PROJECT COMPLETION REPORTS

POLLUTANT REDUCTION FACILITIES (PRF)

The following reports summarize the various capital projects completed with Authority funds as of April 2014.

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Memorandum

To: Chuck Reid, Manager, CCBWQA

Cc: Rick Goncalves, Chairman TAC

From: William P. Ruzzo, P.E.

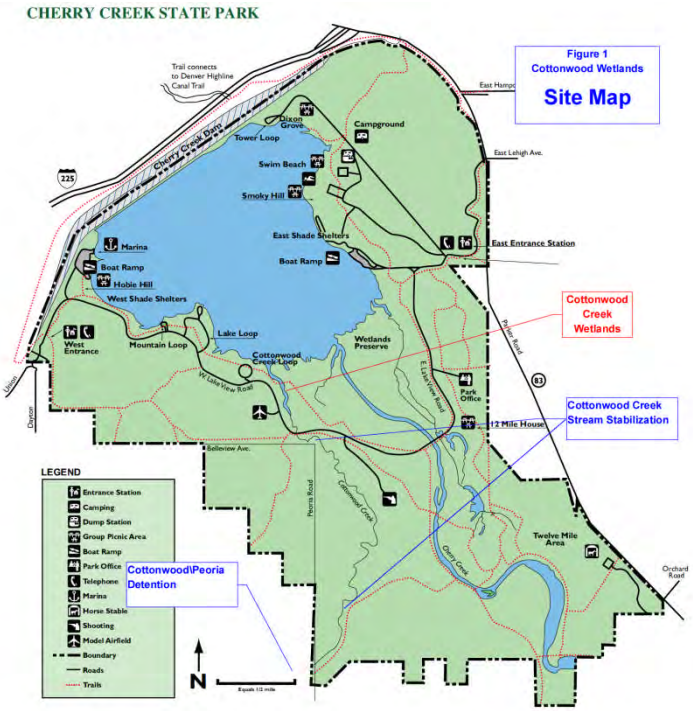
Date: December 27, 2012

Re: Cottonwood Wetlands PRF Rehabilitation – Project Summary

Presented in this memorandum is a summary of the Cottonwood Wetlands Pollutant Reduction Facility (PRF) Rehabilitation project (Cottonwood Wetlands PRF or Project.

BACKGROUND AND PURPOSE

The Cottonwood Wetlands PRF[1] was constructed by the Authority around 1997 for the purpose of trapping sediment from the highly eroded Cottonwood Creek channel within the Park boundaries to prevent sediment and attached pollutants from entering the Reservoir. This project was followed by the Cottonwood\Peoria Wetlands (2001) and the first Phase of Cottonwood Creek reclamation (2004) within the Park. See Figure 1, Site Map.



Despite these upstream stabilization measures, routine monitoring of the inflow and outflow phosphorus loads beginning in 1997 showed that by 2005, the "*…effectiveness of the pond system was greatly reduced*[2]. Restoration of Cottonwood Wetlands

[1] Previously referred to as the Cottonwood Perimeter Road Pond in earlier Authority documents.
[2] Chadwick Ecological Consultants, Inc. March 2006. *Cherry Creek Reservoir 2005 Annual Aquatic Biological-Nutrient Monitoring Study and Cottonwood Creek Phosphorus Reduction Facility Monitoring.*

was identified as a necessary project in the 2005 annual inspection report[3] and included in the Authority's 5-year CIP budget. However, rehabilitation of the Cottonwood Wetlands was delayed until the upstream reaches of Cottonwood Creek from West Lakeview Road (aka perimeter road) to Peoria Street were stabilized to minimize additional sedimentation of the Cottonwood Wetlands PRF.

Phase II of Cottonwood Creek Reclamation was finished in 2008 completing reclamation of the 2.2-miles of highly eroded channel within the Park boundary. The Authority then began preparing plans for rehabilitation of the Cottonwood Wetlands in 2008 by retaining Muller Engineering Company[4] to prepare final plans and construction documents.

INVESTIGATION PHASE – Clay Pigeon Debris

During design of the rehabilitation project, clay pigeons were found at the site in early 2009. Some types of clay pigeons are classified as a solid waste since they contain polynuclear-aromatic hydrocarbons (PAH). In discussions with the Colorado Department of Public Health and Environment (CDPHE) it was determined that only material containing clay pigeons disturbed during construction must be removed and disposed in a qualified landfill. It is not necessary to remove clay pigeons from the entire project site, if they are left undisturbed. Therefore, the Authority redesigned the Cottonwood Wetlands PRF to minimize excavation in areas of the project where clay pigeons were known to exist in order to reduce cost of offsite, landfill disposal.

Figure 2 - Clay Pigeon Debris

The area affected by the PRF and clay pigeon debris is owned by the US Army Corps of Engineers (Corps) and is in the possession of CPW pursuant to a long term lease. The Authority could not assume responsibility for removing waste material from property it does not own, especially since the placement of that material resulted from the actions of third parties over whom the Authority had no control. Because the PRF could not be rehabilitated until the clay pigeons were removed and because of economies of scale, contractor scheduling issues and other matters of contract administration, rehabilitation of the PRF and the removal of the clay pigeons was determined to be best treated as an integrated project and managed by a single owner, CPW.

DESIGN APPROACH

The primary purpose of the Project was to restore the sedimentation function of the PRF, which had become clogged with sediment since construction reducing water quality benefits. However, to avoid damaging the existing cottonwood, sedge, cattail, and rush wetlands that had become

[3] William P. Ruzzo, PE, LLC April 25, 2005. *Annual Inspection of PRF's at Cherry Creek State Park.*
[4] October 1, 2008. *Agreement for Engineering Design Services – Cottonwood Wetlands Project.*

established since construction, the main creek channel was realigned to avoid existing wetlands, which also avoided the known clay pigeon areas. In addition, the main channel was aligned to create a serpentine pathway with localized pools through the pond area to maximize the contact between storm runoff and the existing and newly planted vegetation further improving water quality. These modifications are illustrated in Figure 3 below where the green color represents existing wetlands.

Rehabilitation of the Project did not restore the original sedimentation capacity because of the reduced pond surface area occupied by wetlands. However, the modifications discussed above were considered to offset reduction in sedimentation capacity, particularly since the upstream channel was now stabilized reducing future sediment transport into the Project.

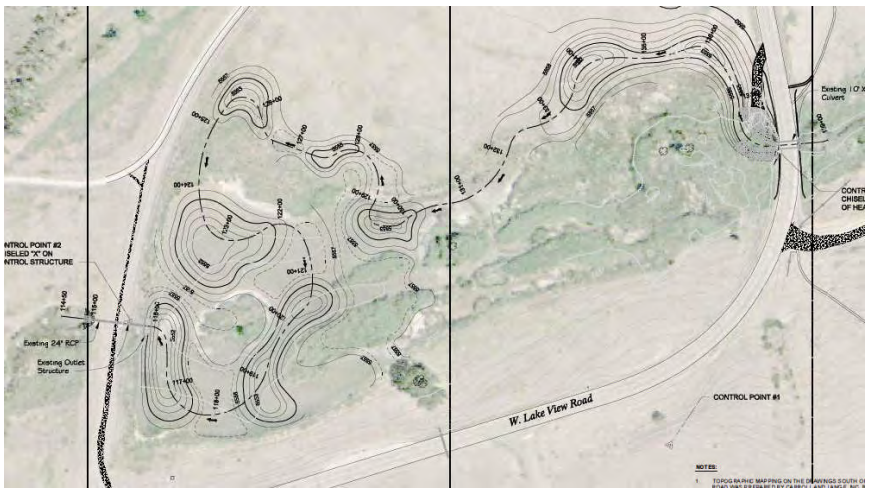


Figure 3 General Project Plan

FUNDING AGREEMENT

Because of the shared responsibility by both parties for the Project, the Authority and CPW entered into a funding agreement in September 2011 to share project costs. Key provisions of the agreement included:

1. Both parties allocated funds for the project to cover all costs, including PRF rehabilitation and clay pigeon removal and disposal.

2. CPW pays for all costs associated with removal and proper, off-site disposal of clay pigeon debris.

3. The Authority pays for all costs associated with rehabilitation of the Cottonwood Creek Wetlands PRF.

4. CPW and the Authority already incurred expenses related to the project that were not their responsibility and therefore each party receives credit for the expenses when determining how the final project costs will be shared. The construction contract administration and quantities have been developed to clearly separate PRF rehabilitation costs from clay pigeon disposal costs.

5. The project was constructed per plans prepared for and approved by the Authority.

The funding agreement was amended (First Amendment) on April 16, 2012 to adjust expected project costs due to greater quantities of sediment that needed to be removed.

PROJECT MANAGEMENT

CPW agreed to manage construction of the project and, with approval of the Authority, contracted with the Authority's consultant to provide construction observation services to oversee the rehabilitation of the Cottonwood Wetlands PRF. CPW managed project bidding and construction contracting paying all project costs from a separate State account initially funded by the State. The Authority provided overall project guidance and direction related to rehabilitation of the PRF working cooperatively with CPW throughout construction. After completion of the Project and all project costs were accounted for, the Authority reimbursed CPW for the balance of the Authority's cost share.

CONSTRUCTION

A single bid was received for the Project and opened on November 22, 2011. Since the bid amount of $326,781[5] compared favorable to the engineer's opinion of probable cost ($337,267) adjusting for increased sediment removal costs, the Project was awarded to 53-Corporation, LLC of Castle Rock. The notice to proceed with construction was issued on January 17, 2012.

To facilitate sediment removal, the pond was drained starting October 7, 2011 which revealed that the pond had experienced greater sedimentation than previously estimated and would require more excavation and sediment removal. During construction of the Project, the Authority also had another project[6] under construction within Cherry Creek State Park by 53-Corporation, which needed earth materials. After determining the suitability of the sediment for use in the 12-Mile Park project, the Authority directed the contractor to haul sediment from the Cottonwood Wetlands project and place it at the 12-Mile Park project to reclaim the wetlands damaged during breach of the Cherry Creek channel. This exchange of material between projects reduced costs to import materials for the two projects and export materials from the Park to preserve flood storage volume[7].

Figure 4 - Beginning excavation

[5] Amount includes the base bid and optional work but not clay pigeon removal.
[6] Cherry Creek Stream Reclamation at 12-Mile Park – Phase I
[7] William P. Ruzzo, PE, LLC July 26, 2012. *Tower Loop, Cottonwood Wetlands, and Cherry Creek @ 12-Mile Park*

In late May of 2012, it was discovered that the original dam embankment for the Cottonwood Wetlands PRF was constructed from 0.5 to 1.5-feet below the design elevation. The contractor was issued a change order to raise the embankment to the original design elevation. On June 6, 2012 a significant storm event occurred over Cottonwood Creek and lower Cherry Creek basin that resulted in minor flood damages at the Cottonwood Wetlands project[8]. The investigation concluded that if the dam embankment had not been raised,"…*it is likely that the dam would have overtopped resulting in significant damage downstream of the dam and to the Cottonwood Wetlands project*."

The Cottonwood Wetlands project was complete as of July 9, 2012. Final project costs and allocation of costs between the Authority and CPW are shown in the adjacent table. The cost allocated to CPW represents the final costs to remove and dispose clay pigeons disturbed as the result of the Project. CPW originally received an estimate of $90,000 to just characterize the solid and hazardous[9] wastes on the site, which costs did not include any removal of clay pigeon debris.

TOTAL PROJECT COSTS	Total	Authority	CPW
Preliminary Engineering	$ 39,750.00	$ 39,750.00	$ -
Final Design Engineering	$ 29,637.00	$ 10,607.50	$ 19,029.50
Construction Engineering	$ 93,494.50	$ 80,761.00	$ 12,733.50
Construction	$306,805.66	$ 289,089.32	$ 17,716.34
Environmental testing	$ 810.20	$ -	$ 810.20
Total	***$470,497.36***	***$ 420,207.82***	***$ 50,289.54***

SEDIMENT SAMPLES

Prior to construction, samples of the sediment were obtained and tested for total phosphorus content[10]. The average total phosphorus (TP) concentration of 744 mg/kg for the Cottonwood Wetlands is consistent with the Authority's results for sediment removed from the Cottonwood Peoria Street wetlands (average of 743 mg/kg). TP concentrations in sediment ponds are approximately 50% higher than found in stream bed and stream banks, which are typically around 500-mg/kg.

WATER QUALITY BENEFITS

Water quality benefits of the Cottonwood Wetlands have been documented in the Authority's annual report of activities to the Water Quality Control Commission required by Control Regulation No. 72. The Authority collects data upstream and downstream of the Cottonwood Wetlands and the Cottonwood Peoria Wetlands which allows each segment of the treatment train

[8] William P. Ruzzo June 7, 2012. *Preliminary Report on the June 6, 2012 Flood Event on Recent Completed PRFs in Cherry Creek State Park.*

[9] Since clay pigeon debris was found there was a possibility that lead from the shot would also be found. Samples of the sediment containing clay pigeons were tested and found to be less than maximum contaminant limits.

[10] William P. Ruzzo, January 12, 2012. *Cottonwood Wetlands PRF Rehabilitation – Soil Phosphorus Content.*

(i.e.: Cottonwood\Peoria Pond, Cottonwood Creek Reclamation, and Cottonwood Wetlands) to be evaluated independently.

The Annual Report for 2011[11] shows that, prior to rehabilitation of the Cottonwood Wetlands, the 2011, flow weighted total phosphorus (TP) into the Project was 101-ug/l and discharged from the Project was 81-ug/l. Measurements during 2012 showed that TP[12] discharged from the Project varied from 87-ug/l to 36-ug/l which is a noticeable improvement in water quality. It is also noted that the discharge TP is less than the proposed in-stream standard for TP, which is 170-ug/l.

[11] CCBWQA March 31, 2012. *Annual Report on Activities Cherry Creek Basin Water Quality Authority.*
[12] One measurement taken in March 2012 during construction resulted in a TP of 156-ug/l.

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Memorandum

To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: December 27, 2013

Re: Cottonwood Creek at Easter Avenue – Project Summary Report

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Presented in this memorandum is a summary of the Cottonwood Creek Stream Reclamation between Easter Avenue and Briarwood Avenue (Cottonwood @ Easter Avenue, Project, see Figure 1 Location Map).

BACKGROUND AND PURPOSE

The Cottonwood @ East Avenue project is part of a watershed master plan[1] prepared under the guidance of the Urban Drainage & Flood Control District for SEMSWA and Douglas County. The Project is approximately 0.42-miles long following the creek thalweg and the drainage area is 5.47-square miles at Briarwood Avenue. SEMSWA began design for the reclamation of the Project reach in 2006 at which time detailed topographic information was obtained. Construction of the project was delayed until 2010 during which time additional erosion in the reach has occurred.

