Nonpoint Source Phosphorus Trading in the Cherry Creek Reservoir Watershed in Colorado

T. Andrew Earles, Ph.D., P.E., D.WRE[1]; Wayne F. Lorenz, P.E.[2]; Wilbur L. Koger[3]; and Molly Y. Trujillo, P.E[4]

Abstract: The Cherry Creek Reservoir in the Denver Metropolitan area is subject to the Cherry Creek Reservoir Control Regulation (control regulation), which establishes a total maximum annual load for the reservoir of 6,473 kg (14,270 lb) of phosphorus. The load is distributed among phosphorus sources including background, nonpoint, and regulated storm water, municipal and industrial wastewater facilities, individual sewage disposal systems, and industrial sources. As a part of the control regulation, the Cherry Creek Basin Water Quality Authority (CCBWQA) is authorized to implement and maintain a trading program that allows phosphorus trading and the sale of phosphorus (kg/lb) in the Cherry Creek watershed. The trading program allows dischargers seeking new or increased phosphorus waste load allocations to obtain additional kilograms/pounds of phosphorus by constructing nonpoint source projects meeting certain criteria to immobilize phosphorus. This paper provides an overview of the CCBWQA trading program guidelines and describes two Arapahoe County Water and Wastewater Authority (ACWWA) trade credit projects: Lone Tree Creek Pond L-3 and Windmill Creek Pond W-6/W-7. The Pond L-3 and Pond W-6/W-7 projects are unique because they are the first two (and only two to date) projects that have successfully obtained trade ratios and estimated trade credits under the CCBWQA trading program. This paper describes the administrative and technical process for determining trade ratios and estimating trade credits for nonpoint-source-to-point-source phosphorus trades in the Cherry Creek watershed. The process for going from an established trade ratio and estimated trade credits to actual trade credits applied to a point source discharge presents its own set of challenges. Actual trade credits must be demonstrated by monitoring, which can be very expensive. The monitoring results must be reviewed and approved by CCBWQA before trade credits are awarded, and the Colorado Department of Public Health and Environment Water Quality Control Division must amend the facility's discharge permit before additional phosphorus can be discharged. Therefore, establishing a trade ratio and estimating trade credits for CCBWQA approval of a phosphorus trading project is only the first step in a potentially expensive and time-consuming process for actually discharging additional phosphorus through a nonpoint-source-to-point-source trade in the Cherry Creek watershed.

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Background on Phosphorus Trading in the United States and Colorado

Pollutant trading is an environmental management strategy in which pollutant loads from one source are controlled to permit discharges from another source. Pollutant trading has been applied in the areas of air quality, wastewater quality, and more recently storm water or nonpoint source pollution control. Types of pollutant trading related to water resources management include point-source-to-point-source trades where a portion of a waste load allocation from one facility may be transferred to another and nonpoint-source-to-point-source trades where projects are constructed to control nonpoint sources of pollution such as storm-water runoff to compensate for increases in point source discharges.

Pollutant trading programs involving nonpoint source projects, which slowly began to emerge in the United States in the mid 1980s, are most common for nutrients, including nitrogen and phosphorus, and for sediments, but such programs have also been developed for other parameters, including selenium and mercury (Breetz et al. 2004; Wood and Bernknopf 2003). Although phosphorus, the subject of this paper, is one of the more common parameters for nonpoint-source-to-point-source trades in the literature, widespread creation and success of trading programs that allow transfer of trade credits earned for removal of phosphorus by nonpoint source pollution control projects to point source discharges have not been documented extensively in the literature. In fact this paper describes only the process of establishing the trade ratio and the process for receiving approval of estimates of trade credits. Actual trade credits must be borne out by monitoring, which is expected to begin in 2008 for the projects described in

[1]Vice President, Wright Water Engineers, Inc., 2490 West 26th Ave., Suite 100A, Denver, CO 80211. Email: aearles@wrightwater.com

[2]President, Wright Water Engineers, Inc., 2490 West 26th Ave., Suite 100A, Denver, CO 80211. Email: wlorenz@wrightwater.com (corresponding author).

[3]Formerly, Assistant General Manager, Water Supply and Acquisition, Arapahoe County Water and Wastewater Authority, 13031 East Caley Ave., Centennial, CO 80111.

[4]Capital Improvements Projects Manager, Southeast Metro Stormwater Authority, 76 Inverness Dr., Suite A, Denver, CO 80112. Email: mtrujillo@semswa.org; formerly, Arapahoe County Water and Wastewater Authority.

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Table 1. Summary of Nonpoint-Source-to-Point-Source Phosphorus Trading Initiative in the United States from *2004 Water Quality Trading and Offset Initiatives in the U.S.: A Comprehensive Survey* (Breetz et al. 2004)

