from alluvial well pumping for the years 1995 through 1997 was estimated to be 2,394 pounds (Baseline Study).

Baseflow Loads. Baseflow concentrations for the Cherry Creek mainstem current condition were measured by Halepaska at eight surface water and groundwater stations. Measurements at station CC-9, just upstream of the reservoir, reflect baseflow loading to Cherry Creek Reservoir. The baseflow load was calculated using Halepaska's measurements in the following general equation:

Baseflow Loads =
*Total Phosphorus Concentration * Surface Water Flow +*
*Total Phosphorus Concentration * Ground Water Underflow*

Baseflow loads from other tributaries that flow into Cherry Creek Reservoir, such as Cottonwood Creek and Shop Creek, were quantified from median measurements made by Chadwick Ecological Consultants (Chadwick) during the 1995 to 1997 timeframe. Chadwick maintains streamflow gaging and water quality monitoring stations along these tributaries, both upstream and downstream of water quality ponds. For purposes of this analysis, data measured upstream of the water quality ponds were used, since the water quality ponds receive phosphorus credit as part of the "Cherry Creek Basin Trading Program." Data collected from these stations reflect baseflow and stormflow conditions. Therefore annual loads were proportioned 30% to baseflow and 70% to stormflow,, since 70% of the total load has historically been associated with stormflow events (telephone communication with Canton). The baseflow loads from Cottonwood and Shop Creek are estimated to be 185 pounds and 90 pounds, respectively. Baseflows to Shop Creek are not expected to change for the future condition. The baseflow loads to Cottonwood Creek are expected to change in the future, with Arapahoe Water and Sanitation District direct discharging to Happy Canyon Creek, a tributary of Cherry Creek, instead of Lonetree Creek, a tributary to Cottonwood Creek.

Mass Balance Analysis for Total Phosphorus

A mass balance analysis was used as the basis for calculating baseflow loads from the Cherry Creek mainstem to the Cherry Creek Reservoir.

The current condition quantifies phosphorus loading by taking into account measured surface water and groundwater concentrations measured by Halepaska, point source inputs, and pumping outputs. Annual phosphorus loading to the reservoir during 1995, 1996, and 1997 was calculated at 3,771 pounds, 3,629 pounds, and 4,127 pounds, respectively. Median values were used for the current modeled condition, therefore the phosphorus loading is 3,771 pounds.

Table 4 shows the phosphorus gains and losses that occur between Castlewood and Station CC-9, just upstream of the reservoir. As indicated, point source dischargers contribute a very small percentage of the total phosphorus delivered to the reservoir.

Table 4. Mass Balance Analysis for Cherry Creek Mainstem - Current Condition

WQ Station		Calculated Loads (lbs)	Well Withdrawals (lbs)	Point Source Discharge (lbs)	Net Gain/Loss[1] (lbs)
Castlewood		2887			
	Castle-CC2				
CC1		5198			2311
	CC1-CC2		771	30	
CC2		6330			1873
	CC2-CC4		474	179	
CC4		6404			369
	CC4-CC5		111		
CC5		7658			1365
	CC5-CC6		402		
CC6		8198			942
	CC6-CC8		515		
CC8		4108			-3575
	CC8-CC9				
CC9		3771			-337

[1]Net gain or loss = Calculated load - well withdrawal + point source discharge

Baseflow IDR's. Baseflow IDR's were developed for current and future baseflow conditions. These ratios were applied to the Baseflow Model to reflect two mechanisms - flow and chemistry. These two mechanisms are combined when generating baseflow IDR's for each segment in Cherry Creek. As described above, most of the flow generated in the Cherry Creek basin is not ultimately transported to Cherry Creek Reservoir. This could be a function of extensive well pumping in the Cherry Creek basin and geologic characteristics which make Cherry Creek a "losing" stream. Additionally, soil and alluvial characteristics in the basin affect chemical interactions and the fate of phosphorus within the alluvium and surface water.

