Stream Reclamation, Water Quality Benefit Evaluation - Interim Status Report

Prepared for the

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
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June 16, 2011

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Stream Reclamation Water Quality Benefit Evaluation - Status Report

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REPORT AMENDMENTS

The Technical Advisory Committee (TAC) of the Cherry Creek Basin Water Quality Authority (Authority) anticipates the need to update this report as more information becomes available and the processes and procedures are refined. Therefore, this report is considered to be “interim” and subject to periodic updates.

The TAC’s intent is to provide supplemental materials or chapter updates as new appendices to this Interim Report and keep a record of the changes using the following table:

Amendment Number	Amendment Date	Amendment Subject

When performing economic analysis for pollutant reduction facilities (PRF), the Authority has traditionally used a discount rate of 7 percent for comparison, which was used in the economic analysis presented herein. The Authority Board of Directors has since determined that a lower discount rate, such as 4%, better reflects the industry standard for construction of public works projects. Therefore, all future economic analysis of PRFs will be based on the lower interest rate at the Boards direction. Whereas the economic analysis presented herein was not modified to reflect the lower interest rate, the results and conclusions will not change as presented in this report. Future modifications to the report will adjust the economic analysis accordingly.

ACKNOWLEDGEMENTS

This investigation and report is the result of the combined effort of many individuals who contributed in some way to the results. The Cherry Creek Basin Water Quality Authority acknowledges the following individuals and organizations who contributed to the development and publication of this *Stream Reclamation Water Quality Benefit Analysis Status Report.*

Technical Advisory Committee

Organization	Individual	Organization	Individual
RG Consulting, Inc.	Rick Goncalves, Chair.	Arapahoe County	Steve Miller
Douglas County	Jim Dederick	Douglas County	Erik Nelson
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Castle Pines North	Vacant	Castle Rock	Pieter Van Ry
City of Centennial	Edward Stafford	Greenwood Village	Ann Woods
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City of Lone Tree	Bob Takeda	Town of Parker	Tom Williams
Special Districts	Max Grimes	Special Districts	Alan Pratt
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Stream Reclamation Water Quality Benefit Evaluation - Status Report
EXECUTIVE SUMMARY

The Cherry Creek Basin Water Quality Authority, (Authority) Technical Advisory Committee's (TAC) prepared this report to document procedures and methodologies, current knowledge, and understanding of water quality benefits associated with reclamation of stream and channel systems. Stream reclamation is a pollutant reduction facility (PRF) which also includes detention, retention, and wetlands for treatment of regulated and non-point source stormwater within the Cherry Creek watershed. This report was prepared as a first step in refining the Authority's procedures for identifying, evaluating, and prioritizing stream reclamation measures to reduce pollutant loads and concentrations discharged to Cherry Creek Reservoir and Cherry Creek as part of the update to the Authority's Watershed Plan 2003.

Control Regulation No. 72[1] defines PRF as:

> *"…projects that reduce nonpoint source pollutants in stormwater runoff that may also contain regulated stormwater. PRFs are structural measures that include, but are not limited to, detention, wetlands, filtration, infiltration, and other technologies with the primary purpose of reducing pollutant concentrations entering the Reservoir or that protect the beneficial uses of the Reservoir."*

The distinction between a PRF and a best management practice (BMP) is that PRFs are primarily structural measures that focus on non-point source pollutants. BMPs focus on pollutants from regulated stormwater (i.e., municipal runoff) and also include non-structural controls, activities, practices, and prohibitions. However, BMPs also include detention, retention, and wetlands measures for which there is a growing body of knowledge regarding their function and performance, including extensive Authority data for Shop Creek, Cottonwood Wetlands, and the Cottonwood\Peoria Street PRFs.

The intent of this investigation was to focus on stream stabilization and reclamation because there was the least amount of data and information regarding water quality benefits compared for those PRFs compared to the more "traditional" BMPs discussed above. Stream reclamation is currently a major component of the Authority's PRF capital improvement program (CIP), but some concerns were expressed that we did not have sufficient information to justify Authority expenditures on stream reclamation. However, it became apparent during the process that some information in this report may apply to all PRFs, not just stream reclamation, and therefore, information provided in this report may be useful when evaluating other PRFs, not just stream reclamation.

During this investigation, the TAC determined that more information is needed to refine the technical approach to prioritizing stream reclamation projects as presented herein. Also, the Authority's budget projections over the next few years show sufficient funds to cover the current funding requests by project proponents such that a final prioritization methodology is not necessary at this time. The TAC decided to publish the report since it provides valuable information regarding stream reclamation and a reference for updating the Authority's watershed

[1] Water Quality Control Commission January 1, 2010. *Cherry Creek Reservoir Control Regulation 5 CCR 1002-72.*

strategic plan. However, the TAC anticipates the need to update the report as more information becomes available: therefore, this report is considered to be "interim."

Purpose and Scope.

The scope of this report included investigating the history of stream stabilization in the Cherry Creek watershed, documenting current procedures for identifying and evaluating PRFs in general, evaluating impacts of recent regulatory changes, presenting the results of a literature search to identify other, nationwide perspectives, preparing more detailed analysis of existing stream water quality data, and identifying additional considerations for evaluating stream reclamation projects. The purpose of the TAC's investigation can be summarized by the following questions:

- Is stream reclamation beneficial to water quality, and if so, why?
- Is stream reclamation used by other agencies or organizations to improve water quality and what is their experience?
- Does the Authority's data support stream reclamation as a cost effective way to improve water quality in the Reservoir and Cherry Creek?
- What additional information is needed to further document water quality benefits of stream reclamation?
- How does stream reclamation fit into future PRFs and other watershed management techniques?

Findings and Conclusions

Stream reclamation is beneficial to water quality in the stream and in the Reservoir. 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 the several years of Authority water quality data collected to evaluate PRFs.

A more detailed analysis of the Authority's data for Cottonwood Creek further shows that stream reclamation projects can reduce phosphorus loads and concentrations to levels below the target flow-weighted concentration levels (i.e., 0.20-mg/l) suggested by the Authority during the April 2009 triennial hearing for Control Regulation No. 72. The Cottonwood Creek data suggest that stream reclamation may also reduce nitrogen loads and concentrations.