Trading program	Comment
Chatfield Reservoir, Colorado	Very similar to Cherry Creek program. Established 2000.
Lake Dillon, Colorado	Established 1984. History of several nonpoint-to-point-source trades involving connection of septic systems to sanitary sewer. Trading guidelines revised in 2006.
Lower Boise River, Idaho	Developed framework in late 1990s/early 2000s in response to total maximum daily load (TMDL). Demonstration project in early 2000s.
Acton, Massachusetts Wastewater Treatment Plant	Proposed nonpoint source (NPS) projects with 3:1 trade ratio to allow construction of new wastewater treatment plant. Project not implemented. Groundwater-based wastewater treatment used instead.
Wayland, Massachusetts Business Center	Diversion of effluent from failing septic systems into wastewater treatment plant in exchange for increased wastewater discharge concentration. 3:1 trade ratio.
Kalamazoo River, Michigan	Demonstration project targeting voluntary nonpoint reductions started in 1997, with credits retired at end of project in 2000.
Rahr Malting Company, Minnesota	Trade of nonpoint source nutrient discharge for point source carbonaceous biological oxygen demand. Four nonpoint source projects, including conservation easements, stream bank stabilization, and feedlot management.
Southern Minnesota Beet Sugar Cooperative	2.6:1 trade ratio for nonpoint source best management practices (BMPs) including cattle exclusions, buffer strips, constructed wetlands, setasides, and cover cropping, to allow construction of new wastewater treatment plant.
Truckee River, Nevada	Program established including nonpoint-source-to-point-source trades for agricultural BMPs.
New York City Watershed	Pilot projects to allow construction of new wastewater treatment plants in basins with TMDLs.
Tar-Pamlico Basin, North Carolina	Credits for structural BMPs have life of 10 years; credits for nonstructural BMPs have life of 3 years. Voluntary implementation of BMPs but no formal nonpoint-source-to-point-source trades as of 2004.
Clermont County, Ohio	Program established to allow for growth under constraints of TMDL. No trades as of 2004.
Great Miami River (Ohio) Watershed Trading Pilot Program	10-year pilot program scheduled to begin in 2004 focused on agricultural BMPs.
Conestoga River, Pennsylvania	Pilot program as a part of overall Chesapeake Bay program. Demonstration project with poultry producer.
Fox-Wolf Basin, Wisconsin	Program established but no trades as of 2004. Lack of trades attributed to costeffectiveness of point source controls given 1.0 mg/L effluent limitation and farmers' opinions on property rights and government involvement.
Red Cedar River, Wisconsin	Trade to allow increased point source discharge by reducing tillage on phosphorus-rich soils. 2:1 trade ratio.
Rock River, Wisconsin	Initial interest in trading by more than 60 dischargers in watershed. Due to economic viability issues, interest waned, and no trades had occurred as of 2004.
Chesapeake Bay Watershed	Voluntary nutrient trading guidelines for Pennsylvania, Maryland, Virginia, and District of Columbia watersheds draining to bay.

this paper. Other trading programs for phosphorus have faced similar challenges, and actual trades that have led to increased point source waste load allocations are not yet common. Examples of nonpoint-source-to-point-source trading programs for phosphorus from around the United States are summarized in Table 1.

In the State of Colorado, Colorado Department of Public Health and Environment has developed a Colorado pollutant trading policy (CDPHE 2004), based on many of the principles in guidance from the U.S. Environmental Protection Agency (U.S. EPA 2003). The Lake Dillon Reservoir Control Regulation established a nonpoint-source-to-point-source phosphorus trading program in 1984, and major reservoirs in the Denver metropolitan area, including Chatfield and Cherry Creek, also have phosphorus trading programs. One of the purposes of the Colorado pollutant trading policy is to promote consistency between these similar programs that are ultimately under the oversight of the Water Quality Control Division (WQCD).

Cherry Creek Reservoir Total Maximum Annual Load

The Cherry Creek Reservoir Control Regulation (CDPHE 2005) establishes a total maximum annual load (TMAL) for phosphorus for the Cherry Creek Reservoir in metropolitan Denver (Fig. 1). The TMAL was developed as a result of the Cherry Creek Reservoir Clean Lakes Study from 1982 to 1984 (Denver Regional Council of Governments 1984). The TMAL of 6,473 kg (14,270 lb) of phosphorus is distributed among the sources listed in Table 2 (CCBWQA 2003b).

Point source dischargers such as the Arapahoe County Water and Wastewater Authority (ACWWA) receive a wasteload allocation under the TMAL to provide water and wastewater service to urban areas in the Cherry Creek Reservoir watershed. ACWWA currently has a wasteload allocation of 182 kg (402 lb) of total phosphorus for wastewater discharges (including the al-

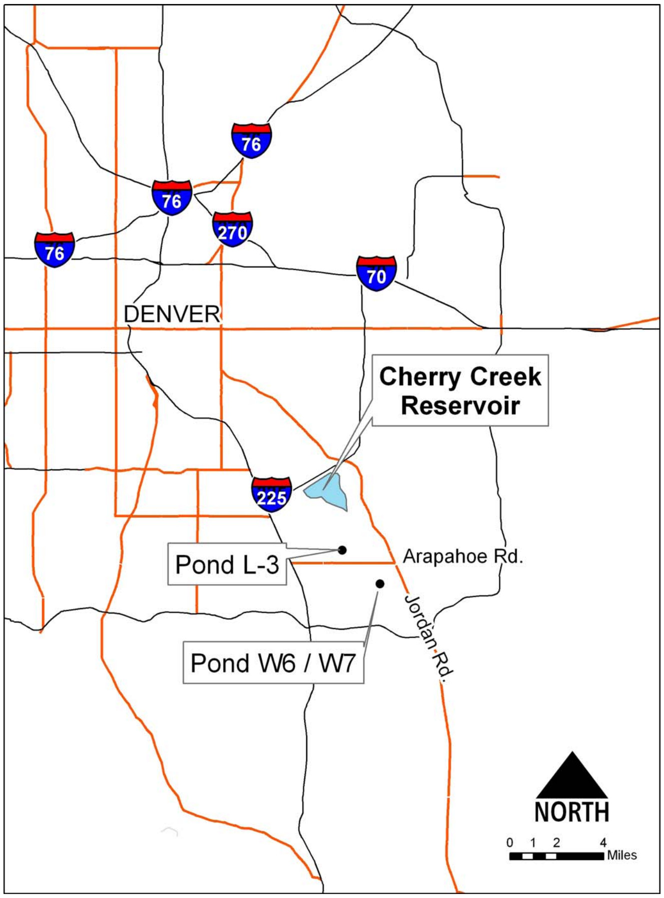

Fig. 1. Location map for Cherry Creek Reservoir

location of the former Cottonwood Water and Sanitation District Treatment Plant, which ACWWA now handles at their Lone Tree Creek Wastewater Treatment Facility) and uses a microfiltration treatment process to achieve very low effluent phosphorus concentrations.