For each monitoring year (1995-1997), changes in loads between control points were quantified. Similar patterns in the location and magnitudes of gains and losses were noted, when compared from year to year. (Attachment D) These gains and losses were then identified as known and unknown changes with respect to loads. Groundwater pumping and treatment plant discharges are known changes to phosphorus loadings. However, there are sections in which changes in loads are present, but a cause is not known at this time. When losses (either known or unknown) occur between control points, the loads entering this segment are discounted. When a gain is measured within a segment, this gain is identified and its fate tracked as it moves downstream. To further elaborate on these observations the chart in Attachment E was produced. The chart conceptually illustrates the Baseflow model phosphorus gains and losses and dramatically shows the very small percentage of phosphorus contributed from wastewater effluent enter the creek in comparison to other phosphorus gains and losses.

The top section of the figure contains sources of loadings to the creek. These include effluent from wastewater treatment plants and un-identified gains. (Un-identified gains and losses will be discussed in greater detail below.) The center section of the chart contains total loads as calculated by adding the total measured surface loads and groundwater loads using data collected by Halepaska at selected sites which contain both surface and groundwater monitoring (control points). The lowest section of the chart contains processes which remove phosphorus from the system. These include removal by pumping and un-identified gains.

Un-identified gains and losses quantify the changes in loads between control points which cannot be explained by effluent inputs and pumping withdrawals. These loads have been observed consistently during the years 1995 through 1997 (Halepaska, 1997). The median value for un-identified changes at each site are used. As more information is gathered regarding the sources of these un-identified gains and losses, this will be incorporated into the model. However, since the model is anchored on measured data at the control sites, identifying the causes of these changes would not effect other portions of the basin.

Examining the figure from right to left, or from the Castlewood site downstream to the Reservoir, several points need to be made. First the pie charts are approximately proportional to the loads represented. Larger pies indicate larger loads. The composition of the pie indicates the origin of the phosphorus load. Withdrawals are made from the most immediate upstream control point and they have the same composition of the upstream control point. Finally, the removal of these loads from the system is reflected in the downstream site.

For sake of illustration, between Castlewood and CC1, monitoring has shown that phosphorous loads consistently increase. Therefore the load at CC1 is composed of the load from Castlewood and the amount of gain between Castlewood and CC1. Examining the segment between CC5 and CC6, we find two processes occurring. First, Arapahoe pumping removes loading from the system. These loads are removed in proportion to measured values at CC5. With the pumping, loads between CC5 and CC6 increase. This un-identified gain then contributes to the loads at CC6. Note also that the relative proportion of all loads moving from CC5 have decreased.

Baseflow IDR's for Current Condition

For the current condition, these losses effecting loading have been expressed as a percent loss between segments due to either pumping or unknown losses. The percentages range from 0 to 100%. Gains are not expressed separately because they are identified as new loads. Finally all percentages are expressed as percentages with respect to the reservoir. For example, loads originating immediately above the reservoir are not discounted because there are no losses (either known or unknown) before the reservoir. A load originating three segments above the reservoir will be discounted as it passes through each segment, so that ultimately, the transport ratio will be the product of each segment's discount ratio. Baseflow IDR's always increase moving downstream, toward the reservoir. Changes in ratios due to known and unknown sources are considered to be absolute quantities. For this reason, these ratios are dependent upon the overall loading to the basin. For small changes in loads, the overall effects on the ratio will be minimal.

Baseflow IDR's for the Future Condition

The Baseflow IDR's change between current and future conditions. These values are a function of loads measured at the control points bordering a segment. Changes in pumping and discharge activities within a segment will effect the movement throughout the segment. For this reason, ratios across the upstream segments can change from the current to the future conditions. In order to extrapolate to the future condition, WWTF flow projections were obtained from the January 8, 1998 Cherry Creek Basin Authority "Wasteload Allocation Survey Responses". Projected effluent flows were multiplied by a phosphorus concentration of 0.1 mg/L to calculate projected phosphorus discharge. This is consistent with the 1989 update to the Cherry Creek Basin Master Plan that provided for an effluent quality of 0.1 mg/L or lower at the design capacity of the plant. For treatment systems utilizing secondary treatment with land application, projected effluent flows were also multiplied by a phosphorus concentration of 0.2 mg/L, taking into account the phosphorus uptake of vegetation.