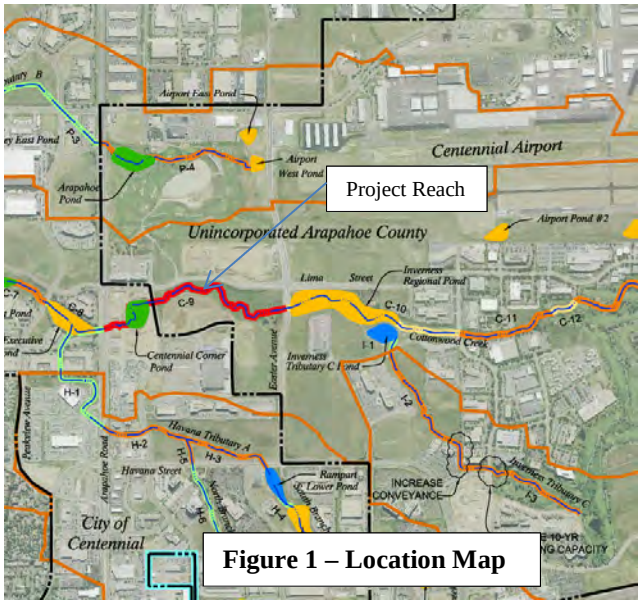

Figure 1 – Location Map

The Cottonwood\Easter Project was reviewed by the TAC in May 2007 at the request of the U.S. Army Corp of Engineers because of a 404 permit application by SEMSWA. Because SEMSWA's design approach to stream stabilization was consistent with the Authority's water quality goals and objectives, the Cottonwood Project was included in the Authority's 2008 Master PRF list by the TAC.

The Master PRF List shows the 2600 foot long project to contribute 50-lbs/year of phosphorus to Cherry Creek Reservoir based on typical erosion rates of silty clayey channels. Capital costs were

[1] Muller Engineering Company August 2010. *Cottonwood Creek (Downstream of Lincoln Avenue) Outfall Systems Plan Conceptual Design Report.*

estimated to be $1,350,000 with an annualized cost of $105,000 including maintenance. Assuming 90% efficiency, the Cottonwood @ Easter Avenue Project would immobilize 45-lbs per year of phosphorus at an annual cost of $2,332 per pound. There are over 30 projects on the Master CIP list with annual cost per pound estimates ranging from as little as $300 to over $3,000, a tenfold variation. The average value is approximately $1,200 and the median value is approximately $400.

PROJECT PARTNERS AND FUNDING

The Authority partnered with SEMSWA through a Memorandum of Understanding (MOU) in 2010 to provide $338,000 for the construction of the Cottonwood @ Easter Avenue project. The MOU was one of the first intergovernmental agreements between the Authority and local governments for the construction of pollutant reduction facilities (PRFs) such as stream reclamation.

WATER QUALITY BENEFITS

The Authority supports the reclamation of streams in the watershed because reclamation provides water quality benefits by reducing erosion and immobilizing pollutants in the channel by filtering them through riparian vegetation. These benefits have been demonstrated by PRF monitoring, literature reviews, and the TAC's investigations[1]. Because of rapid urbanization in Cottonwood Creek watershed, channel degradation had resulted in significant erosion far beyond assumed average or typical conditions for other streams (see Figure 2), rendering the 2006 topographic survey out of date.

Figure 2 – Example of Extensive Erosion

To determine how much the erosion would impact earth quantities that might require design changes, SEMSWA commissioned an additional topographic survey in 2010 and prepared comparative cross sections. The Authority then analyzed the changes in the stream channel geometry using the two topographic surveys for the project. The Authority evaluated the 31 cross sections to estimate the amount of erosion that had occurred during the four year period. Each section was reviewed to determine the change in cross section area related to stream flow erosion. The eroded area was estimated using the following criteria:

1. Change in cross section area was limited to the main channel area, a lateral distance around 80-feet.

2. Where it appeared that bank material sloughed into the channel bed but had not been eroded, the sloughed area of the bank was not included in the erode area calculation since the material is still in the channel bottom.

3. Some cross sections showed that the 2010 topography was higher than 2006 topography, which may be interpreted as deposition or perhaps channel shifting. No erosion was assumed for these sections.

Table 1 below summarizes the calculations performed to estimate the amount of erosion that had occurred over the period from start of design to start of construction.

Table 1 – Channel Erosion Estimate

Total Erosion	2623 cubic yards
Project Length	0.42-miles (thalweg)
Erosion Duration	4-years
Erosion Rate	1574 cy/mi/yr
Sediment Density	90 pcf
Erosion Rate	1912 Tons/mi/yr

When compared to other channel erosion rates, the Cottonwood @ Easter Avenue results show that the erosion rate for the four year period was extremely high when, as shown in Table 2. Ward Branch and Stroubles Creek are results from areas outside of Colorado that were found in the literature.

Table 2 – Comparison of Stream Erosion Rates (tons/mile/year)

Cottonwood Creek		Ward Branch	Stroubles Creek
Cherry Creek State Park	Easter to Briarwood		
182	1912	610	164

The four-year rate for the Cottonwood @ Easter Avenue project is about 10 times what was estimated for Cottonwood Creek within Cherry Creek State Park – which occurred over a period of 50 or more years - and about 19-times the rate the Authority currently uses to approximate sediment loads from an unstable stream system (i.e.: 100 tons/mi/yr). It is likely, however, that Briarwood to Easter Avenue reach would not continue at this rate for an extended period of time.

The Authority also obtained sediment samples and had them tested for total phosphorus content. Total phosphorus concentrations ranged from 431 to 910 mg/kg with an average of 573-mg/kg. This translates to average total phosphorus in the samples of 1.0-lbs P per ton of sediment, which is consistent with the Authority's estimated value for calculating water quality benefits.

Conclusions

The analysis and comparison suggests that when bank sloughing (or wasting) occurs, the sediment loads increase dramatically over normal stream bank and bed erosion rates. The significant increase in sediment loads – and associated pollutants - further demonstrates the importance of stabilizing and reclaiming stream systems well before the condition worsens such as the Easter to Briarwood reach.

Reclamation of the reach of Cottonwood Creek between Easter Avenue and Briarwood will reduce channel bed/bank erosion and pollutant loads to Cherry Creek Reservoir.

Figure 3 – Reclaimed Reach of Cottonwood Creek

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Memorandum

To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: December 27, 2013

Re: Cottonwood Creek Tributary B Airport Ponds East and West – Project Summary Report

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Presented in this memorandum is a summary of the Cottonwood Creek Tributary B Airport Ponds East and West (*Peoria Tributary B Airport Ponds East and West*, Project, see Figure 1 Location Map).

BACKGROUND AND PURPOSE

A Conceptual Design Report for the Cottonwood Creek watershed was prepared for SEMSWA, Douglas County, and the UDFCD in 2010 (called OSP)[1]. An OSP provides a watershed wide plan that addresses drainage, flood control, and storm water quality impacts from urbanization. The Authority provided input to the OSP as a stakeholder by attending progress meetings and commenting on draft documents. The final OSP recommendation included a total of 26 existing, retrofitted, or new regional detention/water quality facilities with 23 of the sites providing excess urban runoff volume[2] (EURV), including modifications to Tributary B Airport West Dam and Airport East Dam to include EURV (see Figure 1).

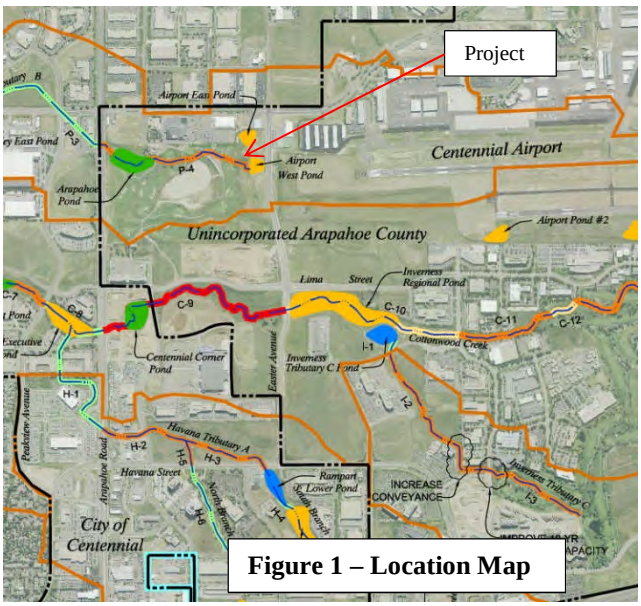

Figure 1 – Location Map

In early 2010, the TAC investigated the Airport's storm water management plan (SWMP) with attention towards evaluation of the Airports deicing management program. The airport uses propylene glycol and in the past ethylene glycol as deicing agents which have high biological and chemical oxygen demands (BOD and COD) that reduce oxygen in receiving waters. High total suspended solids (TSS) concentrations have also been

[1] Muller Engineering Company August 18, 2010. *Cottonwood Creek (Downstream of Lincoln Avenue) Outfall Systems Plan Conceptual Design Report.*

[2] Providing EURV in a water quality pond is believed to provide additional water quality benefits beyond Authority minimum requirements, which is extended detention basin (EDB).

detected in the runoff. The Authority provided comments to the Airport expressing concerns that the SWMP did not adequately address pollutant discharges, specifically glycol COD, BOD, and TSS. The Authority offered to work with the Airport and, as a result, also provided suggestions to the Airport regarding the SWMP, many of which were incorporated into the final Airport SWMP.

PROJECT PARTNERS AND FUNDING

In 2010, the Authority Board adopted the 2011 – 2014, 5-year capital improvement budget (CIP) that included the *Peoria Tributary B Airport Ponds East and West CIP*, based in part on the OSP recommendations and the need to address deicing runoff from the airport. At that time, it was assumed that the Authority would partner with the Airport and SEMSWA to fund the project, which consisted of modification to two existing ponds at a cost $523,000 with the Authority providing of $131,000 (25%).

In March 2011, the Authority was requested to provide comments on construction plans being prepared by the Airport's consultant who was designing improvements to Airport Ponds East and West that included combining the two ponds and providing EURV water quality capture volume. The Airport was modifying the east and west detention ponds per the OSP as a mitigation measure for the FAA directed, safety-related-widening of the nearby runway.

Representatives of the Airport and their consultant attended the October 6, 2011 TAC meeting and reported that the total project cost estimate for the ponds is around $1,500,000, including design, construction, and permitting. The FAA provided $1,200,000 and the Airport provided $134,000 plus the land value. The Authority contribution of $131,000 constitutes 8.7% of the total project cost.

WATER QUALITY BENEFITS

Construction of the *Peoria Tributary B Airport Ponds East and West* will prevent sediment and nutrients in runoff from Centennial Airport from entering Cottonwood Creek and protect water quality and beneficial uses of Cherry Creek Reservoir. The project will also help to maintain higher levels of dissolved oxygen in Cottonwood Creek and the Reservoir[3] and is also part of a comprehensive watershed approach to manage water quality.

Figure 2 – Pond Outlet

Figure 2 shows the pond outlet which was modified to include a rock filter. Water quality sampling and testing by Arapahoe County has identified the natural presence of rust colored bacteria in the storm drainage system at Easter Avenue which includes runoff from Centennial Airport. Research by the Authority suggested that naturally occurring bacteria can reduce glycol concentrations and that other airports have incorporated similar treatment for deicing runoff. Authority recommended modifications to the Airport pond incorporates small, angular rock in the swale and at the outlet to simulate a "trickling filter" common in wastewater treatment.

[3] Until very recently, the Reservoir was on the 303(d) list for dissolved oxygen, which was a concern to the Authority.

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Memorandum

To: Chuck Reid, Manager, CCBWQA

Cc: Rick Goncalves, Chairman TAC

From: William P. Ruzzo, P.E.

Date: June 10, 2008

Re: Cherry Creek Reservoir Destratification Project – Project Summary

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Presented in this memorandum is a summary of the Cherry Creek Reservoir Destratification Project requested by the Board at their May 15, 2008 meeting.

BACKGROUND AND PURPOSE

The Cherry Creek Basin Water Quality Authority (Authority) has been implementing watershed-based, best management practices (BMP) and constructing pollution reduction facilities (PRF) for many years to protect the beneficial uses of Cherry Creek Reservoir. However, the chlorophyll *a* standard (15-µg/l) was not being met from 1996 through 2005, but was met in 2006 and 2007. In addition, there is a trend in water quality improvement since 2002 (see Figure 17 below from the annual monitoring report). Note that the horizontal dashed line represents average value and not the standard). In addition, the phosphorus goal (40-µg/l) has only been met once in 1989 and has been on an upward trend for a number of years (see Figure 15 below).

The 2004 special study[1] of in-lake nutrient enrichment indicated that nitrogen is the limiting nutrient for algae growth. Dr. Lewis also noted that "*reduction in phosphorus concentrations sufficient to induce phosphorus deficiency in the phytoplankton of year 2003 would involve decreases in upper water column concentrations of at least 50%, or about 30 µg/L*". What this means is that controlling algal growth by reducing nutrients in the Cherry Creek watershed alone is very difficult and that algae must also be controlled "…*based on non-nutrient factors*", according to Dr. Lewis

Even though the Authority and others have implemented watershed controls with some success, watershed controls alone are not sufficient nor are the phosphorus reductions timely enough to control algae growth in the near future. Therefore, the need for supplemental strategies to control algae growth, such as in-lake management, became more apparent.

Dr. Lewis found that during periods when the reservoir was not being naturally mixed by wind activity, then algal growth activity was at its highest. He determined that the most practical approach

[1] Lewis, Willam M. Saunders, James F III, and McCutchan, James H. Jr. January 22, 2004. *Studies of Phytoplankton Response to Nutrient Enrichment in Cherry Creek Reservoir, Colorado.*

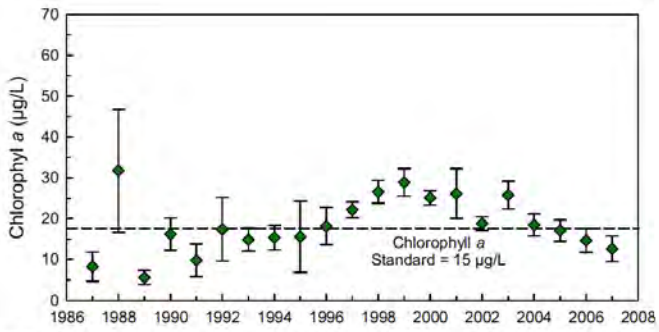

Figure 17: Seasonal mean (July to September) chlorophyll *a* concentrations measured in Cherry Creek Reservoir, 1987 to 2007. Error bars represent 95% confidence interval around each mean.

to controlling this growth would be to artificially mix the reservoir. Since the reservoir is relatively shallow, it can usually be mixed by normal wind activity. Several times throughout the year, however, extended periods of hot, dry and windless weather cause the lake to stop mixing and to stratify. This stratification not only causes anoxic (lack of oxygen) conditions at the bottom of the reservoir, but also allows blue-green algae to bask in the sunlight on the surface of the reservoir, fixing all the nitrogen they need from the air. And, with plenty of phosphorus in the water, they can reproduce explosively. Thus, an algae bloom is created.