A literature search shows that stream reclamation is one of the more extensive practices used to improve water quality in streams and water bodies in total maximum daily load (TMDL) implementation plans. However, more monitoring data are needed to evaluate water quality benefits for stream reclamation projects.

This report documents two quantitative methodologies for evaluating stream reclamation projects, one based primarily on economic factors and the second based solely on hydraulic characteristics of the stream. Comparison of the Authority's methodology (i.e., cost-per-pound) for evaluating stream reclamation to agency methodologies in other parts of the U.S. suggests that the Authority's methodology is consistent with and comparable to results obtained by others. By evaluating stream reclamation projects, as well as other PRFs, on a cost-per-pound basis, the Authority can select the most cost-effective projects for implementation and can clearly show cost-reduction benefits associated with stabilizing a stream before the conditions get worse, as demonstrated by the McMurdo Gulch project. In addition, a methodology to compare water quality benefits of other stream reclamation projects using a backwater analysis (i.e., HECRAS) was developed, based on the design of the reclaimed section of Cottonwood Creek within Cherry Creek State Park. The methodology is based on a statistical analysis of velocity, shear force, and stream power for the mean annual, 2- and 5-year storm events, as well as an average annual, wetted area per mile of channel (ac/mi/year) calculated using probability analysis of the mean annual to the 1% chance flood event.

Stream stabilization and reclamation were recognized in early Cherry Creek watershed plans as a watershed control method for the Cherry Creek Basin to control phosphorus entering the Reservoir. Stream reclamation has been used extensively through out the country to protect and enhance water quality in stream systems and water bodies and is a widely accepted best management practice to control pollutant loads. Stream reclamation has been and should continue to be a priority PRF for the Authority in the future.

Recommendations

The TAC recommends that the monitoring program be reevaluated and consider ecological assessments, not as a replacement to chemical monitoring, but as a way to improve our understanding of water quality benefits from stream reclamation and to include other, less direct measures of water quality.

The TAC recommends that the current procedures for calculating reduction in phosphorus loads be refined to incorporate more robust algorithms for a very complex process, particularly related to riparian and floodplain areas. The more robust procedures would be available to project proponents as a means of justifying a greater financial contribution from the Authority when partnering with the Authority for stream reclamation projects.

Further refine the methodology to compare water quality benefits of stream reclamation using the five channel hydraulic parameters presented in this report that are based on the design of Cottonwood Creek Stream Reclamation within Cherry Creek State Park.

The Authority's watershed model can be used to estimate changes in phosphorus loads and flow-weighted concentrations for stream reclamation-type projects, with some minor modifications to the algorithms, to help assess long-term water quality benefits particularly at the Reservoir. The TAC recommends further investigation into using the watershed model to evaluate stream reclamation, long-term benefits.

In the past, the Authority has evaluated PRFs, including stream reclamation, based primarily on cost-per-pound of phosphorus removal from surface flow. Eleven additional evaluation criteria were developed by the TAC, both quantitative and qualitative as part of this process. The TAC recommends these criteria be refined and considered as a basis for prioritizing projects if required in the future.

The Authority's methodology for evaluation of stream reclamation and other PRFs' utilizes reductions in total phosphorus as the primary metric, since a total maximum annual load (TMAL) for phosphorus had been in effect for the Reservoir from 1984 to 2010. Recent changes to the Reservoir standard and Control Regulation No. 72 eliminated the TMAL, which prompted the Authority to consider a broader range of nutrients and other pollutants when evaluating water quality in the watershed, including all forms of phosphorus, nitrogen, and other chemical, and biological constituents. However, for consistency, repeatability, and practicality, immobilization of total phosphorus continues to be the recommended primary metric for evaluating stream reclamation and other PRFs, although the Authority is investigating other pollutants that may also be used for evaluation in the future.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
Stream Reclamation Water Quality Benefit Evaluation - Status Report

1. Purpose and Scope

This report summarizes the Technical Advisory Committee's (TAC) knowledge and understanding of the water quality benefits associated with stabilization and reclamation of streams systems within the Cherry Creek watershed. The purpose of the TAC's investigation can be summarized by the following questions:

- Is stream reclamation beneficial to water quality, and if so, why?
- Is stream reclamation used by other agencies or organizations to improve water quality and what is their experience?
- Does the Authority's data support stream reclamation as a cost effective way to improve Reservoir water quality?
- What additional information is needed to further document water quality benefits of stream reclamation?
- How does stream reclamation fit into future PRFs and other watershed management techniques?

Whereas most of the information presented herein is based on existing Authority information compiled through 2010, some additional analysis was conducted for this investigation, including more detailed data analysis of Cottonwood Creek and a literature search of stream stabilization and reclamation projects by others.

During this investigation, the TAC determined that more information is needed to refine the technical approach to prioritizing stream reclamation projects as presented herein. Also, the Authority's budget projections over the next few years show sufficient funds to cover the current funding requests by project proponents such that a prioritization methodology is not necessary at this time. Whereas the TAC decided to publish the report at this time since it provides valuable information regarding stream reclamation, the TAC anticipates the need to update the report as more information becomes available and the need for prioritization changes. Therefore this report is titled "interim".

2. Historic Perspective

2.1. What is Stream Reclamation

The Authority has used the following definitions to distinguish between stabilization and reclamation of channels or stream systems. Whereas both measures can result in water quality benefits, reclamation has greater potential than stabilization to improve water quality.

Channel or Stream Stabilization means the activities used to minimize erosion and sedimentation within a surface, stormwater-runoff conveyance. Channel (or stream) stabilizations are designed based on hydrology of the tributary watershed that factors in storm runoff rate, volume, frequency, and duration from projected future-development conditions.

Stabilization activities include, but are not limited to, excavation and grading; placement of fill; construction of check structures, drop structures, and channel bed and bank protection measures; and placement of vegetation that protects the channel area of the conveyance. Stabilization can also be limited to construction of check structures and local grading activities.