Alluvial pumping projections were also made, based on current decreed limits or water supply plans. Under the future condition, loads entering the basin as effluent and alluvial pumping significantly increase. Table 6 summarizes assumptions for pumping and discharge for the future condition. As an example, alluvial pumping in the basin increases from 4,000 acre-feet to over 11,000 acre-feet per year in 2020. Under the projected condition, discharges from WWTF's to the creek increase also from 371 pounds in 1997 to approximately 2900 pounds in 2020. As noted, one such change in the future will be Arapahoe Water and Wastewater Authority's (Arapahoe) point of direct discharge. Arapahoe will direct discharge to Happy Canyon Creek, a tributary of Cherry creek, not Cottonwood Creek. For purposes of this analysis, Happy Canyon Ranch and Rangeview Metropolitan District (Rangeview) are reflected as new dischargers to the system for the future condition. Happy Canyon Ranch is assumed to direct discharge to the proposed Newlin WWTF. Rangeview is assumed to treat effluent at Eagle Gulch WWTF and land apply secondary treated effluent in the Piney Creek basin, which is tributary to Cherry Creek.

Table 5. Alluvial Pumping and Discharge Assumptions for 2020 Condition

	Alluvial Pumping (AF)[2]	Projected Flow (mgd)	Phosphorus Concentration (mg/L)	WWTF Discharge (pounds)
Castle Rock	0	3.02	0.1	919
Franktown	0	0.5	0.1	152
Pinery W&SD	2,000	2.0	0.1	609
Parker W&SD	3,000	4.07	0.1	1237
Happy Canyon Ranch	0	1.73	0.1	527
Rampart Range	0	0.5	0.1	152
Stonegate	0	1.5	0.1	456
Cottonwood W&SD	730	1.0	0.1	304
Araphoe W&SD	1,900	1.28	0.1	390
Aurora	4,000	0	0	0
Rangeview	0	1.20	0.2	730[1]
Meridian	0	1.50	0.2	913[1]
Inverness	0	.91	0.2	548[1]
Total	11,630	19.21		6937

[1] Phosphorus discharge takes into account land application return flow factor of 25% (per Halepaska and Assoc., Aug. 1997)

[2]Alluvial pumping based on maximum limits established in existing decrees and substitute water supply plans in the basin. Aurora's, Cottonwood's, and Arapaho's pumping based on 1998 Regional Substitute Water Supply Plan and projected pumping identified in that plan.

Baseflow IDR's could differ significantly for the future condition based on the uncertainty of anticipated alluvial pumping in the basin, importation of transbasin water, etc. Because of the uncertainty of projected flows and pumping, one possible condition for the future is described, using the pumping and projected flow data from Table 5. Baseflow IDR's derived for this future condition scenario are summarized on Table 6 and based on the same methodology as described for the current condition baseflow IDR's. Attachment D provides more detail on the transport ratio calculations for the future condition.

Table 6. Comparison of Delivery Ratio – 1997 Conditions and 2020 Conditions

Portion of Phosphorus Loads Moving		**1997 Conditions**	**2020 Conditions**
From:	**To:**		
Castlewood	Reservoir	38%	18%
CC1	Reservoir	38%	18%
CC2	Reservoir	49%	24%
CC4	Reservoir	56%	41%
CC5	Reservoir	58%	44%
CC6	Reservoir	63%	49%
CC8	Reservoir	100%	100%
CC9	Reservoir	100%	100%

<u>Assumptions in the Baseflow Model</u>

The following assumptions are made in the Baseflow model.

- For purposes of this model, phosphorus is removed from the system through pumping or a consistent, measured loss. If later, details regarding specific phosphorus removal mechanisms are available, they can readily be incorporated into the model. Losses due to these processes would be handled in a fashion similar to load removal due to pumping.

- A load from an upstream point can only decrease as it moves downstream. Gains, which occur downstream from the site, are not attributed to upstream entities. Losses are taken from all upstream loads, thus reducing loads as they move downstream.

- Within a segment, while effluent discharge may occur above pumping, the pumping is removed from the upstream source and the effluent is attributed to the downstream source.