As a result, the Authority considered in-lake management techniques that could be beneficial to reducing chlorophyll a, as well as nutrients and dissolved oxygen (DO) concentrations in the near term. Dr. Lewis suggested destratification (mixing) as a method to address internal loading and other factors that increase algal growth and therefore, chlorophyll a and phosphorus and nitrogen concentrations. It was noted that watershed management is a necessary component of the Watershed Plan 2003[2] and both BMPs and PRFs should continue to be implemented. The continuation of these programs was also a condition for the approval of the Department of Natural Resources for the installation of the aeration system.

INVESTIGATION PHASE

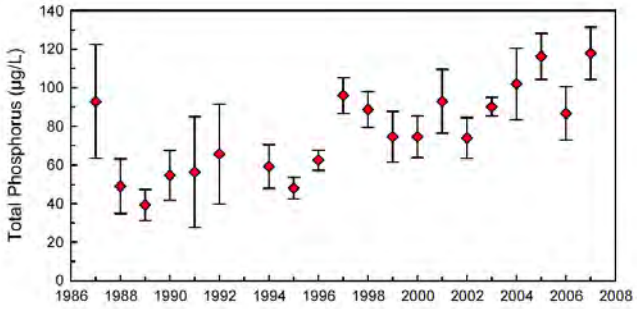

Figure 15: Seasonal mean (July to September) total phosphorus concentrations (µg/L) measured in Cherry Creek Reservoir, 1987 to 2007. Error bars represent a 95% confidence interval for each mean.

The Authority then had prepared a conceptual investigation[3] to identify other lake mixing projects, the pros and cons of aeration for mixing, and the order of magnitude of cost. The investigation concluded that aeration is used in local lakes (e.g., Bear Creek Lake, McClellan Reservoir, Coors lakes and Quincy Reservoir) with varying degrees of success and complexity of the systems, with the simplest systems performing with greater reliability than more complex systems. The projected capital, design, and administration costs were around $700,000.

TECHNICAL FEASIBILITY

The Authority then authorized by contract with AMEC Earth and Environmental (AMEC) dated August 3, 2005 a more detailed investigation[4] to further identify technical feasibility and costs. After

[2] Cherry Creek Basin Water Quality Authority 2003. *Cherry Creek Reservoir Watershed Plan 2003.*
[3] Brown and Caldwell, May 4, 2004. *Conceptual Investigation of Reservoir Destratification for Cherry Creek Reservoir*
[4] AMEC Earth and Environmental May 5, 2005. *Feasibility Report for Cherry Creek Reservoir Destratification.*

a eight month investigation and evaluation that included representatives of Cherry Creek State Park, the Army Corps of Engineers, the Colorado Division of Wildlife and representatives of the fishing and boating community, the AMEC team recommended the installation of a submerged mixing system in the 330 acre portion of the reservoir which is greater than 16 feet deep. The primary objectives for the mixing system were to:

- Destratify and strongly mix the deepest portions of the reservoir,
- Vertically mix algae to compromise their habitat and reduce production of blue-green algae, and
- Oxidize of the deep bottom sediments to reduce the release of nutrients from the sediments into the water column.

The estimated capital costs were projected to be up to $700,000.

FINAL DESIGN AND CONSTRUCTION

The Authority then authorized final design and construction of the AMEC recommended focused mixing system by contract amendment approved by the Board on February 16, 2006. The final design was completed in September 2006 and estimated the construction costs were $810,400. The project was awarded in separate contracts to supply the compressor and aeration line, underwater installation, above water installation and other miscellaneous items, which is summarized in the table below.

Summary of Destratification Project Capital Costs

Item	Cost
Investigation, Design & Administration	
Technical Feasibility Report	$70,000
Final Design and Construction Management	$93,000
Administration	$9,000
Sub-Total Investigation, Design, Admin	*$172,000*
Construction	
Compressor Purchase	$58,500
Hydraulic Hose and Fittings	$243,100
Underwater Construction	$142,500
Above Water construction	$478,600
Power Installation	$12,000
Aerator System Inspection and Adjustment	$11,400
Sub-total	$*946,100*
Less enlarged trail costs in the amount[5]	$150,000
Net Construction	**$796,100**
TOTAL CAPITAL COSTS	***$968,100***

To supply the air to the diffusers, a distribution line was placed partially across the face of the dam and covered with a berm large enough for maintenance access. The berm was enlarged during construction to become a portion of a formal trail across the entire face of the dam at the request of Colorado Division of Parks. The extra cost of $150,000 to enlarge the berm was reimbursed to the Authority by the Department of Natural Resources.

The destratification system was substantially completed by December 14, 2007 and the official start up of the system took place on April 4, 2008. Subsequent to the official start up modifications were made to the compressor building, consisting of duct work to improve the heat ventilation and compressor cooling, installing the extra aerator assemblies, and additional inspection and adjustment of existing aerator assemblies. This work, which is part of the annual operations and maintenance budget, was approximately $15,000.

HOW DOES THE SYSTEM WORK?

The destratification system works by pumping air into the bottom of the Reservoir at a rate of 200 to 250 standard cubic feet per minute (SCFM) at a pressure of 51 pounds per square inch gage (psig). The 125 Hp compressor used to deliver this air is housed in a 19 by 17 foot block building with a metal roof near the Marina and has a rated maximum capacity of 455 SCFM. The reserve capacity of the compressor is available for enlargement of the in-lake portion of the system in the future if that proves to be desirable. The air passes through over 40,000 feet of 1-1/4 inch hydraulic hose leading to 102 air diffusers placed at the bottom of the deepest part of the reservoir, which is greater than 16-feet and covers 350-acres of the 850-acre total surface area. These diffusers are expected to move about 1,000,000 gallons of water per minute (approximately 4,400 acre feet per day) which will "turn-over" the mixing zone about once per day.

HOW WILL IT BE DETERMINED IF THE SYSTEM WORKS?

The aeration and mixing system was designed to meet the following program objectives:

1) Reduce the release of phosphorus and nitrogen nutrients from the bottom sediments into the water column of the reservoir in a typical year by 810 lbs/yr and 1,140 lbs/yr, respectively,
2) Decrease the seasonal mean (July-September) chlorophyll a concentrations by approximately 8 ug/L under typical year conditions,
3) Decrease annual peak chlorophyll a concentrations by up to 30 ug/l,
4) Increase dissolved oxygen concentrations in the deepest and most vulnerable zones of the reservoir into the range of 5 mg/L, and
5) Reduce the production of blue-green algae by making the habitat of the reservoir less suitable for the production of blue-green algae via vertical mixing.

The ultimate test of whether destratification and mixing works will be the reduction of algae biomass and density as measured by chlorophyll a and species identification and enumeration, particularly the blue-green species cyanobacteria. The more immediate test will be to determine if the reservoir stays mixed throughout the algae growing season from May through October, as measured by the vertical temperature and dissolved oxygen profile of the water column.

During the regular growing season, the authority contracts with GEI\Chadwick Division to conduct bi-monthly sampling in the reservoir at three locations. During each sampling episode on the reservoir, three main tasks were conducted, including: 1) determining water clarity; 2) collecting depth profile measurements for temperature, dissolved oxygen, and pH conductivity; and 3) collecting water samples for chemical and biological analyses. In anticipation of construction of the destratification system, the Authority had GEI install three temperature arrays consisting of Onset HOBO® Water Temp Pro data loggers in the deepest part of the reservoir. These data loggers recorded temperature measurements on 15-minute intervals for each 1 meter water layer. This monitoring program was continued in 2008 to determine how well the reservoir stays mixed and may be extended beyond 2008.

In addition to the temperature loggers at the three monitoring sites, GEI will also perform monthly Oxidation Reduction Potential (ORP) profiles along a transect through the deep water zone, including measurements near the water/sediment surface during the July to September period. The sample locations and transect will be consistent with locations previously established by AMEC during their destratification feasibility study.

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Memorandum

To: Chuck Reid, Manager, CCBWQA

Cc: Rick Goncalves, Chairman TAC

From: William P. Ruzzo, P.E.

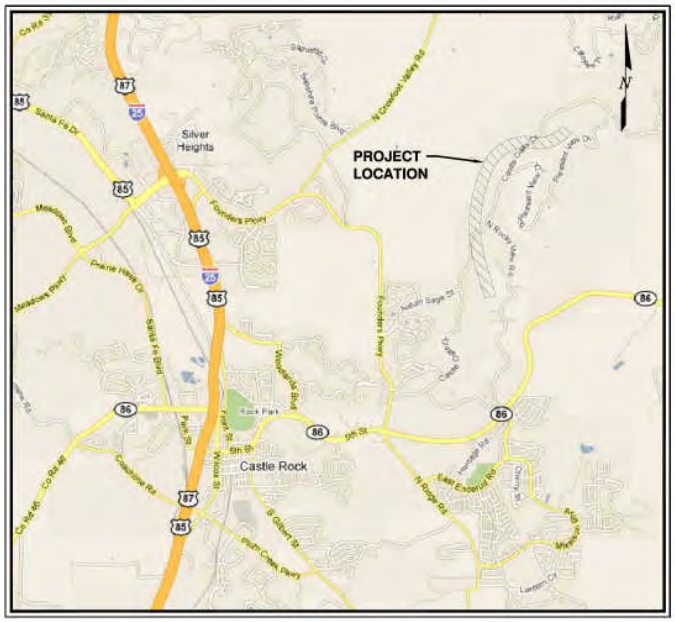
Date: November 16, 2011

Re: McMurdo Gulch Stream Reclamation – Project Summary

Presented in this memorandum is a summary of the McMurdo Gulch Stream Reclamation, which was jointly funded by the Town of Castle Rock and the Authority. Project design occurred during 2009 and 2010 and construction was completed in 2011 at a cost of ~ $1,178,000 for the 2.84-mile reach.

BACKGROUND AND PURPOSE

A reclamation plan for McMurdo Gulch, a major tributary to Cherry Creek in the upper watershed, was developed in 2009 and 2010 and implemented in 2011 under the sponsorship of the Town of Castle Rock and the Authority. Although relatively undeveloped at the time of the study, there are significant plans for further build-out in the McMurdo Gulch watershed, making the timing of the reclamation plan advantageous to implement a proactive approach to protect the gulch and reduce sediment and nutrient loads into Cherry Creek in advance of increased stormwater runoff and degradation. It is believed that implementing measures to protect the gulch *before* the onset of severe erosion will be more cost effective and more favorable to downstream water quality than reacting after increased runoff has a chance to degrade the gulch.



INVESTIGATION PHASE

McMurdo Gulch is a western tributary to Cherry Creek that has a watershed area of 6.5 square miles. The entire McMurdo Gulch channel is approximately 6.7 miles long from the headwaters to the confluence with Cherry Creek. The McMurdo Gulch Reclamation Project study reach accounts for roughly 2.84 miles of channel length and is centrally located in the basin. Over the 2.84 mile project reach, the characteristics of McMurdo Gulch vary significantly. The project reach has three distinct channel reaches: upstream, middle, and downstream. The average gradient through the three reaches varies between 1.3 and 2.0%.

In all three reaches there is evidence of active erosion (see Picture 12 below). The impacts of this erosion were most evident in the lower reaches. Part of this is due to the change in soil characteristics and vegetative cover, which are comprised mainly of sand and cobbles that are more susceptible to erosive forces. Also, in many areas along the channel, erosion has been caused by off-road vehicles crossing and running down the center of the channel.

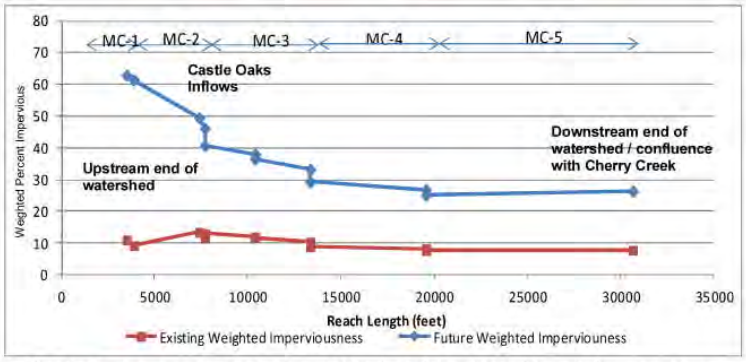


Figure 2. Cumulative imperviousness draining into McMurdo Gulch for existing and future development conditions.

In addition to the proactive channel reclamation aspect of the work, Castle Rock and the Authority also included watershed requirements for existing and new development (MEC 2011-b). For the existing developments, the detention ponds are to be modified to include Excess Urban Runoff Volume (EURV), which is believed to provide greater water quality benefits than minimum requirements of Control Regulation No. 72 (i.e.: extended detention basin). For future development, the minimum requirement would include EURV for detention facilities. Figure 2 above illustrates the anticipated increase in watershed imperviousness as development occurs in McMurdo Gulch (MEC 2011c).

Picture 12: Station 208+00 looking d/s
Typical Channel, Sandy Channel and overbanks

DESIGN APPROACH

Although the channel erosion discovered during field visits to McMurdo Gulch was considered minor, the project sponsors decided on a proactive approach in reclaiming the degrading areas prior to severe erosion taking place (MEC 2011a). As more development occurs in the upstream portions of the basin, flow rates will increase, which will likely increase erosion within the channel.

A reclamation plan was developed consisting of stabilizing eroded sections of the channel with a combination of boulder cascade drop structures, rock lining, bioengineered bank protection, and riparian vegetation. The proposed improvements are segmented in nine improvement reaches within the 2.84 mile project reach: Reach A through Reach I. The improvement reaches cover a total of approximately 4,000 lineal feet and they are separated by reaches with no improvements since they are currently not eroding.