At the time of the trade credit projects discussed in this paper, ACWWA also was responsible for storm-water management within the service area, including portions of the Dove Creek, Windmill Creek, and Lone Tree Creek watersheds that are tributaries to the Cherry Creek Reservoir. In 2006 a new regional storm-water authority, the Southeast Metro Stormwater Authority (SEMSWA), was created. As of early 2007, responsibility for implementation, operation, and maintenance of the regional storm-water drainage and water quality system within these watersheds, including the ponds discussed in this paper, is in transition from ACWWA to SEMSWA. ACWWA continues to assume responsibility of water quality monitoring for trade credit projects, which is a requirement for actually obtaining credits that can be applied to the ACWWA point source discharge.

Table 2. Cherry Creek Reservoir Phosphorus Sources

Source	Annual phosphorus load [kg (lb)]
Background	531 (1,170)
Nonpoint and regulated storm water	4,667 (10,290)
Wastewater facilities	966 (2,130)
Individual sewage disposal systems	204 (450)
Industrial	23 (50)
Total	6,473 (14,270)

The master planning for the Dove Creek, Windmill Creek, and Lone Tree Creek watersheds was originally published in the 1987 report "Outfall System Planning for Lone Tree, Windmill, and Dove Creeks Areas" (WRC Engineering 1987), which presented a regional approach for flood control and water quality including detention and water quality facilities in combination with channel improvements. Since the 1987 report, master planned water quality facilities have been reexamined and planning has been revised on several occasions as new water quality policies have been adopted by the Denver Urban Drainage and Flood Control District (UDFCD) and as conventional thinking on storm-water quality management has evolved. The most current planning effort, representing refinements to the 1987 WRC plan, was conducted by Wright Water Engineers, Inc. (WWE) in 2002 (WWE 2002).

For entities such as ACWWA, who at the time had responsibility for both point and nonpoint source discharges governed by the control regulation and restricted by the TMAL, the trading guidelines established for the Cherry Creek Reservoir provide a valuable tool for balancing point and nonpoint source discharges. The trading program provided ACWWA with a way to obtain phosphorus trade credits by constructing nonpoint source projects that immobilize phosphorus beyond baseline regulatory requirements [requirement for best management practices (BMPs), at a minimum, to be designed in accordance with UDFCD criteria for extended detention with anticipated average 50% total phosphorus immobilization for development after January 1, 2000]. This "excess" phosphorus immobilization may be used to earn trade credits, subject to a trade ratio designed to result in an overall phosphorus load reduction to the reservoir. Trade credits may be used to increase the point source wasteload allocation, giving ACWWA flexibility to respond to continued population growth in the watershed through construction of nonpoint source projects as an alternative to expensive treatment plant upgrades.

CCBWQA Phosphorus Trading Program Guidelines

The CCBWQA describes the purpose of the phosphorus trading program as follows (CCBWQA 2003a):

> The trading program allows allocatees to receive phosphorus pounds for new or increased phosphorus wasteload allocations from two distinct sources, each of which is more fully described herein: (1) the reserve pool in exchange for phosphorus loading reductions from nonpoint source control projects ("projects") built by the allocatees or third parties; and (2) phosphorus credits acquired from the authority's historic trading projects. The goal of the trading program is to encourage and facilitate the construction of projects.

The trading program identifies two types of projects (CCWBQA 2003a):

1. New trade projects. New trade projects allow entities in the Cherry Creek Reservoir watershed to construct nonpoint source phosphorus projects for trade credits. Trade credits may be used by the entity constructing the project or may be sold to other allocatees in the watershed. New trade projects draw from a "reserve pool" of 98 kg (216 lb) of phosphorus allocated in the control regulation for the trading program.
2. Historic trade projects. Historic trade projects include four

projects constructed by CCBWQA between 1991 and 1997. These projects make up a "phosphorus bank" of 98 kg (216 lb) of trade credits, which are available for transfer or purchase from the CCBWQA.