- In future years, un-identified gains and losses will remain constant in magnitude. This is based on the data collected during the first four years of water quality monitoring in the watershed (Halepaska). In the future, if monitoring shows that this assumption is not valid, then the model can be adjusted accordingly.

- The groundwater quality will not change as the surface water quality changes. A comparison between surface water and groundwater concentrations does not show any strong correlation. This will continue to be evaluated with quarterly monitoring.

- Surface water discharge will be available for pumping. Anecdotal information suggests that excessive pumping is able to reduce or eliminate surface flow. This model does not attempt to address hydrological factors such as the availability of water or the ability of water to move through the alluvium. It is conceivable that these factors could override water quality concerns.

Baseflow Model Results

Table 7 summarizes baseflow loading estimates to Cherry Creek Reservoir for the current and future condition. The Baseflow Model loading estimate for the current condition is 4,046 pounds. Point sources are well defined and make up a very small portion of the total baseflow phosphorus loading to Cherry Creek Reservoir. The loading estimate to Cherry Creek Reservoir is calculated by taking the median values of measurements made by Halepaska and Chadwick Ecological Consultants from 1995 - 1997 for the Cherry Creek mainstem just upstream of the reservoir, Shop Creek and Cottonwood Creek. Loading contributions from Quincy and Bellview drainage's are considered negligible, because the flows are ephemeral.

Table 7. Summary of Predicted Baseflow Phosphorus Loading to Cherry Creek Reservoir

Modeled Condition	From Cherry Creek Mainstem (pounds)	From Cottonwood Creek (pounds)	From Shop Creek (pounds)	Total (pounds)
Current	3,771[1]	185[2]	90[2]	4,046
Future	5,043	135[3]	90	5,268

[1] From data measured by Halepaska and Assoc. (Median of 1995-1997 data)
[2] From data measured by Chadwick Ecological Consultants (Median of 1995 -1997 data * .3)
[3] In the future, Arapahoe Water and Wastewater Authority discharges to Happy Canyon Creek, not Cottonwood Creek.

Extrapolating to the future condition required data on projected discharges and alluvial pumping. The loading estimate for the future condition is based on alluvial pumping and discharge assumptions summarized on Table 6. The modeled loading estimate for the future condition is pounds. Additional alluvial pumping data and information will refine the future modeled condition.

CONCLUSIONS

The Cherry Creek Watershed model is a tool to quantify potential water quality changes to the basin in the future. Table 8 summarizes the 1998 Cherry Creek Watershed Model predictions of annual phosphorus loading to the Reservoir. The modeled values do not include loading from precipitation on the Reservoir.

Table 8. Summary of 1998 Cherry Creek Watershed Model Predictions of Annual Phosphorus Loading to Cherry Creek Reservoir

Annual Phosphorus Load	Current Condition, pounds	Future Condition, pounds
Baseflow Load	4,046	5,268
- Point Source Load	278	1,500
- Background Load (surface water + groundwater)	3,768	3,768
Stormflow Load	4,090	5,937
Total Load	**8,136**	**11,205**

Current condition estimates predicted by the 1998 Cherry Creek Watershed Model indicate nonpoint source loading of total phosphorus at approximately 8,100 pounds/year. This modeled value is in the range of data collected by the Cherry Creek Basin Authority 1995, 1996 and 1997 but generally higher than measured values. Extrapolating to the future condition, the model reflects a total phosphorus loading of approximately 11,200 pounds, or a 38-percent increase. This corresponds to a streamflow volume increase of 37-percent.

The stormflow load estimated by the Cherry Creek Watershed Model based on land use patterns in the Reservoir watershed for the current and future conditions were compared to the nonpoint source loads estimated by DRCOG in the 1985 Master Plan (Figure 9). The 1985 methodology for estimating nonpoint source loads assumed that all generated loads reached the Reservoir without taking into account the phosphorus reduction mechanisms in Cherry Creek, such as well pumping, evapo-transpiration, soil moisture, and chemical interactions within the soil and alluvium.

Comparison of the Cherry Creek Watershed Model to Measured Values

The benefit of the Cherry Creek Watershed model is in predicting changes in loading in the future. These changes are expressed in terms of the percent difference in the baseflow and stormflow loads between current and future conditions.