A unique approach to grade control structures, called boulder cascades, were designed to mimic a natural boulder channel characteristic of streams observed in the Rocky Mountains. The structures are comprised of a combination of loose boulders and void-filled riprap. The boulder cascades range from 1 to 4 feet in drop height and the bottom width varies from 10-feet to 35-feet. The structures contain a 6% longitudinal slope down the face of the structures and extend 2.5-feet up each channel bank at a 4:1 side slope. The side slopes are buried with topsoil and covered with erosion control blanket.

The drop dimensions are not intended to provide a specific capacity, but instead are intended to work with the geometry of the existing channel and surrounding areas. In areas where a series of boulder cascades are to be constructed in close proximity to one another, a stable longitudinal slope of 0.6% was used between structures. The photo (MEC 2011) at the left shows a completed structure with wetland vegetation growing before the project was completed.

WATERSHED PLAN

A watershed plan was evaluated to control peak discharges from developed areas to levels similar to or less than pre-development conditions over the whole spectrum of storm events -- from frequent small events to large flood-producing storms (MEC 2011b). At the least, it is anticipated that implementing full-spectrum detention in the watershed (and retrofitting existing detention facilities) to control runoff will reduce the level of improvements required for stream reclamation and will slow the pace of degradation such that funding resources can more easily keep up with the required improvements. At best, it may be found that watershed-wide full-spectrum detention may eliminate the need for capital improvements in some stream reaches.

The initial flow-control plan was focused on the Castle Oaks Subdivision, since in the near term this community contains the largest concentration of impervious area that will drain into the critical reaches of McMurdo Gulch. Eight existing Castle Oaks detention facilities, shown in Figure 4 on the following page, were evaluated for potential retrofitting. Five of these facilities were designed with outlet structures that control the 10 year and 100 year flow rates, one facility was designed to capture and slowly release only the water quality capture volume (WQCV), and two facilities were designed to control the WQCV and the 10 year and 100 year events.

In addition to these recommended retrofit improvements, it is essential that future detention ponds implemented as part of new development be designed as full-spectrum detention facilities and modeled to ensure that runoff levels remain close to pre-developed. Initial coordination between the Town of Castle Rock, Douglas County, and Authority took place during the design process to define a common requirement of implementing full-spectrum detention for all future development within the basin. The findings and recommendations of the detention retrofit investigation are found in MEC 2011b.

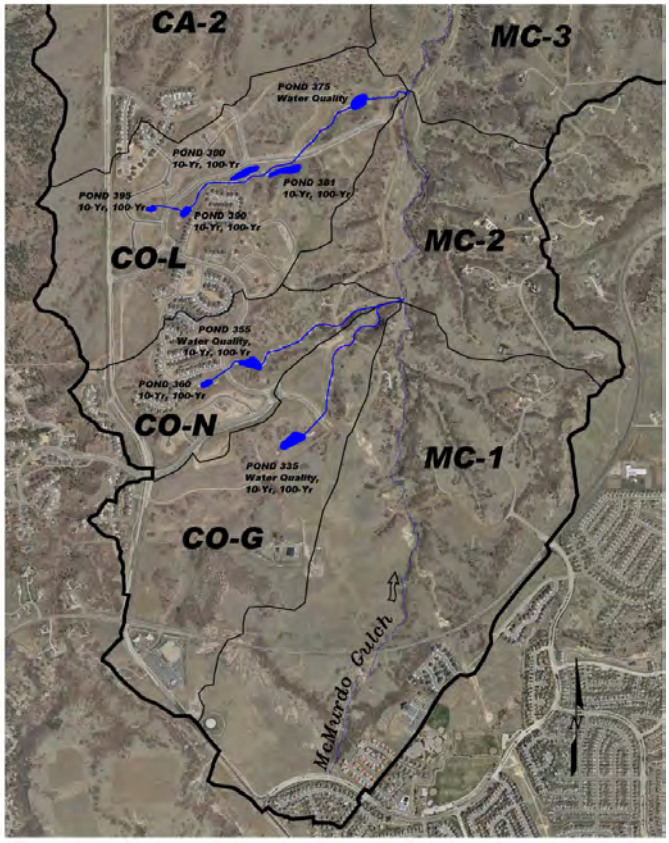


***Figure 4**. Eight existing detention facilities in Castle Oaks community were evaluated for retrofit improvements.*

FUNDING

In December 2009, the Town of Castle Rock and the CCBWQA entered into a memorandum of understanding (MOU) to jointly participate in the McMurdo Gulch stream reclamation project. This project was originally identified in the Authority's capital improvement projects list for 2009. In 2010 Muller Engineering Company was retained by Castle Rock to develop a design for McMurdo Gulch. Throughout this design process the design team, made up of representatives of the Town of Castle Rock and the Authority, maximized the total reach length designed to allow for flexibility in construction.

In the fall of 2010 a request for proposals was sent to four construction contractors that are experienced in this type of work. The low bidder was 53 Corporation with a low bid of $1,099,818. This bid was significantly lower than the engineer's estimate of $1,531,549. A summary of project funding is shown on the following table:

SUMMARY OF PROJECT COSTS

EXPENDITURES	AMOUNT
Engineering Services	$ 291,800
Construction	$ 1,178,200
Total Costs	$ 1,470,000
FUNDING CONTRIBUTIONS	
Town of Castle Rock	$ 840,000
Cherry Creek Basin Water Quality Authority	$ 630,000

MONITORING

Beginning in 2012, the Authority will take grab samples from surface flows on a monthly basis and analyzed for physicochemical parameters, such as nutrients and suspended solids, and identified as either base flow or storm flow samples. Samples will be obtained at the upstream and downstream end of the McMurdo

Gulch project. The sampling is intended to identify if the proactive, surgical approach to stream reclamation will control sediment and nutrients to pre-development levels in the watershed.

WATER QUALITY BENEFITS

Stream reclamation is beneficial to water quality in the stream and in the Reservoir (CCBWQA 2011). Stream reclamation reduces sediment and other pollutant loads and concentrations, including phosphorus and nitrogen. Load and concentration reductions during base and storm flow conditions can occur by reducing flow velocities, providing greater areas for filtration and infiltration of stormwater and, to some extent, through increases in dissolved oxygen. This finding is also supported by literature search of other strategies used by watershed organizations to improve runoff water quality and several years of Authority water quality data collected to evaluate PRFs, particularly Cottonwood Creek.

Summary of Water Quality Benefits

Item	McMurdo Gulch
Project Length (mi) =	2.84
Project Capital Costs =	$ 1,470,000
Project Cost per mile =	$ 517,600
Stream Reclamation Water Quality Benefits (lbs/mi/yr) =	90
Project Annual Water Quality Benefits (lbs/yr) =	255.6
Capital Recovery Factor (4% 35-years) =	0.053577
Annualized Capital Cost =	$ 78,800
Annual O&M Cost =	$ 28,400
Project Annual Unit Cost ($/lb) =	$ 419
Baseline Project Life (yr) =	35
Project Life Time Costs =	$ 2,464,000
Project Life Time Water Quality Benefits (lb) =	8946
Project Life Time Unit Costs ($/lb) =	$ 275

Notes: 1. Project length includes stabilized reaches and reaches without improvements
2. Analysis based on "simplified method". See Stream Reclamation Report.
3. Values in "blue" are input variables.
4. Costs include design, construction, and construction services.

For each pollutant reduction facility (PRF) that the Authority considers for funding and as a minimum, simplified calculations of water quality benefits, as measured by cost per pound of phosphorus immobilized, are prepared. The calculations for McMurdo Gulch are provided in the table above.

Comparison of Project Unit Costs

Item	Cottonwood Creek	McMurdo Gulch	EcoPark Project
Project Length (ft)	13900	15000	7300
Total Projected Cost[1]	$ 2,405,300	$ 1,470,000	$ 3,829,950
Project Cost per mile	$ 913,700	$ 517,400	$ 2,770,200
Annual Project Cost[2]	$ 128,900	$ 78,800	$ 205,200
Annual P Reduction Benefit (lbs/year)	237	256	124
Annual Cost per Pound of P	$ 540	$ 310	$ 1,650
Authority Contribution	$ 2,405,300	$ 630,000	$ 905,000
Authority funding amount (%)	100.0%	42.9%	23.6%
Authority annual cost per pound P	$ 544	$ 132	$ 390

Notes:
1. Stream Reclamation Costs only, no education or recreation costs.
2. Based on 4% for 35-years and not including maintenance

Project costs for McMurdo Gulch are also compared to two other Authority sponsored project, Cottonwood Creek and Eco Park project (see table on the left). Cottonwood Creek project lies entirely within Cherry Creek State Park and was completed in 2008 solely with Authority funds. Cherry Creek Stream Reclamation at Eco Park is scheduled to begin construction in 2012 and is a joint effort between the Authority, SEMSWA, Urban Drainage & Flood Control District, and Arapahoe County.

The table illustrates that the proactive approach to stream reclamation cost per mile is substantially less than Cottonwood Creek or Eco Park projects and, potentially costs less per pound of phosphorus immobilized.

REFERENCES

1. CCBWQA Technical Advisory Committee June 16, 2011. *Stream Reclamation Water Quality Benefit Evaluation – Interim Status Report.*

2. Muller Engineering Company August 30, 2011a. *McMurdo Gulch Reclamation Project Stream Reclamation Improvements Design.*

3. Muller Engineering Company September 2, 2011b. *McMurdo Gulch Reclamation Project Detention Facility Retrofit Improvements Design*

4. Muller Engineering Company September 6, 2011c. *McMurdo Gulch Reclamation Template*

5. PBS&J December 2006. *Final McMurdo Gulch Major Drainageway Master Plan.*

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Memorandum

To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: November 13, 2013

Re: Piney Creek Stream Stabilization at Buckley Road – Project Summary

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Presented in this memorandum is a summary of the Piney Creek stream stabilization project at Buckley Road, which was the Authority's first participation in stabilizing or reclaiming a degraded stream channel for water quality purposes.

BACKGROUND AND PURPOSE

During development of the Watershed Plan 2000[1], stream stabilization was given high priority as a PRF due in part to phosphorus content in sediment. This was not a new concept as controlling erosion in streams was recommended in the 1985 watershed plan[2] and continued in the 1989 revision[3].

In Watershed Plan 2000, Piney Creek was considered a high priority due to rapid development in the watershed and its close proximity to the Reservoir. The cost for stream stabilization in Piney Creek was extracted from the stabilization plan for Piney Creek[4] funded in part by the UDFCD. The 1989 plan costs were updated for inflation but street and utility costs were *not* included. These adjustments resulted in $5,915,000[5] capital cost for 17.4 miles of stabilization. At that time, it was assumed that the Authority would participate at a 1/3 level as a means of accelerating the implementation of stream stabilization measures by local jurisdictions. The total capital costs for the recommended PRFs in the Watershed Plan 2000 were $17,394,000, which included the $5,915,000 for Piney Creek.

EVALUATION OF STREAM STABILIZATION

During development of the 2002 CIP at 2001 TAC meetings (which included some Board members) the Authority's participation in stream stabilization was discussed at length. It was argued that although stabilization was important to managing water quality in the Reservoir, local jurisdictions would share in the costs through the UDFCD, thereby allowing the Authority to fund other priority PRFs.

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[1] CCBWQA June 2000. *Watershed Plan 2000*
[2] DRCOG, September 1985. *Cherry Creek Basin Water Quality Management Master Plan*,
[3] CCBWQA November 1989. *Cherry Creek Basin Water Quality Management Master Plan (Revised 1989).*
[4] Greenhorne & Omeara 1989. *Stream Stabilization and Major Crossing Planning*.
[5] CCBWQA 2000, p5-10

However, it was also determined by the TAC that the Authority could participate in stream stabilization to the extent that improvements go beyond stabilization and include *reclamation* of the stream corridor. The reclamation concept results in more frequent "connection" between flow in the main channel and flow in the floodplain, which results in more infiltration and filtration of storm runoff. Reclamation, which also includes the impacts of increased runoff from urbanization, was considered to provide additional, quantifiable phosphorus reduction benefits and, therefore, should be an Authority focus[6]. This argument was applied to Piney Creek and lower Cottonwood Creek stabilization projects that were subsequently included in the 2002 CIP.

PROJECT PARTNERS AND FUNDING

The Authority contributed $118,000 (~6%) to the Piney Creek stream stabilization at Buckley Road whose total costs was $1,853,000 and included engineering and construction costs. The Project construction, which was a joint effort between UDFCD, Arapahoe County, and the Authority, began in November 2003 and was completed around May 2004.

DESIGN APPROACH

The approach to stabilization of Piney Creek included the construction of 8-sheet pile reinforced drop structures to flatten the grade along with re-vegetation of the stream banks. The design cross section allowed for more frequent connection between the base flows and the channel overbank. The shallower longitudinal grade in conjunction with the sheet pile cutoff wall that forced the shallow ground water to the surface allowed for more rapid and more extensive wetland development.

WATER QUALITY BENEFITS

Although the Authority concluded that stream stabilization of Piney Creek would result in water quality benefits[7], an approach to quantify the benefits in terms of phosphorus reduction had not been developed at the time the project was approved. Therefore, no calculations of phosphorus reduction benefits were performed.

[6] William P. Ruzzo, P.E., April 2, 2002. *Piney Creek Stream Stabilization 2002 CIP.* Memorandum to CCBWQA Technical Advisory Committee.
[7] Ibid.

Memorandum

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To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: January 14, 2014

Re: Quincy Drain – Project Summary Report

Presented in this memorandum is a summary of the Quincy Drainage Detention project.

BACKGROUND AND PURPOSE

The Quincy Drainage Detention (Project) is located in the east part of Cherry Creek State Park (see Figure 1) and consists of a small earth embankment that doubles as a paved park trail (Photo 1) with a pipe outlet and trash rack (Photo 2). The Project, which drains approximately 527 acres[1], was constructed in 1995 at a capital cost of $219,000. To create the detention area, the park trail was relocated to the west around the Cottonwood grove and elevated[WPR1] to create an embankment[2].