Channel or Stream Reclamation means additional measures or enhancements to channel or stream stabilization that typically includes riparian and floodplain vegetation planting or enhancements and a channel cross section that results in more frequent connection and flooding of the overbank area. Riparian vegetation promotes filtration of fine particles with attached nutrients, and over-bank flooding promotes additional filtration and to some extent infiltration both which reduce nutrient loads and concentrations. Therefore, the benefits from stream reclamation include the reduction in sediment and nutrients (i.e.: phosphorus and nitrogen) transport from the main channel, but also reduction in nutrient loads from riparian and floodplain vegetation through more frequent floodplain inundation. Channel and stream reclamation also recognizes that urban development in the watershed has significantly altered the hydrologic regime which affects requirements for design of stream reclamation projects.

2.2. Why Stream Reclamation Projects

Cherry Creek and its tributaries have been degrading for many years in part due to intense development in the watershed. Urbanization increases the rate, volume, duration, and frequency of runoff during storm events resulting in significantly higher stream erosion rates than from undisturbed watersheds. Urban runoff was identified as a major contributor of phosphorus loads to the Reservoir during the Clean Lake Study of Cherry Creek Reservoir, degrading the water quality[2]. The subsequent watershed master plan[3] recommended implementation of control structures[4] in priority subbasins, which included Shop Creek, Cottonwood Creek, Direct Flow #4 (i.e.: Windmill an Dove Creek), and Direct Flow #5 (i.e.: Cherry Creek mainstem from Arapahoe Road to Douglas County line). The most recent Cherry Creek basin master plan[5] in 2003 also recommended stream stabilization to improve water quality. The UDFCD[6] also recommends the “Four Step Process for Stormwater Quality Management,” which includes stabilization of the stream channel.

Stream stabilization and reclamation projects have since been implemented by the Authority and local land use agencies within all of these and other subbasins, and continues to be a an important, high priority PRF in the near future.

Prior to 2000, stream degradation had resulted in large amounts of sediment, nutrients, and other pollutants being discharged into Cherry Creek Reservoir, negatively impacting the water quality of the Reservoir. The Authority has spent 3.5-million dollars[7] on stream

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[2] DRCOG 1984. *Cherry Creek Reservoir Clean Lakes Study.*
[3] DRCOG 1985. *Cherry Creek Basin Water Quality Management Master Plan.*
[4] Control structures are grade controls in the stream bed to flatten the slope, reducing velocities and, therefore, reducing transport of sediment and other pollutants.
[5] URS August 2003. *Cherry Creek Reservoir Watershed Plan 2003*
[6] UDFCD 2010. *Urban Storm Drainage Criteria Manual Volume 3 Best Management Practices.*
[7] CCBWQA February 25, 2009. *Rebuttal Statement of the Cherry Creek Basin Water Quality Authority.* March 2009 Rule Making Hearing.

reclamation type projects since 1989 to improve water quality in Cherry Creek Reservoir[8]. Whereas the Authority began construction PRF's in 1989, the reservoir data suggest that it was around the year 2000 before water quality began to improve or at least reverse the decline in quality. This improvement in reservoir water quality was attributed in a large part to stream reclamation projects and reduction in wastewater discharge phosphorus concentrations[7].

However, there are still uncertainties regarding cost and benefits associated with stream reclamation and whether these benefits are dependent on where in the watershed stream reclamation projects are implemented. Therefore, additional information and data are needed to justify Authority funds on stream reclamation.

2.3. How PRFs are Identified and Prioritized.

PRFs are capital projects that are primarily intended to reduce sediment and nutrient (i.e.: phosphorus) loads to the Reservoir. The definition of a PRF in Control Regulation No. 72[9] is

> *"Pollutant Reduction Facility (PRF)" means projects that reduce nonpoint source pollutants in stormwater runoff that may also contain regulated stormwater. PRFs are structural measures that include, but are not limited to, detention, wetlands, filtration, infiltration, and other technologies with the primary purpose of reducing pollutant concentrations entering the Reservoir or that protect the beneficial uses of the Reservoir.*

Table 1 shows the list of PRFs that the Authority has constructed since 1989 as examples of the types or category of projects that have made the capital projects list. The Reservoir Destratification project is different from the other project categories and is an example of how the Authority can and has considered unique projects to protect the water quality of the Reservoir.

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[8] The Authority's total expenditure on PRF from 1989 through 2009 is over $7-million.
[9] CDPHE, Water Quality Control Commission, January 1, 2010. *Cherry Creek Reservoir Control Regulation.* 5 CCR 1002-72

TABLE 1
SUMMARY OF NONPOINT SOURCE PROJECTS & COSTS

PROJECT	CATEGORY	YEAR	COST
Shop Creek	Detention with wetlands	1991	$ 668,286
Cottonwood Wetlands	Detention with wetlands	1996	$ 342,978
Quincy Drainage	Detention with infiltration	1995	$ 218,672
East Shade Shelter	Shoreline Stabilization	1996	$ 125,754
East Boat Ramp	Shoreline Stabilization	1996	$ 120,000
East Shoreline extension	Shoreline Stabilization	1999	$ 69,000
Tower Loop	Shoreline Stabilization	1999	$ 142,000
Dixon Grove	Shoreline Stabilization	1999	$ 27,600
Cottonwood\Peoria Pond[1]	Detention with wetlands	2001	$ 100,000
Bowtie Property Acquisition	Preservation of stream corridor	2003	$ 300,000
Cottonwood Creek Reclamation Phase I	Stream stabilization	2004	$ 2,405,000
Cottonwood Creek Reclamation Phase II	Stream stabilization	2008	
Sub-total			**$ 4,519,290**

NOTE
1. Cost is Authority's share for a multi-party project. Wetlands detention work completed in 2001 Monitoring began in 2002, but other work continued into early 2003.