Annual average streamflow loading of phosphorus, as measured by Chadwick and normalized to COE calculations, is 5,774 pounds. Chadwick values were normalized to match COE inflows by first subtracting monthly estimates of direct precipitation and net alluvial inflow from the COE values, then determining the proportion each stream (Cherry Creek, Cottonwood Creek, and Shop Creek) contributed to the remaining monthly inflows using Chadwick streamflow values. The percentages were multiplied by the inflow measured by the COE (minus precipitation and alluvial flow) to adjust the estimate of load from each stream's inflow to the Reservoir.

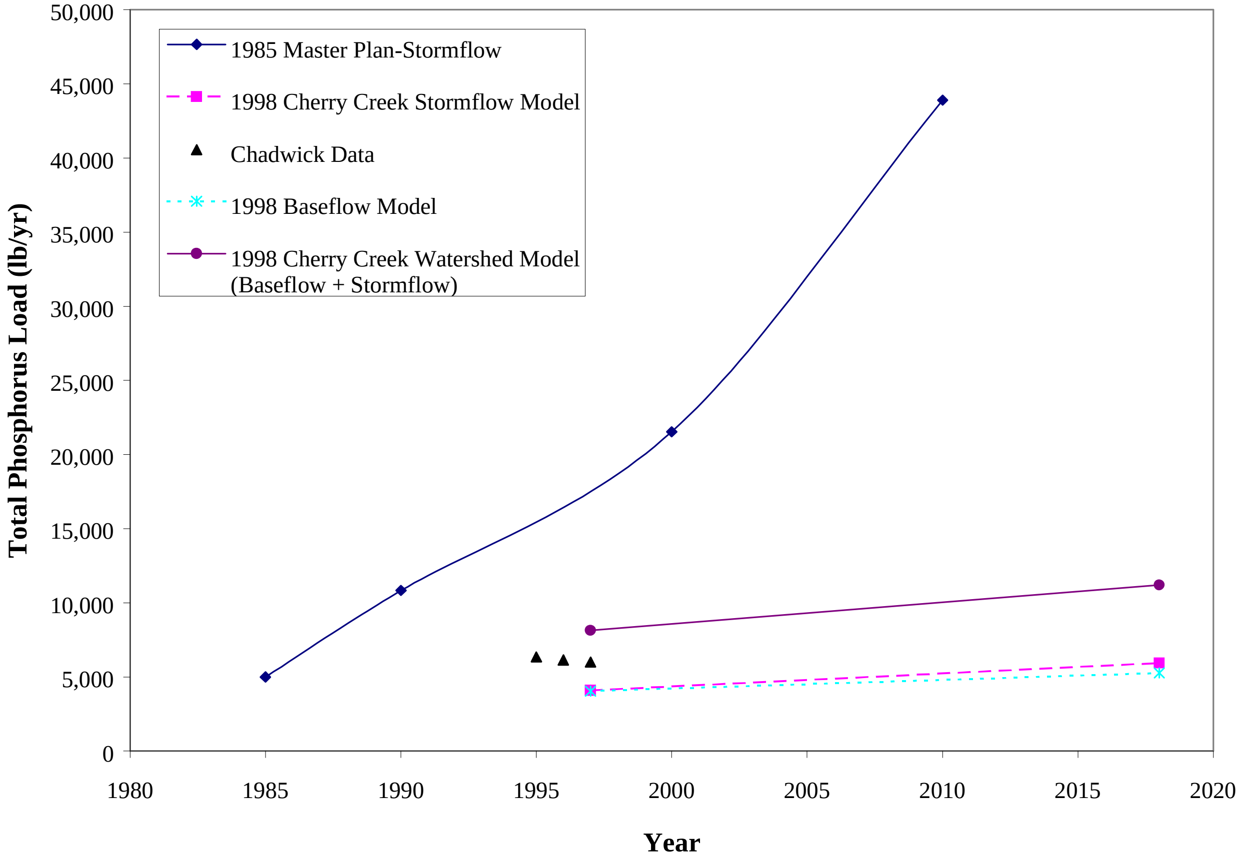

Figure 9. Comparison of measured and predicted phosphorus loading to the Cherry Creek Reservoir.