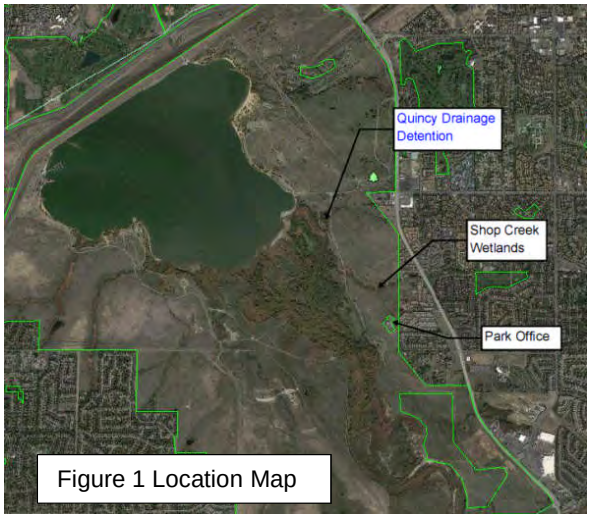


Figure 1 Location Map

PROJECT PARTNERS AND FUNDING

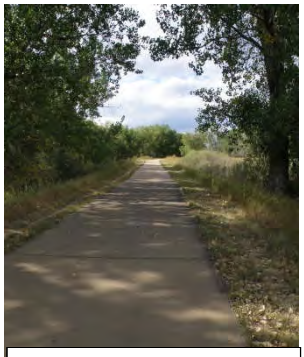


Photo 1 – Park Trail

Quincy Drainage Detention was funded in total by the Authority and was a cooperative effort with Cherry Creek State Park.

WATER QUALITY BENEFITS

Quincy Drainage Detention temporarily detains stormwater which allows for particulate matter (i.e.: pollutants) to settle out in the storage area, which is also a Cottonwood grove. In addition, because the native soils in the detention area are relatively pervious, the Project rarely experiences a discharge through the outlet because the storm runoff infiltrates into the alluvium, providing even greater water quality benefits.


Photo 2 – Pond Outlet

[1] Boyle Engineering Corporation June 1985. *Outfall System Planning Quincy Drainage & Shop Creek.*
[2] Personal communication with Jim Wulliman of Muller Engineering Co., formerly PM for Project with CH2MHill.

POLLUTION REDUCTION FACILITY

A Watershed Solution to Urban Runoff Quality

Cherry Creek Basin Water Quality Authority

The Problem

The Cherry Creek Reservoir Clean Lakes Study (DRCOG 1984) identified that Reservoir water quality and its uses were moderately impaired and that phosphorus was the limiting nutrient. To protect the water quality of Cherry Creek, the Water quality Control Commission (WQCC) originally set an in-lake phosphorus standard of 35-µg/l (1985) and subsequently changed the standard to 15-µg/l chlorophyll a (2000). A maximum phosphorus concentration of 40-µg/l was set as the goal. The Cherry Creek Control Regulation (December 2004), requires the implementation of best management practices (BMP) for all new development and pollutant reduction facilities throughout the watershed (PRF). PRF are typically larger scale BMP with expressed purpose of reduction phosphorus loads to Cherry Creek Reservoir and are primarily constructed with Authority funds.

Shop Creek - One Solution

In the 1980's, an urbanizing watershed of 550-acres within the City of Aurora was causing severe erosion to a small drainage channel (Shop Creek) within Cherry Creek State Park. Soils were also being carried into the Park from upstream development and ending up in the Reservoir, along with other associated pollutants, particularly phosphorus.

The City of Aurora worked with the Urban Drainage & Flood Control District, the Cherry Creek Basin Water Quality Authority and Cherry Creek State Parks to develop a demonstration project for treatment of phosphorus. To maximize phosphorus removal from storm runoff, detention, retention and wetlands were combined in series to provide a "treatment train" (see photo at left). The detention area located upstream of Parker Road (not shown) removes coarse sediment. The retention area (photo below) furthers sedimentation and particulate phosphorum removal. The series of seven wetlands even greater phosphorus removal, including dissolved phosphorus.

Aerial View of Shop Creek (Muller Engineering)

From the Park prospective, the solution complements park values, aesthetics, recreational access, wildlife habitat, low maintenance.

Technical Data

- Watershed area 550 acres
- Imperviousness of 40%, of which 75% is hydraulically connected.
- Permanent pool of 4.8 acre feet, which is 0.10 inches of runoff from entire watershed or 0.26 inches from impervious areas.
- Surcharge above permanent pool of 9.1-acre feet, providing detention for 0.2 inches of runoff from entire watershed.
- Outlet empties 90% of surcharge volume in 30-hours.
- Total of 3.5-acres of wetlands.
- One year storm event velocity of 1-fps.
- Six drop-structures constructed from soil cement.

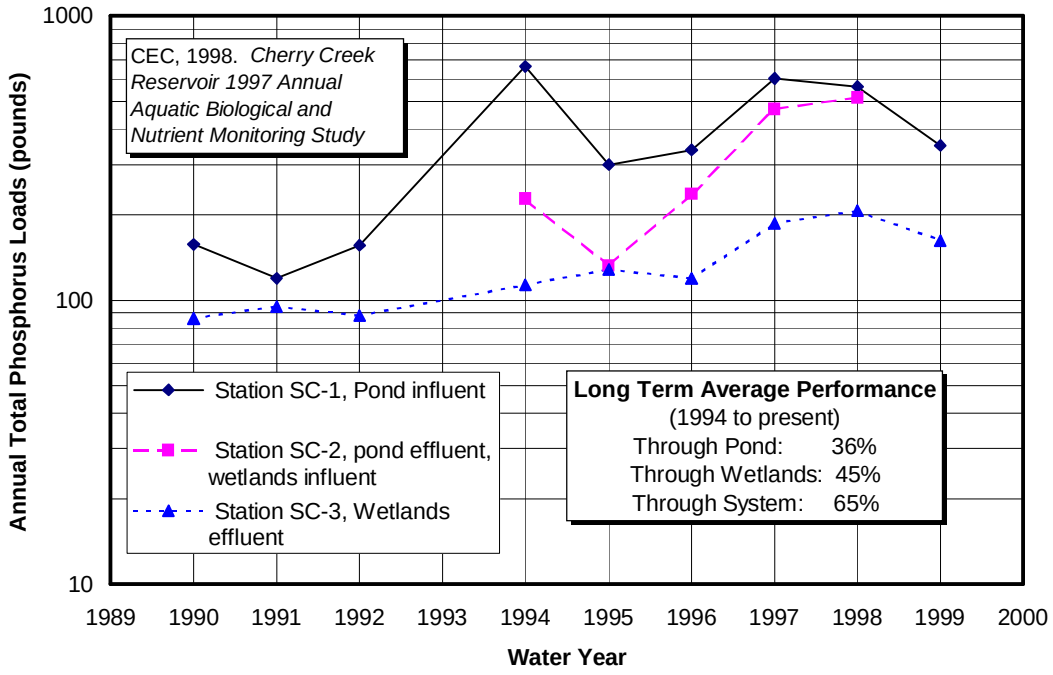
Performance

Regular sampling occurs upstream, downstream of retention pond and downstream of wetlands. In addition to phosphorus (total and dissolved), samples analyzed for nitrates, nitrites, nitrogen, copper, iron, manganese, zinc, alkalinity, chemical oxygen demand, and total suspended solids. Long term performance for phosphorus is shown in the chart below. Sampling upstream and within the wetlands was discontinued in 2000.

Other Pollutant Reduction Facilities (PRF)

The Authority has constructed and is operating, maintaining and monitoring eight major PRFs in the Cherry Creek Reservoir watershed. A ninth facility, Cottonwood Creek Restoration, began construction in 2004.

Shop Creek Detention/wetlands System



- Cottonwood Creek/Perimeter Rd. This PRF is similar to Shop Creek, except that the initial retention basin for Cottonwood Creek is much larger to accommodate the larger runoff volume from the 7,500-acre drainage area. Also, Cottonwood Creek is followed by a single wetland.
- Quincy Drainage. This PRF captures runoff from the 530-acre drainage basin and quickly infiltrates the runoff through the sandy alluvium. Native grasses typical of a semi-arid climate populate the pond. Typically, no surface flows are discharged from this PRF during baseflow conditions and discharges during precipitation events have been limited.

Tower Loop Erosion before Construction (Ruzzo)

Shoreline Protection Projects. The Authority has an ongoing program of projects to protect the shoreline of the Reservoir, thereby limiting sediment and attached phosphorus that directly discharge into the lake. The projects include East Side Shade Shelter (1996) and the Tower Loop (1999) projects (see photo at left).

The Recreation Component

Multiple uses for PRF are vital to their success and provisions for recreation are key to many projects. The before (photo left) and after (next page) photos illustrate the Tower Loop area, a PRF constructed in 1999. Tower Loop is a very popular fishing area and controlling public access was a key factor in the design. Recreation was enhanced by providing "fishing pods"

A mission of the Authority is public education regarding impacts of urban runoff on water quality of Cherry Creek. By providing or enhancing recreation opportunities for PRF, the Authority also enhances its opportunities to educate the public about urban runoff pollution.

Most of the PRF's constructed by the Authority to date have included signage prepared by professional park planners. For instance, along Shop Creek several kiosks have been installed explaining the need and benefits of the project.

The Authority was also recently awarded a Section 319, information and education Grant from EPA. The Authority will work with Cherry Creek State Park Staff to increase the general awareness regarding the importance of BMPs in Cherry Creek Reservoir to gain public support and participation in protecting water quality.

Cherry Creek Basin

The Cherry Creek Reservoir watershed covers 386 square miles of the Front Range corridor, extending upstream to the

Palmer Divide. The basin drains northward from elevation reaching approximately 7,700 feet near Colorado Springs, to 5,600 feet at the Reservoir. Topography within the watershed is quite variable – consisting of pinyon pine covered hillsides, short grass prairie, and canyons, such as those found in Castlewood Canyon State Park.

Aerial View of the Reservoir (USACE)

The Reservoir was impounded in 1950, creating the 860-acre lake and a 3,500 acre State Park.

Precipitation averages from 13" at the Reservoir to 18" at the divide with long-term maximums ranging from 22" to 33". Annual storm runoff has varied over the last 15-years from a low of 5,000 acre feet to a high of 27,700 acre feet in 1999. Phosphorus loads have also varied widely with watershed hydrology, ranging from a low of 4,500 pounds to a high of 18,800 pounds.

Cherry Creek Basin Water Quality Authority

The CCBWQA is a quasi-municipal corporation and political subdivision of the State that has primary responsibility for water quality in the Cherry Creek Basin. The Authority is specifically empowered to develop and implement plans for water quality controls for the Reservoir and watershed. The watershed management strategy of the Authority includes:

- **Regulations**. Stormwater Quality Regulations (Regulations) have been adopted by the Authority (2000). The purpose is to implement, monitor, and enforce technical measures (BMP) to reduce sediments and nutrients reaching Cherry Creek and Cherry Creek Reservoir. The Regulations establish minimum requirements for BMP that address construction erosion (temporary measures) and water quality enhancement for completed developments (permanent measures).

- **Planning**. The Authority has adopted (1999) a Storm Drainage Quality Plan to further protect the water quality of Cherry Creek. The Plan identifies projects, called pollutant reduction facilities (PRF) that include enhanced BMP (i.e.: detention, retention, wetlands, filtration), in-stream and in-lake controls, and shoreline and stream bank protection. PRFs provide levels of protection beyond permanent BMPs by also targeting other pollutants such as sediment, nitrogen, and metals. PRF measures also provide a net environmental benefit by improving riparian health and wildlife habitat. The Authority funds PRF by collecting fees and taxes.

- **Operations and Maintenance Plan.** The Authority is developing a long-term program to insure that technical measures continue to serve their purpose. The goal of the plan is to insure physical integrity and proper hydraulic function for PRF. The plan will identify specific requirements for PRF that address maintenance access, safety and convenience, aesthetic and recreation requirements.

Tower Loop with Enhanced Recreation Features (Ruzzo)

Cherry Creek Stream Reclamation @ Eco Park Project

Cherry Creek Basin Water Quality Authority

BACKGROUND AND PURPOSE:

In October 2009, UDFCD and SEMSWA entered into an Intergovernmental Agreement (IGA) for design of Cherry Creek stream reclamation improvements at Eco Park. In April 2010, upon SEMSWA's request, the Authority entered into an IGA with SEMSWA to participate in funding the project following the Authority's inspection and analysis of the Project area and hydrologic data. The project area is approximately 4,850 linear feet long and connects to the downstream end of the Parker Jordan Centennial Open Space stream reclamation project. The Project site is shown on Figure 1 - Area Map.

The Authority's inspection of the Project area found the channel to be in a severe state of degradation (i.e., "down cutting"); bank erosion resulting in steep slopes and material sloughing; lateral channel migration and loss of wetlands and upland vegetation due to lowering of the water table by the streambed erosion.

The Authority assessed the water quality benefits of the project and determined the Project meets the Authority's goal for stream reclamation. The Project was added to the Authority's Capital Improvement Plan in 2010 and the Authority began monitoring the project design performed by Muller Engineering through 2010 and 2011. On April 15, 2010 the Authority entered into an IGA with SEMSWA for design finds in the amount of $56,000. On May 19, 2011 the Authority approved contributing $905,000 of the total Project cost and entered into an agreement with SEMSWA, dated effective on December 31, 2011.

Figure 1 - Area Map

EXISTING CONDITIONS:

Urbanization and the resulting increase in the rate, frequency, duration and magnitude of stormwater runoff accelerated degradation of the streambed and banks. Typical pre-project conditions are shown on Photos 1, 2 and 3 documenting that Cherry Creek has degraded up to 10-feet within the streambed.

Photo 1 - Existing Condition

Photo 2 - Existing Condition

Photo 3 - Existing Condition

DESIGN APPROACH:
Because of the severity of the channel degradation, areas of topographical constraints and floodplain regulations limiting increases in flood elevations, the approach to reclamation of this reach is a combination of a natural bioengineering approach connecting the streambed to the overbanks and a more engineered approach where topography constrains the channel. In some locations essentially all of the existing channel bank and riparian vegetation had to be removed and replanted due to the substantive changes in channel geometry necessary to accommodate topographic and floodplain limitations. In several areas the preferred design approach for stream reclamation was used whereby much of the existing vegetation was retained and protected, minimizing disturbances and improving the chances of revegetation success.

Hand sculpted concrete drop structures, as shown on Photo 4, are incorporated into the project to flatten and control the longitudinal grade, with sheet pile cut-off walls to protect the structure from damages during the larger flood events. Riffle-pool structures, constructed entirely of rock, were constructed in the channel to aide in conveyance of the mean flood event in the narrower channel. Larger floods in these areas then spread over the broader floodplain, This design approach lowers the runoff velocities allowing for more filtration and infiltration.

Photo 4 - Sculpted Concrete Drop

The Project was designed to raise the streambed and reestablish the water table to prevent further loss of vegetation and down cutting, erosion and sediment transport. The overall project goal was to restore and enhance the aquatic, wetland and riparian functions of Cherry Creek.