Other Authority projects to protect reservoir water quality

Reservoir Destratification[1]	Mixing to control algae	2007	**$ 968,100**
Total Cost of completed projects to protect reservoir water quality			***$ 5,487,390***
CCBWQA 2009 to 2013 CIP Work, including O&M			***$ 1,694,000***
Total Authority Capital Improvement Program (CIP)			***$ 7,181,390***

Selection of Projects for Master PRF List. The first step in the process is development of a list of all potential PRFs (called the master PRF list), which includes capital and operation and maintenance activities and potential benefits in terms of phosphorus reduction (see Appendix A). In addition to Authority initiated investigations, the Authority also identifies pollutant reduction opportunities by participating watershed drainage master plans conducted by the Urban Drainage & Flood Control District (UDFCD) and local jurisdictions, or master plans developed independently by local jurisdictions, such as Castle Rock. Historically, these master plans have often recommend implementation of detention and stream stabilization measures throughout the watershed with the goal of reducing flood damages. More recently, these watershed master plans have included the goal of improving the stormwater quality in the planning process, such as the SEMSWA plans for Cottonwood Creek and Lone Tree Creek and Castle Rocks plan for McMurdo Gulch, which have resulted in a more integrated approach at the sub-watershed or tributary watershed level.

Calculating Cost and Benefits. Once a project is identified as a “potential PRF,” the Authority performs a cost and benefits analysis to develop the metric of “cost per pound of phosphorus immobilized[10]” by the project. Detention, retention, and wetland projects are more readily evaluated, since the amount of sediment (and therefore particulate phosphorus) deposited in the facility can be readily calculated, assuming mean annual runoff conditions, or measured by monitoring inflows and outflows. However, stream stabilization and reclamation projects are much more complex in how they immobilize sediment, phosphorus, and other pollutants. Much of the sediment transport is reduced in a stable stream system by flattening the channel slope,

[10] Since PRF mostly “remove” sediment and nutrients from storm runoff which are then “trapped” by the PRF, the pollutants are considered to be “immobilized” rather than “removed”.

reducing velocity and energy, and stabilizing the channel banks reducing erosion and deposition. However, additional sediment and other pollutants are immobilized by riparian vegetation through filtration, floodplain inundation and filtration and, to a lesser degree, infiltration in the floodplain area, all of which are difficult to calculate or directly monitor.

Currently the Authority uses two approaches to calculate the cost benefit of stream reclamation projects. One approach (Approximate Method) relies on erosion data from a TMDL study in Michigan, which provided historic erosion rates in a channel for similar soils over a period of several years. This method only estimates benefits from reduced erosion, and therefore phosphorus, in the main channel. The second method uses project specific data, such as that available for Cottonwood Creek, to estimate the erosion that has occurred over time, as well as additional phosphorus reduction benefits of riparian vegetation and more frequent floodplain inundation. This second approach, called Site-Specific Method, has been found to result in higher phosphorus load reductions per mile of stream than the Approximate Method because actual erosion rates are used and because additional benefits from riparian vegetation filtration and flood inundation are included. However, the Approximate method is used in the annual CIP projections because site specific data is often lacking at the time the budgets are prepared.

More detailed descriptions of the calculation procedures for both of these methods can be found in Appendix B. Results for Cottonwood Creek are presented in Table 2 and suggest that water quality benefits, as measured by pounds of phosphorus immobilized, are noticeably more cost effective when using site specific information. Using the Approximate Method, the project immobilizes 197-lbs/year whereas using the Site Specific Method the project would immobilize 736-lbs/year. How well this information compares to results nationwide is discussed further in Section 3.2 below.

Table 2 Comparison of Approximate and Site Specific Methods for Cottonwood Creek

Method	**P Reduction Rate**			**Total**		**Costs**		
	Zone	Value	Units	Value	Units	Capital	Annual[1]	$/lb P
Approximate	Channel	90	lbs/mile/year	**197**	lbs/year	$ 2,405,000	$ 121,700	$ 617
Site Specific	Channel	210	lbs/mile/year	460	lbs/year			
	Riparian	10	lbs/acre/year	200	lbs/year			
	Floodplain	1	lbs/acre/year	76	lbs/year			
			Total	**736**	lbs/year	$ 2,405,000	$ 121,700	$ 165

Notes 1. Annual cost based on 7% interest and 35-year return period

Selection of Projects for 5-year Capital Improvement Program. If project costs and benefits appear to be reasonable, the TAC recommends to the Board that the project be included on the 'Master PRF List'. The next step then is to select the best projects from the master list of PRFs to be included on the five-year CIP list. The TAC annually evaluates the projects on the master list and forwards recommendations to the Board for inclusion in the annual update of the five-year CIP. The Board then selects projects from the five-year CIP based, in part, on recommendations from the TAC and subject to available funds.

Inspection of the 2010 Master PRF List in Appendix A shows that PRFs can vary in annual cost from just over $200 per pound of phosphorus to over $4,000 per pound using the Approximate Method. However, the projects selected for the 5-Year CIP list are more on the order of $300 to $600 per pound. Beginning in the year 2002, the CIP project list included potential funding partners and began showing cost per pound values with and without the funding partner's participation. Since funding partners could not always be identified at the time of CIP development, the TAC recommendations for the 5-Year CIP List began limiting Authority's participation to the $600 per pound value based on past PRF performances. Thus, the 'CCBWQA Share' in percent was adjusted such that the 'Unit Cost' ($/pound)' was no greater than $600 in the "w/cost sharing' column (see Appendix A). If Authority costs were less than $600 per pound with or without a funding partner, the PRF was often placed on the 5-Year CIP list, with preference given to those PRFs with the least cost and subject to available annual funds.

For example, the "Cherry Creek Stream Reclamation at Eco-Park" PRF (Project # CCB-5.7) is included in the Authority's 2010 CIP for the amount of $154,000. This amount was based on a projected total project cost (design and construction) of $532,000. This capital cost was derived from the Cherry Creek corridor master plan[11] for the 1,150 linear foot long stream stabilization work[12]. Whereas it is likely that the final cost for this project will increase, the Cherry Creek Corridor master plan was the best information available at the time the project was first included in the 5-year CIP. As the design progresses and costs are refined, the TAC can update the 5-year CIP. The long-term, annual reduction in phosphorus loads was projected to be 20-pounds which resulted in a project annual cost of almost $2,100 per pound[13]. Since the Authority's portion was limited to approximately $600 per pound, the actual funding level for the project was set to $154,000 (i.e.: 600/2100 x 532,000). The Authority has also considered other factors besides cost per pound when determining the appropriate funding level.