New trade projects, such as the Pond L-3 project constructed by ACWWA, include the following (CCBWQA 2003a):

1. Additions to existing development—these trade projects are for land development activities that took place prior to January 1, 2000 for which BMPs for phosphorus immobilization were not provided. For land development activities after January 1, 2000, BMPs designed in accordance with UDFCD criteria are required and are anticipated to achieve an average of 50% immobilization rate for phosphorus; however, new BMPs constructed to provide phosphorus immobilization for development prior to this date may qualify for trade credits.
2. Expanded or retrofitted BMPs—for projects constructed prior to January 1, 2000 for which BMPs were constructed, retrofits to facilities for enhanced phosphorus immobilization are eligible for trade credits. The CCBWQA regulations consider such facilities pollutant reduction facilities (PRFs)—projects that go beyond the baseline BMP-level phosphorus immobilization requirements in the control regulation for development after January 1, 2000. Only phosphorus immobilization beyond the existing immobilization provided by the facility is eligible for trade credits.
3. New projects exceeding baseline immobilization requirements—BMPs constructed for land development activities after January 1, 2000 that provide enhanced physical, biological, or chemical immobilization mechanisms, or that use operation and maintenance practices to achieve phosphorus immobilization beyond the baseline requirement may qualify for trade credits for the additional phosphorus immobilization. Such projects are considered PRFs. As with other projects under the trading program, credits can only be earned for phosphorus immobilization demonstrated by monitoring.
4. Cooperative CCBWQA projects—projects in which a third party assists with construction or funding of a CCBWQA-sponsored project may warrant trade credits. Trade credits for such projects are awarded based on the level of participation of the third party in the CCBWQA project and must be justified by monitoring.
5. Engineered CCBWQA projects—third parties have the ability to earn trade credits through construction of projects for which CCBWQA has completed preliminary engineering and design. CCBWQA must approve the third party's plans for construction of such projects for trade credit eligibility.
6. Water supply operations—municipal water supply treatment that goes beyond the typical incidental phosphorus immobilization of normal operations may be eligible for trade credits for additional phosphorus immobilization. This class of trade credit projects is targeted at immobilization of phosphorus from alluvial groundwater and irrigation return flows. Water that is treated and then used for beneficial uses such as drinking water or irrigation is excluded.

All trade credits are based on monitoring and are subject to a trade ratio determined during the application and approval process through engineering analysis, input from the CCBWQA technical advisory committee (TAC), and CCBWQA consultants. The minimum trade ratio is 2:1 (pounds immobilized:trade credits awarded). The minimum trade ratio is designed to provide a net benefit to the Cherry Creek Reservoir in terms of meeting the TMAL. The trade ratio may be adjusted (upward) to account for factors including:

1. Ratio of dissolved and particulate phosphorus of the nonpoint and point source discharges—for example, an extended detention basin may be effective at removing particulate phosphorus by sedimentation because of the slow release rate and long detention time; however, it may have little effect on the dissolved fraction of phosphorus in storm-water runoff. On the other hand, the point source discharge that the trade credits may be applied to may discharge almost entirely dissolved phosphorus (especially for microfiltration treatment processes), which is more available for algal growth and eutrophication in the Cherry Creek Reservoir. The trade ratio does not explicitly account for the type of BMP used; however, in evaluating immobilization and retention of particulate and dissolved forms of phosphorus, the type of BMP, presence of wetland vegetation, filtration processes, biological processes, and other transformation or immobilization mechanisms are considered in adjusting the trade ratio.
2. Fate and transport characteristics—considerations including chemical, biological, and physical transformations of phosphorus and the effects of travel time are also reflected in the trade ratio. When the nonpoint source project and point source discharge to which the trade credit will be applied are proximate, this is not a large factor in determining the trade credit. In cases where the point source (predominantly dissolved phosphorus) discharge is close to the reservoir and the nonpoint source project is farther away with greater potential for transformation of phosphorus released during runoff in transport to the reservoir, the trade ratio may be adjusted.

The control regulation specified a maximum trade ratio of 3:1 at the time of the Pond L-3 trade credit project approval in December 2004. Prior to the Pond W-6/W-7 application in May 2005, the cap on the maximum trade ratio was removed, opening the door to potentially have trade ratios in excess of 3:1. This cap was lifted by the CCBWQA Board to allow for potentially greater net benefit to the reservoir (i.e., phosphorus immobilized by a nonpoint source project versus phosphorus discharged through an awarded trade credit) and to provide a larger buffer, when warranted, for uncertainty associated with performance of nonpoint source projects. The concept of a trade ratio as implemented in the Cherry Creek trading program is consistent with an approach recommended by the U.S. EPA *Final Water Quality Trading Policy* (U.S. EPA 2003) for compensating for nonpoint source uncertainty.

Pond L-3

As described in the 1987 outfall system planning for Lone Tree, Windmill, and Dove Creeks areas (WRC Engineering 1987), Pond L-3 is located near the outfall of the Lone Tree Creek watershed. Preliminary facility designs presented in the 1994 design report for Lone Tree, Windmill, Dove, and Cottonwood Creeks Drainage and Water Quality Facilities indicated phased implementation of Pond L-3, initially as an on-line extended dry detention pond with the capability of later modification to a retention or wet pond for enhanced water quality treatment. Fig. 2 shows a general location map and aerial photograph of Pond L-3, the ACWWA Lone Tree Creek Wastewater Treatment Facility, and the Cherry Creek Reservoir.