CONSTRUCTED PROJECT:
Two bids were advertised for this project. The first was for construction of four sculpted concrete drop structures and the second was for the stream reclamation work. Bids for the project were opened on August 15, 2012. The successful bidders, ECI Site Construction (stream reclamation) and Naranjo Civil Constructors (sculpted concrete drops), were awarded contracts in the combined amount of $3,607,351.60. Two notices to proceed were issued for September 24, 2012. The work was substantially complete on September 9, 2013. The final project cost totaled $3,780,899.37.

The Project included secondary channels in two locations, three sculpted concrete drops, one sculpted concrete splitter drop, one lateral weir drop, and six riffle drops. The sculpted concrete splitter drop, located closest to the the Eco Park trail access bridge over Cherry Creek provides for an interactive creek crossing, see Photo 5.

The lateral drop weir and the sculpted concrete splitter drop each divert stream flows into a secondary channel section as the water level in Cherry Creek rises to the diversion invert elevation. This design feature allows for the stream flow to widen out into two channels and further reduce velocities. The secondary channels are beneficial for reconnection of the water table with portions of the floodplain. Six different types of bioengineered bank protection details were installed along the realigned/reshaped channel through the project. The bank protection types were unique for

Photo 5 - Sculpted Drop Creek Crossing

straight sections, inside bends, outside bends and for the secondary channel. As part of the revegetation efforts the project included installation of:

- 28 acres of seeding.
- 10,315 grass plugs.
- 11,281 willow stakes.
- 217 trees.
- 824 shrubs.

A flow monitoring and sampling station was installed near the lower end of the project to provide a data collection point for the Authority as shown on Photo 6. This data collection point is one of a series used by the Authority along Cherry Creek to monitor nutrient loading and stream flows within the Cherry Creek Basin.

Photo 6 - New Monitoring/Sampling Station

September 14, 2013 Storm Event:

On Sunday September 14, 2013 the upper reaches of Cherry Creek received heavy rainfall that at its peak was measured at approximately 1,000 cfs.

An on-site inspection followed that found that all major structures designed and installed to control the minor and significant storm runoff events each functioned as expected. None were damaged or adversely impacted. The upper banks where the revegetation work had not re-established itself yet, received the majority of the damage. Seeded areas had eroded, upper bank material was displaced and low areas filled in. Crusher fine trails were washed out in specific locations where runoff was concentrated. The project team quickly assessed the damage and the project consultant prepared an overall restoration plan. Restoration work began promptly to repair areas impacted by the flooding. It was anticipated that the flood damages would have been minimal if the project vegetation had a season or two to establish itself. This is confirmed following a brief site visit to the Parker Jordan Centennial Open Space project immediately upstream of Eco Park. It is strong testimony that bioengineering design works for stream reclamation after the vegetation is established.

Photos 8, 9, 10 and 11 show some of the typical damage from the storm.

Photo 8 - Flooding Damage

Photo 9 - Flooding at a Trail Crossing

Photo 10 - Flooding Damage

Photo 11 - Flooding Damage

WATER QUALITY BENEFITS:

An assessment of the water quality benefits for the entire project was made by the Authority[1] as part of the ongoing water quality analysis of all projects listed on the 5-year capital improvement program. Based on the outcome of this assessment it is calculated that 117 lbs of phosphorus per year will be eliminated from being transported downstream from the Eco Park stream reclamation improvements. The project was found to lower stream velocities, channel shear and stream power from that found prior to reclamation, all which minimizes the transport of sediment and pollutants.

[1] *Water Quality Benefits of Shoreline Stabilization Memorandum, dated October 23, 2008; William P. Ruzzo, P.E., LLC*

COTTONWOOD CREEK RECLAMATION

Stream Stabilization Approach to Urban Runoff Quality

Cherry Creek Basin Water Quality Authority

The Problem

The Cherry Creek Reservoir Clean Lakes Study (DRCOG 1984) identified that Reservoir water quality and its uses were moderately impaired and that phosphorus was the limiting nutrient. To protect the water quality of Cherry Creek, the Water quality Control Commission (WQCC) set an in-lake, seasonal chlorophyll *a* standard of 15-µg/l and set a phosphorus goal of 40-µg/l (2000, 2001). The Cherry Creek Control Regulation (2004), requires the implementation of best management practices (BMP) for all new development and pollutant reduction facilities throughout the watershed (PRF). PRF are typically larger scale BMP constructed by the Authority that reduce phosphorus loads to the Reservoir.

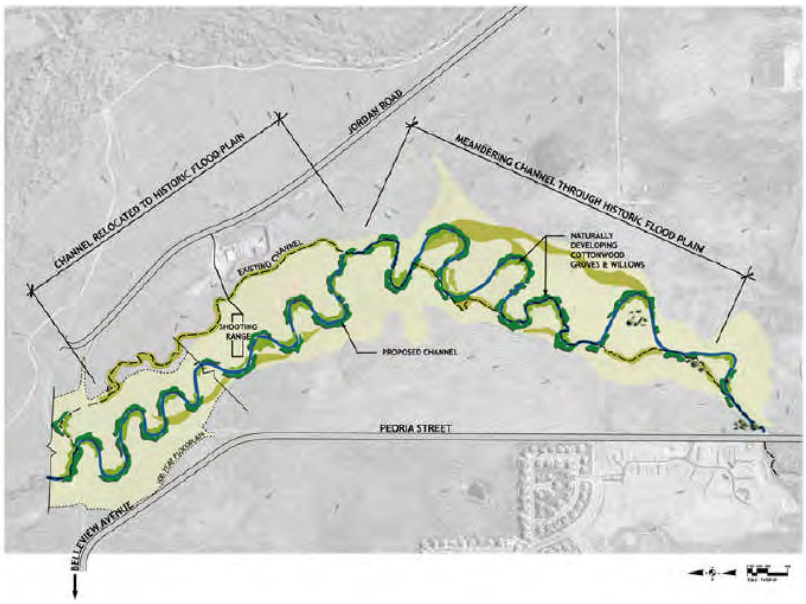
Urbanization of the Cottonwood Creek watershed (8.5 square miles) greatly increased during 1980's and continues today. Urbanization increases the rate, frequency, duration and magnitude of storm runoff, all of which increases erosion of the streambed and banks. This erosion is evident in the adjacent photo, which shows that the Creek had degraded up to 10-feet within Cherry Creek State Park. These soils, along with other associated pollutants, particularly phosphorus, are being carried into the Reservoir, degrading its quality. Soils were also being carried into the Park from upstream development and ending up in the Reservoir.

Flood History

Cottonwood Creek through Cherry Creek State Park has a history of flood events that have severely eroded the channel bed and banks and confined it to a narrow section beginning at Peoria Street (see photo above). Flooding has been reported in the past at the intersection of Peoria Street and Belleview Avenue, and within the shooting range, most recently in August 2004. Previous farming activities have apparently relocated the lower portion of the channel up on a ridge through the shooting center, rather than in the valley, which has altered the flood plain.

Stream Stabilization – One Solution

The Cottonwood Creek Stream Reclamation project extends from Peoria Street to the Perimeter Road within Cherry Creek State Park. This reach constitutes phase III and IV of the four phase improvements for Lower Cottonwood Creek. Phase I was the perimeter road wetlands constructed in 1996 and Phase II was the Peoria Street extended detention basin, completed in 2003. Phase III stream reclamation-Peoria Street to the confluence with Lone Tree Creek-was completed in 2004. Phase IV-confluence to the Perimeter Road-is scheduled to begin construction in 2006.



The primary purpose of stream stabilization (Phase III and IV) is to reduce erosion of the streambed and stream banks. Phase III and IV will also enhance growth of wetland and riparian vegetation, will attract wildlife, and will provide passive recreation opportunities, all of which are important objectives in the design approach.

The proposed design concept will go beyond simply stabilizing the Creek in place. Improvements will re-create, as closely as possible, a natural, well-vegetated, functional stream system that establishes close ties between its baseflow channel and its broad, flat floodplain overbanks (see picture at left).

Water Quality Benefits

Cottonwood Creek will be reclaimed as a meandering, shallow prairie stream that will overtop with fairly frequent storm events, allowing over-banks and secondary channels to dissipate flood flows, thereby reducing velocities and erosive forces. Hydrologic conditions will be conducive to the regeneration of cottonwoods, willows, and other natural riparian species along the channel. This additional vegetation will further help to slow down flood flows, reinforce channel banks, enhance water quality, and provide other environmental benefits. In an attempt to quantify the phosphorus reduction benefits, the Authority has estimated the reduction in phosphorus from stream stabilization and the additional floodplain area and wetlands.

1. **Stream Bank Stabilization**.
   The improved stream will increase the length from 11,600 linear feet, with a sinuosity of 1.37 to 14,260 feet, with a sinuosity of 1.74. Authority estimates for stream stabilization (both banks for Cottonwood Creek only) is approximately 210 pounds of phosphorus per mile for 2.19 miles, per year or around 460 lbs.

2. **Flood Plain Area**.
   Existing 2-year floodplain width is 5.3 acres, which will increase to over 80 acres. This will increase the riparian corridor area from 4.4- to 24.9 acres and provide for greater infiltration and filtration by vegetation. Estimates were made of long term phosphorus removal by inundating the floodplain for various flood frequencies, based on dynamic, particle-settling theory. These estimates resulted in a long-term average 1.0 lbs/P per acre/year of floodplain, or around 70 pounds per year.

3. **Riparian Wetlands**.
   The existing channel has less than 0.5 acres of riparian wetlands, which are primarily associated with limited channel bottom. The project will widen the channel and increase the frequency of riparian flooding. These improvements are expected to increase riparian wetland areas by 20-acres and immobilize from 200-lbs annually (i.e.: about 10-lbs/ac/yr).

4. **Annual Phosphorus Reduction**
   Total of all components is 460 + 70 + 200 = 730 pounds P.

Cottonwood Creek Reclamation Phase 1 was completed in early August 2004 with the first flood occurring on August 18, 2004. Based on water-marks at Peoria Street, the peak flow entering the newly constructed channel was estimated to be 1400 cfs, which compares to the projected 100-year event of 4,000cfs. The photo below shows the restored creek during the flood event. The success of the project is attributed to the "low-energy" design. This approach flattens the channel slope decreasing velocity (kinetic energy) and allows the flood to spread over larger areas, increasing flow area and decreasing velocity.

Additional Information

Information about the Cherry Creek Basin Water Quality Authority can be obtained from our recently created website at www.cherrycreekbasin.org

Mountain - Lake Loop Shoreline Stabilization Project

Cherry Creek Reservoir Shoreline Stabilization

Cherry Creek Basin Water Quality Authority

BACKGROUND AND PURPOSE:

The Cherry Creek Reservoir *Shoreline Stabilization Mountain and Lake Loop Alternative Development and Analysis* (Project) was part of the Authority's *2008 Capital Improvement Program* (2008 CIP) which was developed to identify and to prioritize activities and projects necessary to achieve water quality standards in Cherry Creek Reservoir. The project area is located on the southwest side of the reservoir as shown on Figure 1 - Area Map. The project site covers approximately 6.5 acres including the area between the foot trail and the shoreline and approximately 2,300 feet of shoreline, see Figure 2. The project objectives include construction of shoreline and bank stabilization measures that:

1. Minimize sediment from wind, rain, ice, surface runoff, wave action and park user access reaching the reservoir.
2. Minimize water quality impacts from two parking lots and other impervious surface runoff.
3. Integrate and enhance the proposed uses within Cherry Creek State Park.

Figure 1 - Area Map

Figure 2 - Project Site

EXISTING CONDITIONS:

Wave action, wind, ice push and shoreline users have each contributed to erosion of the reservoir shoreline and major cut banks. This point along the shoreline is exposed to wind and wave actions during every season of the year. As the ice cover breaks up each spring, the north wind pushes ice to the south shore and in particular this point. Typical pre-project conditions are shown on Photos 1, 2 and 3.

Photo 1 - Existing Condition

Photo 2 - Existing Condition

Photo 3 - Existing Condition

DESIGN APPROACH:
The overall design approach is best described as "stabilization" rather than "reclamation". In 2008 the Authority performed an in depth assessment of the water quality benefits of shoreline stabilization[1]. This assessment concluded that phosphorus reduction from shoreline stabilization differs from stream bank stabilization, primarily because shorelines are impacted by additional erosive forces besides storm runoff, including wave and wind forces as well as recreation impacts. The conclusion of this assessment is that, over the long term, shoreline stabilization is expected to reduce phosphorus concentrations into the reservoir from pre-project conditions and likely would reduce phosphorus concentrations to a level consistent with the Authority's goal of 0.20-mg/l.

The assessment also concluded that , based on historical data, for the majority of the time(≈80%) the water surface of the reservoir varied within one foot plus/minus of the normal recreational pool (Elevation 5550). And, the water level remained within two feet of the normal recreational pool over 95 percent of the time. Thus the shoreline stabilization work for this project will be implemented between the elevations of 5548 and 5552.[2]

The vertical banks were trimmed back to provide manageable vegetated slopes, the shoreline in critical areas was armored with boulders, shoreline point locations were enhanced to protect adjacent shorelines from the prevailing winds, recreation access to beach areas was enhanced, crusher fine trails were created and pedestrian access was directed to the trails using strategically located heavy rail fence; a park standard detail. Runoff from the parking lots was collected and directed into infiltration basis where the storm water is filtered through a select material that allows rapid infiltration.

CONSTRUCTED PROJECT:
Bids for the project were opened on July 24, 2012 and the construction contract was issued to 53-Corporation LLC of Castle Rock on August 16, 2012 in the amount of $750,436.29. The notice to proceed was issued for September 13, 2013 and the work was substantially complete on June 7, 2013. The final project cost, which included watering of the trees, shrubs and turf totaled $725,121.97.

Construction of the boulder point with riprap bank protection provides armoring at the Lake Loop point. The boulders were anchored on the reservoir side with Type H riprap sloping at a 3:1 grade into the water. This detail pushes any ice upward and onto the top of the boulders rather than displacing them. A photo of the constructed point is shown as Photo 4 - Constructed Lake Loop Point.

The shape and location of the point (at Lake Loop and at Mountain Loop) protects adjacent shoreline from the direct prevailing winds and wave action.

The beach areas were re-established along the shoreline for recreational uses. The beach areas along the Mountain and Lake Loop project are in continual use by park users for picnics, fishing or a day in the sun as well as providing a convenient location to launch kayaks and long boats.

Photo 4 - Constructed Lake Loop Point

[1] *Water Quality Benefits of Shoreline Stabilization Memorandum, dated October 23, 2008; William P. Ruzzo, P.E., LLC*
[2] *Recent water rights administration and weather patterns have resulted in more fluctuations in the reservoir pool level. For future projects, the limits of protection are anticipated to be greater.*

Photo 5 - Constructed Mountain Loop Point

Photo 6 - Beach Area

Infiltration basins were incorporated at both the Mountain Loop parking lot and the Lake Loop parking lot. These BMP's are intended to capture minor storm events from the parking lot and provide filtration and infiltration treatment of the runoff. Photo 7 shows an infiltration basin in action at Lake Loop.