Another example is funding level of McMurdo Gulch PRF Project No CCB-7.1, which was initially set at $430,000 divided equally for the 2009 and 2010 budget[14]. This amount was based on a projected total project cost (design and construction) of $890,000. This capital cost was derived from the McMurdo Gulch master plan[15] and conceptual level design for the 3-mile stream reach undertaken by the Town of Castle Rock. The long-term, annual reduction in phosphorus loads was projected to be 270-pounds resulting in a project annual cost of $272 per pound, which is less than the $600 dollar threshold. In this instance, the cost share recommendation was 50/50 due to the low cost-per-pound[16].

Once the Board approves the project for inclusion on the master list, any future Authority funded work towards design and construction, also authorized by the Board, is considered to be part of capital expenses of the Authority. If the PRF does not have funding partners, the

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[11] URS January 2004. *Cherry Creek Corridor – Reservoir to Scott Road Major Drainageway Planning Preliminary Design Report*

[12] As of August 2010, the projected project costs are $3,912,000 of which $873,000 are specifically allocated to water quality.

[13] Since 2000, the Authority has consistently used an interest rate of 7% for 35-years to evaluate PRFs. Whereas this interest rate and return period may not be appropriate for any given year, consistency in its use is important to compare relative benefits of PRFs over time.

[14] Funding for two consecutive years was necessary meet Castle Rock TABOR limits.

[15] PBS&J 2006. *McMurdo Gulch Major Drainageway Master Plan.*

[16] The cost share was subsequently reduced again to 48% due to Castle Rock TABOR limits related to funds provided by the Authority.

Authority is wholly responsible for engineering, construction, administration, and maintenance costs, most of which is sub-contracted to a qualified consultant and contractors. If the PRF has funding partners, such as for the Cherry Creek Stream Reclamation at Eco-Park project, the Authority's role is primarily design review and oversight to assure Authority funds are used to benefit water quality.

2.4. Why the need to Evaluate Stream Reclamation

The evaluation methodologies discussed above provide a reasonable and comparable basis for identifying and prioritizing projects to reduce phosphorus loads into Cherry Creek Reservoir. However, there are improvements that can be made to the approach, particularly for stream reclamation type PRFs:

- The Approximate method appears to under estimate benefits associated with stream reclamation and, therefore, the costs per pound of the projects are likely less than that used to identify and prioritize projects. This cost conservatism may eliminate worth while projects from funding opportunities – or significantly reduce the Authority's contribution - since a unit cost threshold is often applied to potential PRFs. Conversely, project costs can increase significantly from master plans used to initiate the 5-year CIP to final project costs determined through a detailed design process. Therefore, it may be necessary to update the cost and benefits through out the 5-year CIP process to provide a consistent basis for comparing projects.

- Stream Reclamation projects provide greater water quality benefits than just reduction in phosphorus loads, such as reduction in nitrogen and metals, and increases in oxygen (see Section 3.1 Literature Search). Reduction in these pollutants are beneficial to the Reservoir water quality, but have not yet been quantified.

- Stream Reclamation also improves overall ecological health of the stream system by improving habitat for benthic macro-invertebrates and terrestrial wildlife, which are indirect measures of water quality. Stream reclamation can also lead to greater public understanding of the importance of water quality and overall enjoyment of the wildlife such as has been the experience at Cottonwood Creek reclamation within Cherry Creek State Park.

Therefore, since stream reclamation will likely continue to play a major role in capital projects designed to control the discharge of watershed pollutants to the Reservoir, a better understanding and quantification of water quality benefits is needed.

2.5. Changes in Control Regulation 5 CCR 1002-72.

Recent revisions to the Reservoir Standard (5 CCR 1002-38) and the Reservoir Control Regulation (5 CCR 1002-72) have changed the way watershed management and PRFs are evaluated. Since Cherry Creek Reservoir has been delisted for phosphorus from Section 303(d) of the Clean Water Act and since the Commission adopted a nutrient concentration based approach for watershed management, there is no longer a total maximum annual load (TMAL) limitation for phosphorus. As discussed above, the current methodology for evaluating PRFs is to calculate reduction in phosphorus loads by the PRF, which helps keep total phosphorus loads entering the Reservoir below the TMAL.

Under the new regulation, 5 CCR 1002-72, the PRF metric of cost-per-pound of phosphorus need not be the only measure or primary to evaluate PRFs such as stream reclamation. The revised nutrient management strategy for Cherry Creek watershed is to control flow-weighted phosphorus concentrations[17] to values of 0.20-mg/l or less. Authority data collected on Cottonwood Creek stream system (see Section 3.3 below) show that phosphorus concentrations less than 0.20-mg/l can be achieved by combination of PRFs (i.e.: treatment train) including detention, wetlands, and stream reclamation. Therefore, it may be more appropriate to measure stream reclamation benefits in terms of how low phosphorus concentrations can be managed with the PRFs, which further illustrates the need to refine the methodology to evaluate water quality benefits of stream reclamation.

3. Investigations

3.1. Literature Search

A literature search was conducted using the internet to determine if stream stabilization and reclamation was beneficial to water quality and, if so, to what extent. Searches were conducted on key words such as: "stabilization," "reclamation," "restoration," and "corridor" combined into key phrases using "channel" and "stream." The greatest return of pertinent information was received when searching on "stream restoration" or "stream corridor restoration." Several publications were also provided by GEI as part of an independent literature search as well as information in the files of the principal author.