Pond L-3 receives runoff from an approximately 3.1 km^2

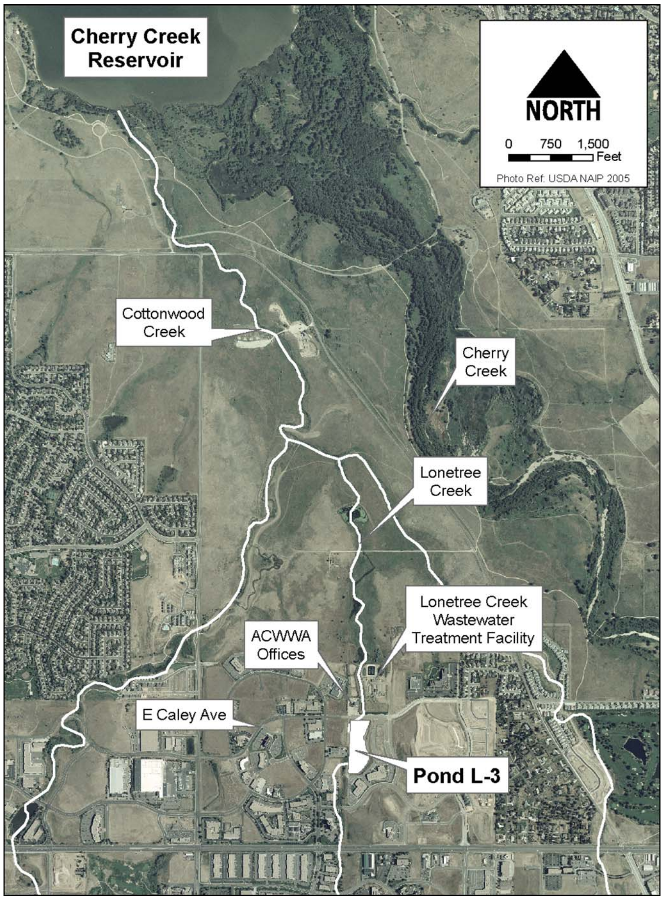

Fig. 2. Aerial photograph (2003) showing locations of Pond L-3, ACWWA Lone Tree Wastewater Treatment Facility, Cherry Creek Reservoir, and other features

(1.2 mi^2) watershed with an existing imperviousness of about 67%. Future projected imperviousness is 80%. Prior to retrofit for enhanced water quality, the facility provided detention for a minor storm event via two reinforced concrete pipes (RCPs) 46 cm (18 in.) diameter and 69 cm (27 in.) diameter and for the major (100-year) event via a concrete spillway. Prior to the retrofit, outlets did not meet UDFCD criteria for water quality drain time (prior to the retrofit, the drain time was approximately 6 h for the water quality capture volume versus 24 h per UDFCD criteria for a wetland basin).

Prior to the retrofit, the facility provided a water quality capture volume (WQCV) of 2.3×10^4 m^3 (18.5 acre ft) (less than required by UDFCD) and a sediment forebay volume of 300 m^3 (0.24 acre ft) [less than the 1,230–2,460 m^3 (1–2 acre ft) recommended by UDFCD criteria]. The 2000 Cherry Creek Basin Water Quality Watershed Plan (watershed plan) identified the retrofit of Pond L-3 as a PRF as one of the "most cost-effective natural system technologies investigated to reduce external phosphorus loads," and identified Pond L-3 as a PRF with a priority group number "Group 1: best opportunity for a retrofit project." These are some of the reasons why ACWWA pursued this as a trade credit project. The Pond L-3 trade credit project was the first application for trade credits to receive approval from the CCBWQA Board.

The retrofit of Pond L-3 increased the WQCV of Pond L-3 to 2.49×10^4 m^3 (20.2 acre ft), closer in line with UDFCD criterion of 2.52×10^4 m^3 (20.5 acre ft), and extended the WQCV drain time from approximately 6 to 24 h. The forebay size was to be increased from 300 m^3 (0.24 acre ft) to 1,160 m^3 (0.94 acre ft), again closer to the recommended UDFCD criterion.

Fig. 3. Existing wetland vegetation in Pond L-3

An additional facet of the project affecting water quality was the decision to leave the well-established wetlands (Fig. 3) in Pond L-3 largely undisturbed. Prior to the retrofit, the pond supported dense wetland vegetation, predominantly cattails, over most of the pond bottom. Originally, ACWWA and WWE had contemplated greater increases in the WQCV; however, the water quality benefits provided by the existing wetlands, the increased risk of erosion (and associated phosphorus loadings to the Cherry Creek Reservoir) during the time to reestablish wetland vegetation, and the immediacy of benefits due to the increased drain time with plants left undisturbed, led to the decision to settle for a slightly smaller WQCV and forebay with the benefit of avoiding additional disturbance.

ACWWA initiated the trade credit application process by submitting the necessary application materials and fee to the CCBWQA in July 2003. Since the retrofit of Pond L-3 brought the facility closer in line with UDFCD criteria rather than far exceeding criteria (i.e., much larger WQCV or longer drain time), the primary basis for the trade credit request was the fact that the facility provided treatment for development constructed prior to January 1, 2000, when baseline treatment requirements went into effect. After submission of the application, monthly TAC meetings and subcommittee sessions commenced to review the application and determine the appropriate trade credit and trade ratio. ACWWA originally requested a trade credit of 43 kg (94 lb) of phosphorus and proposed a trade credit of 2.1:1. Following the TAC and subcommittee review meetings, a trade credit for current conditions of 26 kg (57 lb) of phosphorus, and a trade ratio of 2.9:1 were agreed upon. CCBWQA referred the trade credit application to CDPHE to review the trade credits and trade ratio resulting from the TAC and subcommittee meetings, along with a referral letter from CCBWQA's consultant to gain CDPHE approval of the trade credit.

After a monitoring plan acceptable to the CCBWQA Board was developed (which will be used annually to determine actual trade credits awarded), the Board approved ACWWA's application in December 2004. The retrofit construction began in June 2004 and was completed in September 2004.