Photo 7 - Infiltration Basin @ Parking Lot

September 14, 2013 Storm Event:

On Sunday September 14, 2013 the upper reaches of Cherry Creek received heavy rainfall that at its peak ; the upstream flows were measured at approximately 1,000 cfs. Prior to this event, the water level in Cherry Creek Reservoir was 3.6 feet below normal recreation pool (WSL at 5546.4). On September 16th the reservoir water level was at 5553.2.

An on-site inspection followed on September 18th that found moderate erosion of the trails and graded areas above the upper limit for design (Elevation = 5552) based on the 2008 reservoir water level assessment findings . The boulders and armored structures were not impacted by the flood stage. Following that review, a restoration plan has been completed and construction is anticipated this fall / winter to restore the site to its post construction condition. Photos 8 and 9 show some of the typical damage from the storm.

Photo 8 - Trail Damage

Photo 9 - Sand Deposition on Trail & Vegetation

WATER QUALITY BENEFITS:

An assessment of the water quality benefits was made in 2008 by the Authority[3] as part of the ongoing water quality analysis of projects on the 5-year capital improvement program. Based on the outcome of this assessment it is calculated that 54 lbs of phosphorus per year will be eliminated from directly entering the reservoir from the shoreline improvements. Additionally the discharge of sediment and other pollutants from the two parking lots is also minimized from entering the reservoir by the infiltration basins.

[3] *Water Quality Benefits of Shoreline Stabilization Memorandum, dated October 23, 2008; William Ruzzo, P.E.*

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Memorandum

To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: March 19, 2013

Re: Cherry Creek Stream Reclamation @ Parker Jordan Centennial Open Space – Project Report

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Presented in this memorandum is a summary of the Cherry Creek Stream Reclamation at Parker Jordan Centennial Open Space (Project).

BACKGROUND

In 2008, reclamation of Cherry Creek from the Bronco's Parkway trailhead to the pedestrian bridge (see Figure 1) was in preliminary design by J3 Engineering under contract with the Parker Jordan Metro District (PJMD). Project partners included SEMSWA, City of Centennial, and Arapahoe County Open Space. The Authority inspected the Project area and found the channel to be in a severe state of degradation (see Photo 1, next page). Observations included: extensive bed erosion (i.e.: "down cutting"); bank erosion resulting in steep slopes and material sloughing; lateral channel migration; damage from vehicle crossing the stream at several locations; and loss of wetlands and upland vegetation due to lowering of the water table by the bed erosion.

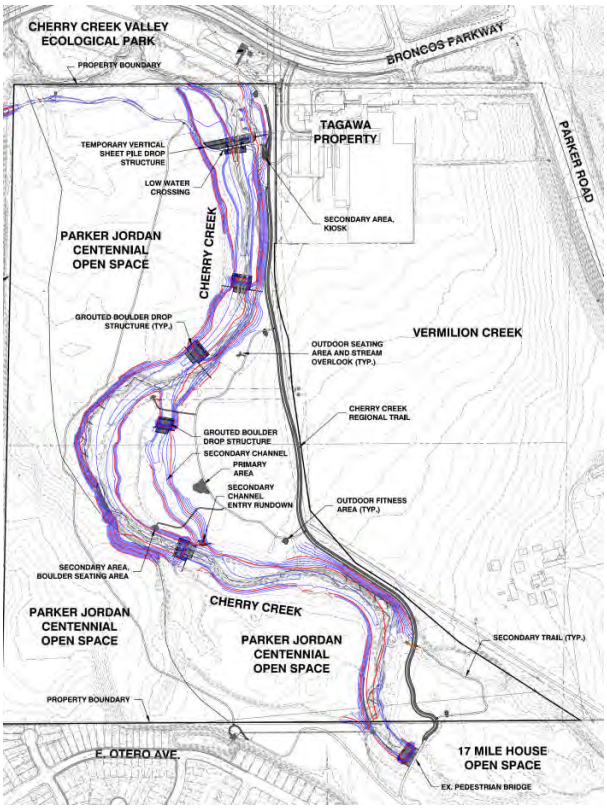


Figure 1 - Location Map

The Project was added to the Authority's capital improvement program (CIP) in 2008 and the Authority began monitoring the design in late 2009 through 2010. The Authority assessed the water quality benefits of the project and determined the Project meets Authority goals for stream reclamation. On March 8, 2010, the PJMD requested funding assistance from the Authority which led to a reimbursement agreement with the PJMD dated June 17, 2010 to provide $56,000 for design purposes.

On February 8, 2011, the PJMD requested construction funding assistance from the Authority, which was formalized in a participation agreement with PJMD dated June 16, 2011 in the amount not to exceed $586,871[1]. Construction began in September 2011 and was substantially complete by July 2012.

DESIGN APPROACH

Because of the severity of the channel degradation, areas of extreme topographical constraints, and floodplain regulations limiting increases in flood elevations, the approach to the Project reach resulted in a more formal approach to reclamation of Cherry Creek. For instance, essentially all of the existing channel bank and riparian vegetation had to be removed and replanted due to substantive changes in channel geometry necessary to accommodate topographic and floodplain limitations. The preferred design approach for reclamation is to retain and protect as much of the existing vegetation as possible, minimizing disturbances and improving the chances of re-vegetation success.

Photo 1 - Pre-Project

Drop structures necessary to flatten and control longitudinal grade are grouted boulder drop types with sheet pile cut-off walls to protect the structure from damages during larger flood events. The preferred approach for reclamation conveys the mean flood event in a narrower channel that uses riffle-pool structures constructed entirely from rock and to allow rarer floods to spread out into a large floodplain, which lowers velocities, allowing more filtration and infiltration. Because each project is unique, more formal drop structures (i.e.: grouted boulder and sculpted concrete) are often used in reclamation projects where additional channel "anchoring" is deemed necessary by site constraints and greater risks of damages from the more rare flood events.

Photo 2 - Post project drop structure

The Project was designed to raise the channel bed and reestablish the water table to prevent further down cutting, erosion, and subsequent sediment transport on Cherry Creek[2]. The goal of the channel improvement portion of the project was to restore and enhance the aquatic, wetland, and riparian functions and values of Cherry Creek, and to construct a wider and flatter floodplain by reshaping and raising the channel invert an average of 5 feet throughout the project area. This was accomplished by reshaping the main channel of Cherry Creek; constructing a secondary channel; laying back the upper channel banks; and installing five grouted-

[1] The Authority's financial contribution to the Project was limited to components of the Project that provided water quality benefits. The total project cost that provided water quality benefits was found to be $3,017,253.
[2] U.S. Army Corps of Engineers, September 14, 2011. *Department of the Army Permit No. NOW-2009-02909 Parker Jordan Open Space Cherry Creek Restoration Project.*

boulder drop structures, one vertical sheet pile drop structure with an integrated low-water pedestrian crossing, and seven types of bank protection. The proposed drop structures and bank protection measures include varying types of bioengineered and hard treatments.

Photo 3 - Post project with side channel

In addition to the improvements along the main channel, an overflow channel was constructed along the inside of a bend of Cherry Creek to reduce the stream pressure along the banks of the main channel during frequent flooding events (e.g., 2-year events) and reconnect the water table with portions of the floodplain. The overflow channel is about 1,200 feet long and constructed along the remnants of a historical channel on the east side of Cherry Creek. A sloping grouted-boulder drop structure was constructed at the downstream end of the overflow channel to transition the elevation to match the elevation of the main channel.

Seven different types of bioengineered bank protection were installed along the realigned/reshaped Cherry Creek channel throughout the project area. The protection types were designed to meet site-specific needs through the project reach. The protection types are unique for straight sections, inside and outside bends, bend-way weirs, and for the secondary channel.

CONSTRUCTION ISSUE

During construction, localized dewatering (i.e.: groundwater pumping) was necessary in order to construct drop structures in dry conditions, which is a common practice in stream reclamation projects. The State Engineer's Office (SEO) rules for water well construction[3] includes construction dewatering wells and requires that a notice of intent (NOI) be filed with the SEO prior to dewatering activities, which the contractor had failed to do. The construction site was inspected by the SEO and it was determined that the dewatering practices resulted in consumptive use (i.e.: water loss through evaporation and transpiration or resulted in a time-lag before returning to the source). The contractor was required to file an NOI, modify the dewatering practices to prevent consumptive use, prepare and file a temporary substitute water supply plan (SWSP) and augment for the consumptive use.

The contractor also modified the construction BMPs to minimize water losses during conveyance and treatment activities to reduce sediment in the water, such as using pipes for transport, covered tanks for sediment removal from construction water, and eliminating land-application of construction water.

Whereas not all stream reclamation projects will result in consumptive use of ground or surface water, there is a greater likelihood that augmentation water will be needed for future stream reclamation projects. The Authority is currently investigating if the "Bowtie[4]" property water rights can be used to augment consumptive uses from construction activities, which also includes evaporative losses from practices that

[3] Office of the State Engineer January 1, 2005. *Rules and Regulations for Water Well Construction, Pump Installation, Cistern Installation, and Monitoring and Observation Hole/Well Construction.*

[4] The Bowtie property is located at the confluence of Cherry Creek and Piney Creek and is named after the shape of the property that was acquired by local governments as a stream corridor preservation activity. The Authority participated in the acquisition and received the water rights associated with a shallow and a deep, pre-senate bill 319 well.

reduce sediment discharges caused by construction activities. The investigation may also include using the water rights for temporary, supplemental watering of new vegetation.

JUNE 6, 2012 FLOOD EVENT

Photo 4 Post project flood June 6, 2012

Prior to the June 6, 2012 flood event, the majority of the construction effort had been completed but final inspection had yet to occur and final acceptance had not been granted. The improvements included low water crossing, drop structures, bendway weirs, bank stabilization measures, secondary channel construction and stabilization, erosion control protection, vegetation installation, and the majority of final stabilization of the disturbed construction area. Due to the size and magnitude of the Project, it was built in multiple phases. As a result, the project had a varying range of stabilization and vegetation establishment at the time of the flood. Phase 1 had the most advanced stage of re-vegetation in the low flow terrace due to its completion occurring at the beginning of March. Phase 3 vegetation was installed only 2-3 weeks prior to the event; therefore, seedling germination and establishment was minimal.

The impact of the flood event on the Project was analyzed[5], concluding that:

> *… stream reclamation project of Cherry Creek within PJCOS experienced an estimated 2-year storm event[6] on the evening of June 6th through the morning of June 7th. This storm occurred at a time when the project was vulnerable since vegetation was not fully established or in some cases minimal growth of vegetation occurred and portions of the project were not completed (i.e. erosion control blanket staked, vegetation installed). Although this storm even caused damages to the project, the integrity of the channel improvements functioned as intended in the design. Minor damages occurred to isolated areas of the structural components (drop structures, bendway weirs, grouted boulder edge walls). Minor to moderate damage occurred in vegetated areas and the general observation was that areas planted from February to mid-April functioned much better than portions more recently seeded and blanketed.*

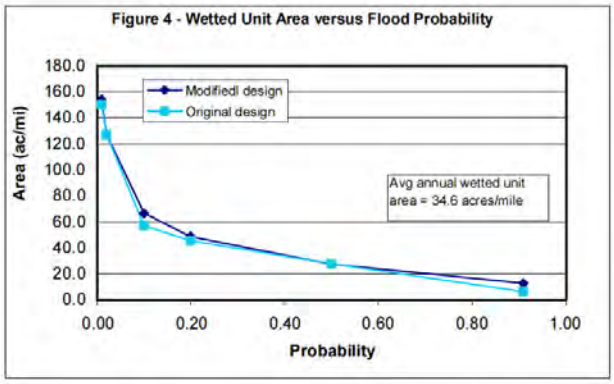
Most stream reclamation projects are designed to minimize, not eliminate, flood damages during events up to and including the 1% chance (i.e.: 100-year event) and therefore some damages are expected. The projects are most vulnerable, however, during the period before adequate vegetation becomes established to protect the channel from erosion. The design includes measures, such as biologs, riprap, and blanket, to temporarily protect the more critical sections of the channel, such as the toe of slope and the main channel bank.

[5] J3 Engineering Consultants and The Restoration Group, Inc. June 20, 2012. *Documentation of the June 6th and 7th Flood Event on Cherry Creek through the Cherry Creek Low Water Crossing South of Arapahoe Road.*
[6] The estimated flood peak discharge was 1,700-cfs at the Project.

The PJCOS project was tested by a flood event at its most critical time and yet received relatively minimal damages, which the Authority believes is evidence that the approach to stream reclamation is technically sound.

WATER QUALITY BENEFITS

An assessment of the water quality benefits for the entire Project was made by the Authority[7]. The Project was found to lower stream velocities, channel shear, and stream power from values prior to reclamation, all of which minimize the transport of sediment and associated pollutants. It was also determined that the channel was in an extremely unstable state that resulted in erosion rates that were over 140-times rates that were considered "typical" for Cherry Creek.



Stream stabilization benefits and evaluation procedures have been documented in the Authority's Stream Reclamation Interim Report[8]. Benefits include reductions in sediment and other pollutant loads and concentrations, including phosphorus and nitrogen. These benefits are supported by Authority data, literature research, and quantitative analysis.

[7] William P. Ruzzo, PE, LLC December 27, 2010. *Cherry Creek Stream Reclamation at PJCOS Modified Design*
[8] CCBWQA Technical Advisory Committee, June 16, 2011. *Stream Reclamation, Water Quality Benefit Evaluation – Interim Report.*

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Memorandum

To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: January 28, 2013

Re: Cherry Creek Stream Reclamation @ 12-Mile Park Phase I – Project Summary

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Presented in this memorandum is a summary of the first phase of the Cherry Creek Stream Reclamation at 12-Mile Park (Project). The second and final phase of the Project, which is scheduled to begin construction in the fall of 2013, will be summarized in an addendum or separate memorandum.