Publications by various agencies and groups were reviewed and included state and federal agencies, university institutes, stream restoration working groups, TMDL watershed groups, and others. A pdf copy of each document was obtained and compiled into an annotated bibliography (see Appendix C) which included quotes from the documents or important information relative to this investigation into stream reclamation benefits. TAC evaluation of the bibliography concluded that the Authority's stream reclamation approach is supported by the literature as illustrated by the following excerpts:

a. Most stream stabilization projects include the objective of improving water quality, which have been found to be cost effective water quality management techniques. *"The quality of water in the stream corridor is normally a primary objective of restoration, either to improve it to a desired condition, or sustain it."* (FISRWG 2000). "*This study has shown that stream restoration can be one of the most cost-effective methods of preventing phosphorus from entering lakes*." (Dove 2009).

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[17] Control Regulation No. 72 defines "Flow-weighted phosphorus concentrations" as the total external load, including precipitation, groundwater, stream flow, and ungaged runoff, divided by total inflow volume.

b. There is a general lack of monitoring data to show benefits of stream stabilization. "*While the importance of vegetation in streambank stabilization is widely acknowledged, the impacts are complex and have yet to be fully quantified*." (Center for TMDL and Watershed Studies)

c. Limited monitoring data show that stream reclamation results in increases in oxygen, and decreases in phosphorus and nitrogen. "…*stream restoration projects that were hydrologically connected to their floodplains had increased rates of denitrification relative to restored streams that were not as well reconnected to their floodplains.* " (Berg 2009)

d. Ecological monitoring provides *earlier* indication of stream health problems than chemical monitoring alone. *"The restoration evaluation should usually focus on aquatic organisms and instream conditions as the "judge and jury" for evaluation restoration success….biological criteria detected an impairment in 49.8 percent of the situations where no impairment was evident with chemical criteria alone.* (FISRWG 2000).

e. Authority's cost per pound of P immobilization metric is supported by two other independent investigations[18], which is described in more detail in Section 3.2 "Comparison to Other Projects Nationwide" below. (Virginia Tech 2006, Dove et. al. 2009).

f. Not all investigations concluded that riparian stream buffers would reduce nutrient concentrations. "*Reductions in TP exports were not evident and the amount of P moving associated with particles 0.45 mm or in dissolved form increased following improved riparian management*." (McKergow et. al. 2002)

3.2. Comparison to Other Projects Nationwide.

As part of the literature search (see Section 3.1 above), two independent investigations were found that used an approach similar to the one used by the Authority to quantify benefits of stream reclamation in terms of pounds of phosphorus immobilized. One study was performed on Ward Branch in Springfield Missouri (Dove 2009) and one for Stroubles Creek in Virginia (Virginia Tech 2006). Both the Ward Branch and Stroubles Creek investigations were part of a TMDL study to identify and quantify costs and benefits associated with different management techniques, including stream reclamation that used monitoring data and construction costs to quantify phosphorus reduction amounts.

Data from both of these investigations was used to compare to the Authority's approach to quantifying cost effectiveness of phosphorus immobilization using stream reclamation. A comparison of the various key aspects of stream reclamation is provided in Table 3. The left part of the table compares basic data whereas the right part compares cost information. Note that the "annual cost per pound P removal" results for Cottonwood Creek (right side of table) are

[18] The UDFCD has updated Volume 3, Best Management Practices, and Chapter 2 "BMP Selection" contains a section on Cost Effectiveness that provides a methodology to calculate cost per pound of pollutant removed by the BMP.

presented for both the Approximate and Site Specific Methods, which explains the range of results.

Table 3 Summary Comparison of Loads, Concentrations, and Costs for Stream Reclamation Projects

Item	Ward Branch	Stroubles Creek	Cottonwood
Erosion Rate (tons sed/mile/year)	610	164	182
P Conc in Sediment (mg/kg)	400	1200	743
P Erosion Rate (lbs P/mile/year)	488	389	271

Item	Ward Branch	Cottonwood	Stroubles Creek
Annual Cost per Pound P Removal	$188	$252 to $942	$483
Interest Rate Adjusted Annual Cost per Pound P Removal	**$188**	**$165 to $617**	**$317**

Examination of Table 3 suggests that although the different metrics can vary from site to site, the Authority's data and approach appears to be reasonably consistent and comparable to approaches used in other parts of the country. In addition, when the interest rate used in Table 3 is adjusted to 4.5% with a return rate of 50-years (bold numbers in the table) the results are closer, even for the Approximate Method.

3.3. Analysis of Cottonwood Creek Monitoring Data.

A major premise behind the Authority's pursuit of enhancing stream stability is that the silty-clayey soils within the basin have a greater affinity to bind up phosphorus, and thus, eroded stream bank soils can release phosphorus further downstream and into the Reservoir, degrading water quality. This premise was the primary purpose for the Cottonwood Creek Stream Reclamation project between the Peoria Pond Wetland PRF (lat 39.604848, long -104.848810) and the Cottonwood Wetlands (lat 39.626343, long -104.849647). This reach of Cottonwood Creek exhibited substantial bank erosion at key gradient features as well as a deeply incised channel in the lower portions of the reach. Phase I of the reclamation project focused on the upper reach by widening the channel and increasing the meandering of the stream to reduce the velocity of flow and minimize erosion potential. Also, the main channel capacity was reduced to allow more frequent connection to the riparian zone and floodplain. Additionally, a mixture of geotextile fabrics and riparian vegetation were used to stabilize banks and to provide an infiltration zone during storm events. Phase II of the project relocated the lower portion of the stream to the historic channel, to provide a more suitable reach rather than the deeply incised channel that resulted when the stream was originally moved due historic farm practices or perhaps to roadway construction. The lower reach was similarly transformed to minimize velocity and to dissipate storm flows by creating a more expansive channel that allows for filtration and infiltration. The completion of Phase I and II effectively completed a "treatment train" of sediment and nutrient removal structures that have stabilized approximately three miles of Cottonwood Creek upstream of the Reservoir.