The watershed model current condition was used to look at the relative percent increase with respect to absolute values. Therefore, the current measured loading was used and extended to the future condition using the 38% relative increase (Table 4-9). As shown, the current condition of the model was reset to match the measured values of Chadwick. Based on the watershed modeling, the magnitude increase in loading for the baseflow and storm event flow is 30-percent and 45-percent, respectively. Based on these magnitudes of increase, future conditions could be calibrated. As shown, baseflow conditions in the future total 5,268 pounds. The storm event flow totals 2,500 pounds. Assuming a 38-percent increase in measured loads going into the Reservoir, as predicted by the model, results in an approximate streamflow load of 7,768 pounds for the future condition. Continued water quality monitoring will refine predictions.

Table 4-9. Adjustment of the Watershed Model

Load Condition	Load, pounds			Flow, acre-feet		
	Current Condition	Future Condition	Percent Change[4]	Current Condition	Future Condition	Percent Change
Average Streamflow Load to the Reservoir (pounds)[1]	5,774	7,768	138%	9,857	13,465	137%
Baseflow/Storm Returns[2]	4,046	5,268	130%	6,993	9,269	133%
Storm Event Flow[3]	1,728	2,500	145%	2,864	4,196	147%

1) Average measured load to the Reservoir for current condition minus average load from precipitation (6,622 pounds – 848 pounds).
2) For current condition, measured values from Halepaska and Chadwick.
3) Average streamflow load to Reservoir minus measured baseflow.
4) Percent change based on 1998 Watershed model magnitude of change in loading from current to future condition.

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ATTACHMENT A

CHERRY CREEK BASIN WATERSHED MODEL STORMFLOW COMPONENT INPUT

Model Configuration

The Cherry Creek Stormflow Model was designed in Microsoft's Excel™ Version 7.0, a spreadsheet application, to calculate the annual average total phosphorus load from the Cherry Creek Watershed to the Cherry Creek Reservoir. The following series of worksheets were set up within the file Cherry Creek Stormflow Model:

- 'Table 1 (Data from DRCOG)'
  Land use data from DRCOG
- 'Table 2 (Model Land Uses)'
  Land use acres used as input to the loading algorithm
- 'Table 3 (Data)'
  Hydrologic and water quality input data
- Table 4a 'Industrial Loads'
  Phosphorus loading for industrial land use acres, using industrial EMC's and Runoff Coefficients
- Table 4b 'Commercial Loads'
  Phosphorus loading for commercial land use acres, using commercial EMC's and Runoff Coefficients
- Table 4c 'Residential Loads'
  Phosphorus loading for residential land use acres, using residential EMC's and Runoff Coefficients
- Table 4d 'Undeveloped Loads'
  Phosphorus loading for undeveloped land use acres, using undeveloped EMC's and Runoff Coefficients
- Table 5 'Estimated Total Phosphorus Loading from Stormwater'
  Total phosphorus loading by sub-basin and land use

Descriptions of the fields used in these worksheets are presented below. Values were rounded to the nearest whole number, except in the case of the unit loading factors.

Worksheet 'Table 1 (Data from DRCOG)'

Worksheet 'Table 1 (Data from DRCOG)' is a placeholder for land use data received from DRCOG. In Table 1a, columns A-O are intended to be reserved for raw data from DRCOG, and columns A-C are used for values generated during the conversion of information into ArcView 3.0. Table 1b, Revised Land Uses, includes columns S-AE. The configuration of this worksheet is presented in Table A-1.