For 2004 watershed conditions and imperviousness, the estimated trade credit is 26 kg (57 lb), representing a trade ratio of 2.9:1. Table 3 summarizes the calculations agreed upon by CCBWQA, the TAC, ACWWA, and their consultants for estimated trade credits for this project. Actual trade credits awarded will be based on monitoring data reviewed and accepted by the TAC and Board. Additional trade credits may be available as additional development occurs in the watershed if demonstrated by monitoring and approved by CCBWQA.

Table 3. Estimated Trade Credit Calculation for ACWWA Pond L-3 Project

		Existing project and existing development conditions		Modified project and existing development conditions		Modified project and future development conditions	
Row	Consideration	TP	TDP	TP	TDP	TP	TDP
1	Annual phosphorus load from watershed	188.2 kg (415 lb)	67.5 kg (149 lb)	188.2 kg (415 lb)	67.5 kg (149 lb)	231.8 kg (511 lb)	83.5 kg (184 lb)
2	Annual phosphorus load discharged from project	150.6 kg (332 lb)	54.0 kg (119 lb)	75.3 kg (166 lb)	57.2 kg (126 lb)	92.5 kg (204 lb)	70.3 kg (155 lb)
3	Net reduction in phosphorus, (row 1–row 2)	37.6 kg (83 lb)	13.6 kg (30 lb)	112.9 kg (249 lb)	10.4 kg (23 lb)	139.3 kg (307 lb)	13.2 kg (29 lb)
4	Net reduction in phosphorus w/adjustment to account for existing project	n/a[a]	n/a[a]	75.3 kg (166 lb)	57.2 kg (126 lb)	101.6 kg (224 lb)	77.1 kg (170 lb)
5	Net reduction in phosphorus w/adjustment for fate and transport ratio (row 4/2.2)	n/a[a]	n/a[a]	34.0 kg (75 lb)	25.9 kg (57 lb)	46.3 kg (102 lb)	34.9 kg (77 lb)
6	Net reduction in phosphorus w/adjustment for TDP/TP ratio (row 5/1.32) calculated final trade credits	n/a[a]	n/a[a]	25.9 kg (57 lb)	25.9 kg (57 lb)	34.9 kg (77 lb)	34.9 kg (77 lb)
7	Requested final trade credits	n/a[a]	n/a[a]	42.6 kg (94 lb)	n/a[a]	42.6 kg (94 lb)	n/a[a]
8	Calculated final trade ratio (row 4/row 6)	n/a[a]	n/a[a]	2.9	2.2	2.9	2.2

Note: TDP=total dissolved phosphorus; TP=total phosphorus. The above table takes into account that the project will also service new development occurring since January 2000. This new development is represented by the projected increase in imperviousness from 60 to 80%. As such, available trade credits for future development conditions are based on the reduction in phosphorus beyond 50%. It was assumed that the existing facility will immobilize 20% of the total phosphorus load and the proposed project will immobilize 60% of the total phosphorus load on a long-term average basis. Whereas the 60% estimate is higher than normally projected for extended detention basins, the calculations suggest a higher than typical performance can be expected due to higher phosphorus concentrations in runoff sediment than typically used by Brown and Caldwell (2003). The applicant based the ratio of dissolved phosphorus to total phosphorus (i.e., 0.76 dissolved versus total) on the CCBWQA's monitoring results for the Shop Creek water quality facility, which is believed to be representative of the project's watershed. The applicant proposed a trade ratio of 2:1. Brown and Caldwell originally suggested a ratio of 2.2:1. The WQCD recommended a ratio of 3.1:1. The influent TDP/TP ratio is based on the ratio of event mean concentration (EMC) for TP and TDP, as presented in Volume 3 of the *UDFCD Criteria Manual*. This value used to estimate TDP from urban runoff w/o BMPs. Due to the low detention time of the existing project (i.e., 6 h), the project discharge TDP/TP ratio is assumed equal to urban runoff ratio. This value used to estimate TDP in effluent from existing project. The difference between the TP load from the future developed watershed and the load from the existing watershed represents the load portion that must meet minimum BMP requirements (i.e., 50% reduction). The calculation of TDP is based on the ratio presented above times the calculated total phosphorus value, and not a subtraction of different rows and columns in the table. The control regulation considers the adjustment for relative TDP/TP to be part of the trade ratio. Therefore, when calculating the final trade ratio, the calculation divides total phosphorus in row 3 by the calculated trade value. For instance for modified project and future development, the final trade ratio is 2.9 (224/77=2.9). The TDP/TP ratio for the point source discharge is an assumed value. The adjustment for TDP/TP only applies to the "total" phosphorus column in the above table, since the "dissolved" column already accounts for the TDP/TP ratio.

[a]n/a=not available.

Monitoring will include hydrologic and water quality measurements of storm and baseflows and assay of sediments and other material removed from the forebay and pond as a part of maintenance. The pond inlet and outlet will be equipped with automated sampling equipment, programmed to collect representative flow-weighted samples. Samples of material removed from the forebay and micropool during maintenance will be characterized in addition to the automatic sampling to quantify phosphorus content, since some of the coarser material may not be collected by automatic samplers. A tipping bucket rain gauge will be installed at the site to collect precipitation data. Parameters for analysis will include total suspended solids, total phosphorus, particulate phosphorus, and dissolved phosphorus. Results will be reported to CCBWQA annually in support of the request for actual trade credits for the year. The trading guidelines specify annual reporting and have provisions for upward or downward adjustment of the actual trade credit awarded based on monitoring data. It is anticipated that monitoring will be capable of detecting seasonal variations in performance of the facility, since monitoring will take place throughout the year; however, calculation of the trade credits is based on the annual amount of total phosphorus immobilized by the facility, subject to the trade ratio. Trade credits will be evaluated annually based on monitoring data. It is not yet clear if it may be feasible to obtain trade credits in the future with a reduced monitoring regimen if performance has been demonstrated for a number of years—currently the trading guidelines do not have a provision for a waiver from monitoring or a reduced requirement. The cost of continuous annual monitoring is a significant component of the overall cost of phosphorus trade credits.