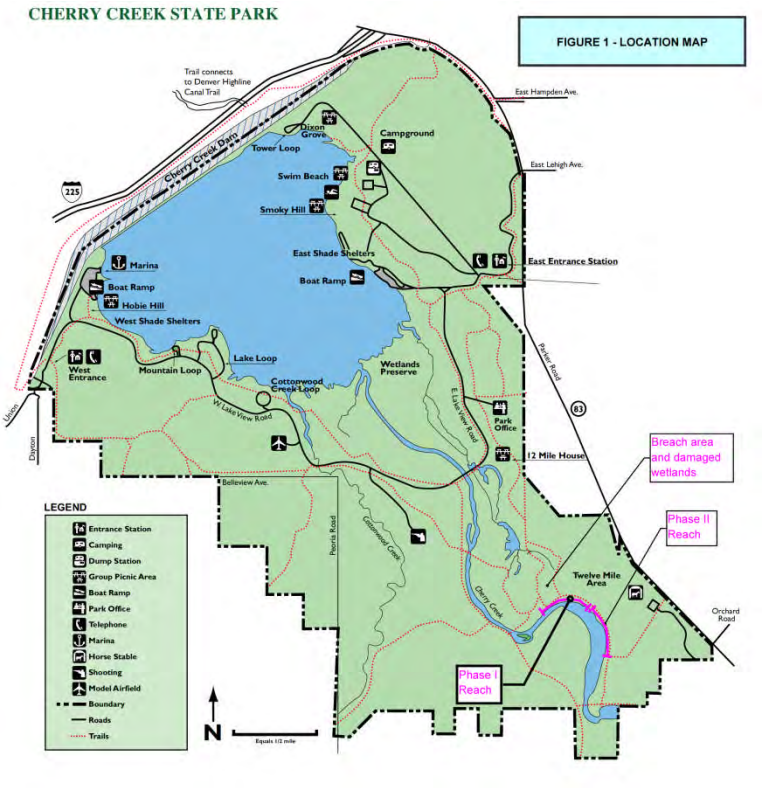
BACKGROUND AND PURPOSE

In 2007, Cherry Creek State Park (Parks) and the Authority inspected the reach of Cherry Creek along the "big-bend" in the Creek adjacent to the dog off-leash area near the south east area of the Park. Severe damage to bank vegetation and channel erosion were observed throughout the area where people, dog, and horse activity were concentrated (see Photo 1). The Authority evaluated the water quality impacts from these activities and decided to investigate the technical feasibility of stabilizing the channel banks. Funds for investigation were included in the 2008 capital improvement program (CIP).

Photo 1 - Cherry Creek 01-28-2008

On January 2008, the Authority met with Parks to discuss coordination between the Parks construction of a formal dog off-leash area (DOLA) and the Authority's channel stabilization measures. The parties agreed to a design approach that would integrate stream stabilization measures with DOLA users by controlling access to the creek and creating a larger vegetated buffer between the creek and the fenced-in DOLA for water quality purposes, but also to continue allow dogs and people to access the creek for recreation purposes in the same areas as existed at that time. Through 2008 and 2009, the Parks conducted a public process to review the DOLA improvement plans.

The Authority advertised for engineering consultants to prepare a stream reclamation plan for the entire reach of the Project (see Figure 1) and contracted with CH2M Hill for the work on May 20, 2010. Prior to selection of a consultant, the right bank of Cherry Creek breached causing the creek to change course through the downstream cottonwood grove, damaging the wetlands which is evident in Photo 2. Therefore, the engineering contract included a task to develop an immediate solution to repair the breached right-bank.



CH2M Hill provided a draft alternative evaluation report[1] and recommended permanent repairs to the breached bank area, dividing the Project into two phases. The Authority then amended the CH2M Hill contract on January 20, 2011 for final design of the breach area (Phase I) and again on October 1, 2011 for bidding and construction services.

DESIGN APPROACH

The overall design approach is best described as "stabilization" rather than "reclamation". First, no improvements are required along the left bank (looking downstream), which is a heavily vegetated, stable, wetlands and uplands area. Second, because the right bank is so high (up to 8-feet), reconnection of the channel and the floodplain is impractical along the right bank. However, because of the intensive use of the right bank of Cherry Creek by the DOLA users, stabilization measures were limited to "harder" structures such as rock toe and timber access points. The new and existing vegetated bank areas also require ingress/egress protection using various types of barriers such as fencing along the top of bank installed as part of the DOLA project. The final plans, however, include eight separate creek-access areas along the right bank constructed from boulders and/or timber to allow DOLA users to have the same experience as prior to DOLA and stream stabilization improvements.

Photo 2 - Wetlands damage from breach

[1] CH2M Hill April 2011. *Cherry Creek at 12- Mile Park DRAFT Alternatives Evaluation Report*

CONSTRUCTION

Bids for the Project were opened on October 31, 2011 and the construction contract was issued to 53-Corporation, LLC of Castle Rock on December 8, 2011 in the amount of $227,588. The notice to proceed was issued for January 23, 2012 and work was substantially complete as of June 6, 2012. Final project costs, which included additional work to restore the damaged wetlands, are $236,778.

Photo 3 - Boulder Toe Wall

Repair to the breach along the right bank included a combination of a boulder toe wall (Photo 3) and sheet-pile cut-off wall along the upper bank (Photo 4).

During work on the 12-Mile Park Project, the Authority also had another project under construction by 53-Corporation within Cherry Creek State Park which had excess earth materials. After determining the suitability of the sediment for use in the 12-Mile Park project, the Authority directed the contractor to haul sediment from the Cottonwood Wetlands project and place it at the 12-Mile Park project to reclaim the wetlands damaged during breach of the Cherry Creek channel. This exchange of material between projects reduced costs to import materials for the 12-Mile Park project and export materials from the Park to preserve flood storage volume[2]. Photo 5 shows the restored wetlands and Photo 6 shows the restored right bank of Cherry Creek that had breached.

Photo 4 - Sheet Pile Cut-Off Wall

Photo 5 - Restored Wetlands

Photo 6 - Restored Breach Area

[2] William P. Ruzzo, PE, LLC July 26, 2012. *Tower Loop, Cottonwood Wetlands, and Cherry Creek @ 12-Mile Park*

June 6, 2012 Flood Event

At the time of inspection (~ noon 6-7-12), the flows in Cherry Creek had begun to recede. Photo 6 above is looking downstream at the right bank where the creek previously was breached. The high flow debris-line is clearly visible just to the right of the water surface. The top of newly restored bank is along the wooden fence posts. This clearly shows that the flood did not breach the repaired bank at the breach area. Analysis by CH2M Hill of the debris line using HEC-RAS developed for the Project suggests that peak flow on June 6, 2012 reached values near 2,000-cfs.

Photo 7 - Bank Overflow Area

Photo 7 shows the downstream end of the project where the grade was tied back into existing grade in front of the trees. The existing channel bank did overtop in this area, outside of the project limits, then flowed back into the project area and did result in some localized erosion. The area downstream of the breach (to the right of the photo) showed minor erosion and sedimentation and possibly some seeded areas were impacted.

Preliminary conclusion is that the project experienced minor local erosion damage and can be repaired during Phase II of the project at a minor cost. It is also my opinion that if the breach had not been repaired, the environmental damage in the breach area would have been extended wider and further downstream damaging other wetlands and far exceeding the minimal damages observed.

WATER QUALITY BENEFITS

An assessment of the water quality benefits for the entire Project was made by the Authority[3]. Water quality benefits from the combined 12-Mile Park and DOLA projects (combined projects) fall into one of two categories, stream stabilization or recreation management.

Stream stabilization benefits and evaluation procedures have been documented in the Authority's Stream Reclamation Interim Report[4]. Benefits include reductions in sediment and other pollutant loads and concentrations, including phosphorus and nitrogen. These benefits are supported by Authority data, literature research, and quantitative analysis.

The 12-Mile Park Stream Reclamation Plan also addresses the dispersed runoff from the DOLA by including a swale along the top of the east bank of Cherry Creek. This BMP is intended to capture minor storm events from the DOLA and provide filtration and infiltration treatment of the runoff. Because of the breach that occurred in the right bank of Cherry Creek, the 12-Mile Park project also includes repairs and restoration of Cherry Creek and the damaged wetland area.

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[3] William P. Ruzzo, PE, LLC May 25, 2011. *Cherry Creek Stream Reclamation at 12-Mile Park – Water Quality Benefits and Costs.*

[4] CCBWQA Technical Advisory Committee, June 16, 2011. *Stream Reclamation, Water Quality Benefit Evaluation – Interim Report.*

The Park's DOLA project includes extensive improvements, relative to water quality, such as perimeter fencing, controlled access to Cherry Creek, and waste management practices. In addition to management of the dog use area, the overall DOLA project includes modifications to the horse boarding area, which is adjacent to the DOLA area on the west and south. The principal modification to the horse area, relative to water quality, will be an updated manure management plan.

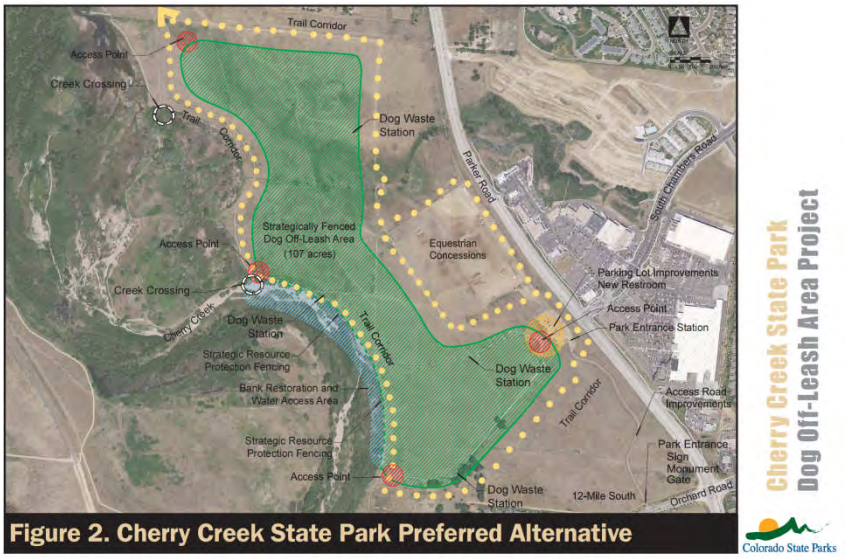

Figure 2. Cherry Creek State Park Preferred Alternative

The analysis by the Authority suggests that when concentrated nutrient (phosphorus) sources are addressed, along with stream reclamation, the water quality benefits are significantly increased, and can reduce water quality protect costs. This supports the Authority's approach of also addressing local sources of nutrients, when partnering with others on stream reclamation projects.

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Memorandum

To: Chuck Reid, Manager, CCBWQA

CC: Rick Goncalves, Chairman, TAC

From: William P. Ruzzo, P.E.

Date: January 10, 2014

Re: Bow-Tie Property Acquisition – Project Summary Report

Presented in this memorandum is a summary of the Authority's participation in the acquisition of a parcel of land located at the confluence of Cherry Creek and Piney Creek. Because of the unique shape, the project was referred to as the Bow-Tie Property Acquisition.

BACKGROUND AND PURPOSE

In 2002, the Authority was approached by the Trust for Public Lands (TPL) to participate in the acquisition of the Bow-Tie Property for the purpose of "…*preservation of open space and creation of parks in the Cherry Creek Corridor from Castle Wood Canyon to Cherry Creek's confluence with the South Platte River*[1].

The Bow-Tie Property is adjacent to Cherry Creek State Park in the northeast ¼ of Section 19, Range 67 West Township 5 South (see Figure 1 Location Map). The property is 21.4 acres in size, of which 16.4 acres is floodplain and the remaining area is upland. The Bow-Tie Property is also adjacent to land owned by Arapahoe County, which includes a detention pond for the Prairie Creek Subdivision north of Piney Creek.

Figure 1 – Location Map

PROJECT PARTNERS AND FUNDING

Acquisition of the Bow-Tie Property was a joint effort between the Authority, City of Centennial, Urban Drainage and Flood Control District, Colorado Parks Department[2], Arapahoe County, and The Trust for Public Land. The multi-party agreement was signed in early 2003 during a late-winter snow storm event that stranded at least one member of the signing party.

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[1] The Trust for Public Land January 11, 2002. Letter from Douglas M. Robotham to Jim Worley, Cherry Creek Basin Water Quality Authority.

[2] Now Colorado Parks and Wildlife.

Agency[3]	Contribution
Cherry Creek Basin Water Quality Authority	$350,000
City of Centennial	$260,000
Urban Drainage & Flood Control District	$50,000
Colorado State Parks	$99,000
Arapahoe County	$100,000
TOTAL	$859,000

In addition to the Authority's right to construct water quality related improvements along Cherry Creek and Piney Creek, the Authority's contribution included $100,000 for the property and water rights for an alluvial well, a Denver Basin well, easements for ingress and egress, and all the related pumps, equipment, pipelines and appurtenances. The Authority is currently evaluating future uses of these wells related to the Authority's business of protecting water quality in Cherry Creek. As the result of the Bow-Tie proect, the Authority has included stream corridor preservation in the capital improvement program (CIP) since 2002.

WATER QUALITY BENEFITS

Protection of the floodplain, riparian corridor and other environmentally sensitive lands through public acquisition or conservation easement and restoration of the same lands for nutrient control through erosion control, revegetation or other means is identified by the Water Quality Control Commission (WQCC) as a nonpoint source nutrient control measure[4].

The Authority evaluated the Bow-Tie Property Acquisition for water quality benefits using two different approaches. The first was based on construction of wetlands at the confluence of Cherry Creek and Piney Creek[5]. This analysis suggested that with a capital cost of $826,200, land costs of $300,000 and annual O&M of $6,400, the projected annual phosphorus costs could be from $300 to $400, based on an annual phosphorus reduction of 235-pounds. The second approach evaluated the acquisition based on preventing a portion of the property from being developed into single family housing[6]. A finding of this analysis was that development of approximately 9-acres would increase phosphorus loads by around 2.5-times over preserving the land as open space. This increase takes into account that the development would be required to implement post-construction best management practices (BMP) that could reduce phosphorus loads by 50% annually.

CONCLUSIONS

Although the Bow-Tie Property Acquisition was the first and only Authority PRF that was based on preservation of floodplain and riparian corridor, the Authority continues to include in its CIP budget funds for future acquisitions to take advantage of the opportunity which can occur on short notice.

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[3] Trust for Public Land, August 28, 2003. *Tying the Bow at Cherry Creek State Park.* Press Release

[4] CDPHE, Water Quality Control Commission November 30, 2012. *Cherry Creek Reservoir Control Regulation.* @72.6.6. See Statement of Basis, Specific Statutory Authority and Purpose (May 2001).

[5] Ruzzo, William P. and McGregor, Dr. Robert F. November 5,2002. *Updated Analysis of Bow Tie Property.*

[6] William P. Ruzzo, PE. January 28, 2002. *Bow Tie Property – Phosphorus Contribution from Developed Land.*