TABLE A-1. Configuration of Worksheet Table 1, Raw Data Received from the Denver Regional Council of Governments

Column	Functional Description
Column A	area (ft^2) for each of the 31 sub-basins within the Cherry Creek watershed basin
Column B	area (acres) for each of the 31 sub-basins
Column C	perimeter (ft) of each of the 31 sub-basins
Column D	sub-basin identification number
Column E	sub-basin name
Column F	Sf_acres (single family residential), includes dwelling units, normally used as a dwelling place by one family, accessory buildings, and yard space. Land associated with farm dwellers is included within this category to the extent of one acre, except when precise delineation of non-agricultural land areas directly associated with the dwelling is possible.
Column G	Mf_acres (multi-family residential), includes land and associated structures and yard space where two or more families or households have their dwelling, such as; townhouses, duplexes, high rise apartments, mobile home parks and group quarters. Structures intended for transient use are excluded.
Column H	C_acres (commercial), includes establishments and associated land, the main purpose of which is the retailing of goods and services to the general public. Included in this category are dwellings intended for transient use, general retail business, personal and commercial services, restaurants, shopping centers and commercial entertainment services.
Column I	O_acres (office), includes structures and associated land, the main purpose of which is the provision of office-type activities and services, such as administrative services, government offices, finance, real estate, insurance operations, business services, and professional services; sales offices and ranches; and offices of agents and brokers primarily engaged in wholesale distribution. No warehousing, except samples.
Column J	Pu_acres (public and semi-public), includes structures, operations, and land which are financed by public funds and operated as part of the governmental function; uses operated by private individuals or institutions for a public purpose, but with limited public control or access; and cultural, education, medical, protective, and correctional facilities, cemeteries, and military installations. Administrative offices of government are included under the Office category.
Column K	It_acres (industry, transport, communication), includes structures and associated land concerned with the manufacturing, treatment, processing, fabrication, or bulk storage of goods or materials; mining and quarrying operations; non-manufacturing industrial uses, which are connected with heavy repair, open air storage, and warehousing; lands and structures used for transporting passengers and freight (e.g., railroads and freeways); transportation equipment maintenance; transportation services; automobile parking not directly related with other use; structures and land uses for the collection and distribution system of utilities and communications facilities, such as telephone and telegraph systems, radio and electric utilities systems, post offices, utilities, water supply systems, sewerage systems, and disposal facilities.
Column L	A_acres (agriculture), includes land and structures associated with the growing of agricultural crops, plants, and trees and the keeping, grazing, and feeding of livestock; greenhouses; nurseries; fish hatcheries; and feedlots.
Column M	Pr_acres (parks and recreation), includes lands, waters, and structures developed for active or passive recreation; facilities such as stadiums, coliseums, gymnasiums, race tracks, tennis courts, golf courses, parks, campgrounds, open spaces, and greenbelts; and private and public park and recreation areas.
Column N	V_acres (vacant), includes both lands and structures characterized by the absence of any activity.
Column O	S_acres (special), includes lakes, reservoirs, forest and range lands, and wetlands or other environmentally sensitive areas, or right-of-way, other than those within park lands.

Worksheet 'Table 2 (Model Land Uses)'

Worksheet ‘Table 2 (Model Land Uses)’ contains the land uses acres used as input to the loading algorithms in Table 1b. The following four land use categories are used by the Cherry Creek Stormflow model: residential, commercial, industrial, and undeveloped. The manner in which this table is set up is presented in Table A-2.

TABLE A-2. Configuration of Worksheet ‘Table 2 (Model Land Uses)’, Basic Land Use Input Data for the Cherry Creek Basin Stormflow Model

Column	Functional Description
Column A	area (ft^2) of each sub-basin
Column B	area (acres) of each sub-basin
Column C	basin identification number assigned to each sub-basin
Column D	basin name
Column E	Residential Area (acres), is the summation of Sf_acres and Mf_acres from Table 1b.
Column F	Commercial Area (acres), is the summation of C_acres, O_acres, and Pu_acres from Table 1b.
Column G	Industrial Area (acres), is the summation of It_acres from Table 1b
Column H	Undeveloped Area (acres), is the summation of A_acres, Pr_acres, V_acres, and S_acres from Table 1b.
Column I	Total Area (acres), is the total of the four different land uses assigned to each sub-basin

Worksheet ‘Table 3 (Data)’

Worksheet ‘Table 3 (Data)’ includes the coefficient of runoff (CR) for each land type (Table 3a), rainfall volume (Table 3b), and event mean concentration (EMC) values (Table 3c) used to calculate the loading. The manner in which this table is set up is presented in Table A-3.