A database of monitoring data will be maintained by ACWWA and their consultants and will be provided to CCBWQA in hard copy and electronic formats. Monitoring of Pond L-3 has not yet begun, because ACWWA's existing phosphorus allocation for the Lone Tree Creek Wastewater Treatment Facility is sufficient to accommodate increased wastewater treatment demands for the near future given the advanced treatment level provided by the plant and a recent plant expansion. The trade credits assigned to ACWWA for the Pond L-3 project provided ACWWA with a valuable long-range planning tool to increase the wastewater phosphorus allocation when growth puts pressure on treatment capabilities of the Lone Tree Creek Wastewater Treatment Facility.

Pond W-6/W-7

At roughly the same time as Pond L-3 trade credits were approved by CCBWQA, ACWWA was undertaking the design of another regional facility in the Windmill Creek drainage of their service area. This project, initially planned as a water quality facility, Pond W-6, and a flood control detention pond, Pond W-7, presented another opportunity for ACWWA to pursue trade credits for facilities aimed at removing nonpoint source phosphorus from storm-water runoff. Unlike the Pond L-3 project, the existing Pond W-7 was strictly a flood control facility and provided little to no benefits in terms of water quality.

In the course of design, ACWWA and their engineers determined that to effectively use the available space, it would be best to create a combined water quality and flood control facility rather than two adjacent, separately functioning facilities. The combined facility was named Pond W-6/W-7. Fig. 4 shows the location of Pond W-6/W-7 relative to the ACWWA Lone Tree Creek Wastewater Treatment Facility and the Cherry Creek Reservoir. The Pond W-6/W-7 facility is located approximately 4 mi from the Cherry Creek Reservoir near the intersection of East Briarwood and Jordan Road in Arapahoe County, Colorado. Prior to construction, it consisted of a rough-graded open depression draining to a $2.4\ \text{m} \times 3.05\ \text{m}$ ($8\ \text{ft} \times 10\ \text{ft}$) reinforced concrete box culvert underneath East Briarwood. A small $2,470\ \text{m}^3$ (2 acre ft) pond was located adjacent to the Pond W-6/W-7 site but was believed to provide few benefits in terms of water quality due to the lack of a water quality outlet, erosion occurring at inflows to the pond, and insufficient WQCV.

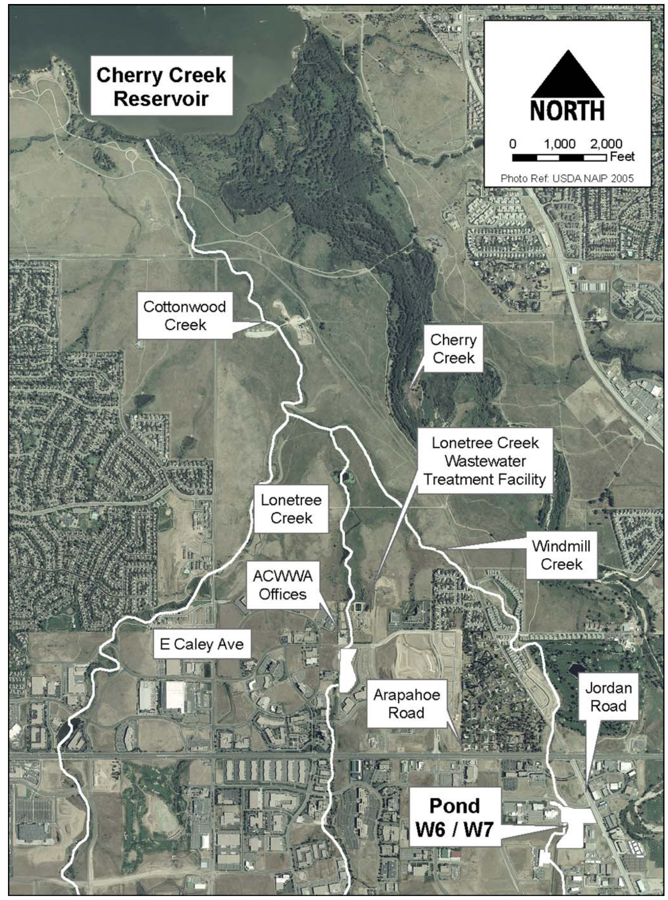

Fig. 4. Aerial photograph (2003) showing location of Pond W-6/W-7, ACWWA Lone Tree Creek Wastewater Treatment Facility, and Cherry Creek Reservoir

The Pond W-6/W-7 facility has a drainage area of approximately $3.1\ \text{km}^2$ ($1.2\ \text{mi}^2$), which prior to January 1, 2000 had an imperviousness of approximately 21% due to development activities that occurred prior to institution of water quality requirements by CCBWQA. Projected buildout imperviousness for the watershed tributary to Pond W-6/W-7 is estimated at 76%. The Pond W-6/W-7 facility was designed jointly as a water quality facility with a WQCV of $2.2 \times 10^4\ \text{m}^3$ (17.7 acre ft) with a 40 h drain time and as a flood control facility with an additional $3.7 \times 10^4\ \text{m}^3$ (29.8 acre ft) of detention storage to attenuate 10- and 100-year peak flow rates to allowable master plan levels based on future developed conditions. In addition, the project involved constructing a forebay and micropool per UDFCD standards, each with approximately $1,230\ \text{m}^3$ (1 acre ft) of capacity. Fig. 5 is a photograph of the outlet and micropool. The micropool is a unique design feature of many regional ponds in UDFCD's