The Authority's data collection efforts have focused on evaluating the effectiveness of both wetland PRFs at either end of the stream reclamation reach. Base flow and storm flow nutrient concentrations, along with gaged flow data, provide nutrient loading information for inflows and outflow for each wetland PRF. The relative differences between the inflow and outflow data quantify the effectiveness of each PRF and reducing nutrient loads and flow-weighted concentrations. This effectiveness largely depends on the system's ability to capture the particulate fraction and to allow the transformation (decomposition) to a more soluble form that can be incorporated into wetland vegetation. Additionally, the hydrological retention and the ability of each system to allow overbank infiltration increase the phosphorus removal potential. However, as with most constructed wetland systems, the PRF's ability to capture phosphorus is not limitless. Once the storage and transformation capacity is reached, excess nutrients leave the wetland through surface and subsurface outflows (Mitsch and Gosselink, 2000), decreasing the effectiveness of the PRF. Therefore, periodic maintenance and sediment removal are key components to the success of nutrient removal in the PRFs.

While the Authority has not specifically developed a monitoring program for the Cottonwood Creek Stream Reclamation project, the data currently being collected at existing PRFs may provide some insight into the effectiveness of stream reclamation and its ability to reduce phosphorus loads. Sites CT-P2 and CT-1 essentially provide an upstream – downstream monitoring location for the reclamation project. The phosphorus loads may be more relevant for evaluating the effectiveness of this reclamation project because there is also a point source to Cottonwood Creek within the reclamation reach. The Arapahoe County Water and Wastewater Authority (ACWWA) typically discharge approximately 190 lbs per year to Lone Tree Creek, which is a tributary to Cottonwood Creek. The Lone Tree confluence is approximately one mile downstream of Site CT-P2, at the transition between Phase I and Phase II reclamation projects.

The historical monitoring data show that the stream reclamation reach is a gaining stream in both terms of annual flow and annual phosphorus load, albeit not surprising given the inputs from ACWWA. Site CT-1 typically shows about 1.9 times the amount of flow (i.e., 190 percent) passing by the gage as compared to Site CT-P2, and approximately 2.6 times the annual phosphorus load (i.e., 260 percent). The additional flow can be largely attributed to the discharge volume associated with ACWWA. Using ACWWA's reported annual total phosphorus load (CCBWQA Annual Reports), a rough approximation of the associated discharge was determined by assuming a flow-weighted discharge concentration based on Regulation #72 discharge limits pertinent to each year. The annual discharge volume for ACWWA was added to the annual flow volume at Site CT-P2, and compared to the flows at Site CT-1 for the period of 2003 to 2007 (Table 1). The period of record was limited to 2003 – 2007, since 2002 represented a partial monitoring year for Site CT-P2 (completion date June 2002) and Phase II construction was completed in May 2008. The additional flow from ACWWA accounts for some of the differences in flow, although there appears to be other contributions such as alluvial flow. Notably, when Phase II construction restored Cottonwood Creek to its historic alignment, there was sufficient alluvial flow remaining in the old channel, such that the lower portion of the old channel (e.g., downstream of the shooting range) could not be reclaimed. Therefore, the old channel was reconnected to the new Cottonwood Creek channel, immediately upstream of Site CT-1, to provide a pathway for the alluvial flows to reenter the system.

Table 4. Measured annual flow for monitoring sites on Cottonwood Creek and the estimated annual discharge for ACWWA.

Year	CT-P2 Flow (af/yr)	Estimated ACWWA Flow (af/yr)	CT-1 Flow (af/yr)	Relative Difference CT-1 minus (CT-P2 + ACWWA) (af/yr)
1997	--	707	1,858	--
1998	--	710	2,632	--
1999	--	783	2,924	--
2000	--	783	2,092	--
2001	--	949	2,743	--
2002	448[a]	625[a]	1,934	--
2003	2,096	971	2,589	-478
2004	2,450	1,088	3,874	336
2005	1,811	787	3,899	1,301
2006	1,448	978	4,110	1,684
2007	2,055	1,758	3,814	1
2008	927	1,133	1,818	-242
2009	2,242	2,957	3,887	-1,312
[a] Partial year data				

Following the same logic pathway of adding the ACWWA load to the Site CT-P2 load and comparing the sum with Site CT-1 data, approximately 50 percent of the load remains unaccounted for by the mass balance approach for the period of 2003 to 2007 (Table 2). Understandably, when additional flow enters the system, there will likely be an additional phosphorus content associated with the flow. However, depending upon the source of flow the phosphorus content can be highly variable. For example, if the additional flow is due to alluvial contributions, the phosphorus content is expected to be fairly consistent and mainly comprised of dissolved fractions; however, if the additional flow is due to storm events, then the phosphorus content will likely be quite variable and mainly comprised of particulate fractions.

Prior to 2008, there is no consistent pattern in the way the relative differences in flow track with the relative differences in loads. For example, in 2003 there is a negative flow difference indicating there was less flow at the downstream segment as compared to the upstream segment, although the relative difference in phosphorus load was positive. Regardless of these inconsistencies, the phosphorus load at Site CT-2 has always been considerably greater at the downstream segment, which indicates there is an additional source of phosphorus, above and beyond what is likely attributed by the additional flow. The additional source of phosphorus was likely attributed to the degrading streambank conditions and soil-bound phosphorus inputs along Cottonwood Creek.

Following completion of Phase II in 2008, the data show a net loss of approximately 18 percent in flow and 15 percent in total phosphorus loads, when the additions from ACWWA are accounted for at Site CT-1. This consistent decrease in both flow and load at Site CT-1 indicates the stream reclamation – stabilization project has had a net benefit within this reach. While the patterns in flow and load are encouraging during the past few years, additional years of monitoring should provide a more long-term estimate of the net benefit of stream reclamation on phosphorus load reduction.

Table 5. Measured annual total phosphorus loads for monitoring sites on Cottonwood Creek, and ACWWA's total phosphorus loads to Lone Tree Creek.