TABLE A-3. Configuration of Worksheet ‘Table 3 (Data)’, Basic Water Quality and Hydrologic Input Data for the Cherry Creek Basin Stormflow Model

Column/Row	Functional Description
Table 3a[1]	
Column A	Runoff coefficient for undeveloped land, 0.017
Column B	Runoff coefficient for residential land, 0.15
Column C	Runoff coefficient for commercial land, 0.65
Column D	Runoff coefficient for industrial land, 0.67
Table 3b[2]	
Row 11, Column B	Rainfall volume for the mean event in Denver, 0.43 inches
Row 12, Column B	Mean number of precipitation events for storms 0.4 inches or greater, 14
Row 13, Column B	Blank
Row 14, Column B	Annual rainfall volume in Denver, 6.02 inches
Table 3c[3]	
Row 21, Columns B-E	Event mean concentration (mg/L) for TP for undeveloped, residential, commercial, and industrial land uses, respectively—0.4, 0.65, 0.42, 0.43

[1] U.S. Environmental Protection Agency. 1983. Results of the Nationwide Urban Runoff Program. Volume 1. Final Report, Water Planning Division, U.S. EPA, Washington, D.C.

[2] Driscoll, E. et. Al., 1989. Analysis of Storm Event Character for Selected Rainfall Gages throughout the U.S. 89-10148B 1100.

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'Industrial Loads' (Table 4a), 'Commercial Loads' (Table 4b), 'Residential Loads' (Table 4c), and 'Undeveloped Loads' (Table 4d)

The worksheets 'Industrial Loads' (Table 4a), 'Commercial Loads' (Table 4b), 'Residential Loads' (Table 4c), and 'Undeveloped Loads' (Table 4d) have the same set up. However, both CR and EMC values vary depending on the type of land use. The manner in which these four sheets are set up is presented in Table A-4.

TABLE A-4. Configuration of 'Industrial Loads' (Table 4a), 'Commercial Loads' (Table 4b), 'Residential Loads' (Table 4c), and 'Undeveloped Loads' (Table 4d)'

Column/Row	Functional Description
Column A	the specific land use area for each sub-basin, acres
Column B	the basin name
Column C	the unit loadings for TP, lb/acre/yr
Column D	the total loadings for TP, lb/yr

'Total Phosphorus' (Table 5)

The set up of worksheets 'Total Phosphorus' (Table 5), is presented in Table A-5. These worksheets summarize total loading for each constituent by sub-basin and land use.

TABLE A-5. Configuration of 'Total Phosphorus' (Table 5)

Column	Functional Description
Column A	sub-basin name
Column B	area (acres) of the sub-basin
Column C	total phosphorus loading contributed by the undeveloped land (i.e., for the sub-basin Cherry Creek Reservoir, 44 lb of phosphorus are contributed annually by undeveloped land (this value is copied from worksheet 'Undeveloped Loads', Column F))
Column D	total phosphorus loading contributed by the residential land (i.e., for the sub-basin Cherry Creek Reservoir, 0 lb of phosphorus are contributed annually by residential land (this value was copied from the worksheet 'Residential Loads', Column F))
Column E	total phosphorus loading contributed by the commercial land (i.e., for the sub-basin Cherry Creek Reservoir, 0 lb of phosphorus are contributed annually by commercial land (this value was copied from the worksheet 'Commercial Loads', Column F))
Column F	total phosphorus loading contributed by the industrial land (i.e., for the sub-basin Cherry Creek Reservoir, 0 lb of phosphorus are contributed annually by industrial land (this value was copied from the worksheet 'Industrial Loads', Column F))
Column G	summation of the phosphorus loadings from all four land use types for each sub-basin
Column H	stormflow IDR (IDR) assigned for each sub-basin
Column I	total phosphorus loading contributed by each sub-basin taking into account the IDR, lb/yr

ATTACHMENT B

CHERRY CREEK BASIN STORMFLOW OUTPUT

ATTACHMENT C

CHERRY CREEK BASEFLOW MODEL INPUT

ATTACHMENT D

CHERRY CREEK BASEFLOW MODEL OUTPUT