Fig. 5. Pond W-6/W-7 outlet and micropool

jurisdiction. It is less commonly used on smaller ponds. Although the micropool does provide water quality benefits in terms of biological activity in the permanent pool, perhaps the most important feature of the micropool is the role it plays in preventing clogging of the outlet orifice plate. This is achieved by providing a flow path from the micropool into the outlet structure beneath the permanent water surface elevation. While debris often accumulates on the outlet screen and trash rack above the permanent water surface, as the water surface rises and falls during a runoff event, the below-the-water-surface flow path resists the drain and clogging cycle that occurs on the upper part of the outlet.

One of the most notable differences between the Pond W-6/W-7 project and the Pond L-3 project was the trade ratio applied to determine the potential trade credit. Actual trade credits can be adjusted upward or downward depending on the monitoring data; however, the trade ratio is set as a part of the application approval process. Although the trade credit calculations, which resulted in 39 kg (86 lb) of total phosphorus immobilized per year on average for development prior to January 1, 2000, were very similar to those of Pond L-3, a trade ratio of 2.5:1 was approved by CCBWQA. As with the Pond L-3 project, ACWWA initially proposed a lower trade ratio for Pond W-6/W-7. This ratio was slightly higher than the 2.1:1 trade ratio that had been proposed for Pond L-3 and was adjusted upward to account for the greater distance from the Pond W-6/W-7 facility to the Lone Tree Creek Wastewater Treatment Facility, differences in transport characteristics to the reservoir, and the fact that primarily particulate phosphorus would be immobilized by the pond. Initially, the TAC recommended a trade ratio in excess of 3:1; however, based upon discussion and analysis of the above factors and the economic viability of entities such as ACWWA constructing projects for trade credits at high ratios, the TAC and ACWWA agreed on a trade ratio of 2.5:1. This was accepted by CCBWQA.

The final trade credit approved by CCBWQA for Pond W-6/W-7 was a credit of 15 kg (34 lb) per year for immobilization of 39 kg (86 lb) per year of phosphorus for development occurring before January 1, 2000, resulting in a net benefit to the reservoir of a 51 lb reduction in phosphorus loads on a long-term average annual basis. Construction of Pond W-6/W-7 began in 2005 and the facility was completed in 2006. As with Pond L-3, ACWWA has not yet commenced monitoring of this facility to demonstrate phosphorus immobilization. This is a requirement before trade credits can actually be applied to increase phosphorus discharges from the Lone Tree Creek Wastewater Treatment Facility. The Pond W-6/W-7 trade credit project was the second trade credit project approved by CCBWQA. As of December 2007, Ponds L-3 and W-6/W-7 have been the only two projects that have successfully navigated the process.

Conclusions

The trading program implemented by CCBWQA for the Cherry Creek Reservoir is an innovative approach to meeting the requirements of the TMAL for phosphorus and improving reservoir water quality. The program, which includes a trade ratio designed to provide a net benefit to reservoir phosphorus loading and water quality, is a valuable option for dischargers in the watershed (such as ACWWA) that balance point and nonpoint source discharges to the reservoir. This program is an incentive to more effectively manage nonpoint sources of pollution in a metropolitan area that is rapidly growing with new demand for storm-water and wastewater services. The Pond L-3 trade credit project was the first example that the trading program and regulations can successfully be applied. The application and review process is intensive but navigable, and the actual trade credits awarded will be borne out by monitoring.

These projects demonstrate successful navigation of a new regulatory process designed to accommodate growth and development while providing water quality improvements for the Cherry Creek Reservoir through control of nonpoint source pollution. Both projects have demonstrated the ability of the trading program to evaluate trade credits for projects that provide benefits for development that was constructed prior to current water quality regulations in the watershed. Although trade credits have not yet been applied to the point source discharge, since monitoring has not yet begun, the nonpoint source projects began benefitting the water quality of the reservoir when they were constructed in 2004 and 2006. In addition, this paper discusses changes that have occurred in determining the trade ratio from the 2.9:1 used for the Pond L-3 project to the 2.5:1 used for Pond W-6/W-7.

This paper describes the administrative and technical process for determining a trade ratio and estimating trade credits nonpoint to point source phosphorus trades in the Cherry Creek Watershed. The process for going from an established trade ratio and estimated trade credits to actual trade credits applied to a point source discharge presents its own set of challenges. Actual trade credits must be demonstrated by monitoring, which can be very expensive, with an estimated annual cost for the 2008 Pond L-3 and Pond W-6/W-7 monitoring program of more than $100,000/year for the two sites. The monitoring results must be reviewed and approved by the TAC and the CCBWQA Board before trade credits are awarded, and the CDPHE WQCD must amend the facility's discharge permit before additional phosphorus can be discharged. Therefore, establishing a trade ratio and estimating trade credits for CCBWQA approval of a phosphorus trading project is only the first step in a potentially expensive and time-consuming process for actually discharging additional phosphorus through a nonpoint to point source trade in the Cherry Creek watershed.

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