Year	CT-P2 Load (lbs/yr)	ACWWA Load (lbs/yr)	CT-1 Load (lbs/yr)	Relative Difference CT-1 minus (CT-P2 + ACWWA)
1997	--	250	2,360	--
1998	--	193	1,556	--
1999	--	213[a]	1,141	--
2000	--	213	1,618	--
2001	--	129	1,181	--
2002	88[b]	85[b]	637	--
2003	621	132	1,355	602
2004	895	148	2,022	979
2005	635	107	1,574	832
2006	533	133	1,923	1,257
2007	649	239	1,683	795
2008	212	154	299	-67
2009	509	402	804	-107

[a] Estimated value
[b] Partial year data

The initial benefit of stream reclamation – stabilization, is further illustrated by the flow-weighted total phosphorus concentrations measured at sites CT-P2 and CT-1. As previously discussed, the stream reach between these sites show a substantial gain in phosphorus, both in terms of total load and flow-weighted concentration (Table 3). However, following completion of Phase II, the flow-weighted phosphorus concentration showed a reduction at the downstream segment. From 2003 to 2007, the typical flow-weighted total phosphorus concentration at Site CT-1 was 172 µg/L, and is approximately 40 percent greater than the upstream value. Since completion of the reclamation project, the typical flow-weighted concentration has been approximately 68 µg/L, and represents roughly a 20 percent decrease from the upstream site. Notably, the difference between periods of record is also substantial (e.g., 2003-2007, 172 µg/L compared with 2008-2009, 68 µg/L). However, this trend is also apparent at Site CT-P1 which is the furthest upstream monitoring location on Cottonwood Creek. This pattern indicates that the overall phosphorus content in Cottonwood Creek has diminished in the past few years, although the reason for the substantial decline is not fully understood.

Given the infancy of the stream reclamation project, these past few years of monitoring data are encouraging and indicate that phosphorus reduction is a benefit of stream reclamation – streambank stabilization. By reducing the velocity and widening the wetted width of the channel, the stream reclamation project appears to have facilitated the infiltration and or evaporation of flows along this reach. In addition, the total phosphorus content within the flow has been greatly reduced. There are likely multiple mechanisms behind the phosphorus reduction, with the primary mechanism being control of streambank – soil erosion. Other mechanisms include the filtration – sedimentation of soil bound phosphorus by vegetation which is also facilitated by reduced flow velocities, as well as the vegetative uptake of dissolved phosphorus. Based on these total phosphorus results, other phosphorus fractions including total nitrogen and total suspended solids are being examined to determine whether similar patterns exist.

Table 6. Flow-weighted total phosphorus and total nitrogen concentrations for sites CT-P2 and CT-1.

Year	Total Phosphorus		Total Nitrogen	
	CT-P2 (µg/L)	CT-1 (µg/L)	CT-P2 (mg/L)	CT-1 (mg/L)
1997	--	467	--	--
1998	--	217	--	--
1999	--	143	--	1.68
2000	--	284	--	2.10
2001	--	158	--	2.33
2002	72	121	1.39	2.70
2003	109	192	1.35	1.94
2004	134	192	1.47	3.24
2005	129	148	1.45	3.13
2006	135	172	1.45	2.60
2007	116	162	1.36	2.55
2008	84	60	1.39	2.38
2009	83	76	1.28	1.50

Preliminary results for total nitrogen are less insightful regarding potential water quality benefits of the stream reclamation – stabilization project, albeit not unexpected. Total nitrogen and its various fractions do not exhibit the same affinity to bind to soil particles, like phosphorus. Thus, the soil erosion – sedimentation mechanisms are not effective. Furthermore, the role of the microbial community in the nitrification – denitrification process can greatly affect the amount of nitrogen in the system, thus it is very difficult to implement water quality management controls that reduce nitrogen.

The flow-weighted total nitrogen concentration has been remarkably consistent in flows that exit the Peoria Pond Wetland PRF, although the concentration increases considerably between sites CT-P2 and CT-1. The ACWWA discharge is the obvious source for the additional nitrogen, but the Authority currently does not have that information to determine the relative contributions. Nonetheless, in 2009, the flow-weighted total nitrogen value at Site CT-1 did show only a 17 percent increase over the upstream concentration which is considerably less than the typical 90 percent increase observed in previous years. This reduction may be associated with new vegetative growth along this reach, but any benefit is too early to confirm. The future dissolved phosphorus analyses will also be used to determine the relative contributions of particulate versus dissolved fractions with respect to the total phosphorus content. These analyses and future monitoring data may provide insight into which mechanism: control of soil erosion, capturing of the particulate fraction, or dissolved fraction uptake by plants, plays a greater role in the reduction of phosphorus in Cottonwood Creek.

3.4. Using the Watershed Model to Evaluate Stream Reclamation.

From mid-2006 through August of 2008, the Authority redeveloped the Watershed Model to calculate total phosphorus loads and water yield from the watershed into the Reservoir. The Watershed Model was the results of a collaborative effort between several Authority consultants and the Division, who reviewed and commented throughout the process. The Division expressed support for the model in a memorandum on July 2, 2007[19]. The scientific basis and the results of the calibration efforts are described in detail in the model documentation[20], which compares the model predictions for an eight-year period to the monitoring results presented in the Authority's annual monitoring report to the Commission.

As part of the prehearing statements for the March 2009 standards hearing before the Commission, the Authority submitted a report[21] summarizing investigation into several watershed management scenarios using the new watershed model. The purpose of the scenarios was to identify likely watershed management strategies to reduce phosphorus loads and concentrations discharged to Cherry Creek Reservoir to control chlorophyll *a*.

Two scenarios were investigated that included improvements to BMPs distributed throughout the watershed, one requiring enhanced BMPs for new development and one requiring retrofit of existing detention ponds to improve performance. Both scenarios were found to result in long-term reduction in phosphorus loads and concentrations that would benefit the water quality of the Reservoir. These results support the approach that watershed management strategies, such as stream reclamation, can provide water quality benefits at the Reservoir.

What was missing from the management scenario models was the implementation of stream reclamation projects, primarily within Cherry Creek from the Park upstream to the Hess Road in Douglas County. Modeling of stream reclamation was not included at the time because of the several projects were in progress at various locations within Cherry Creek and necessary details were not available. Several projects have been constructed since the 2008 watershed modeling efforts with several more in progress. Based on the 5-year CIP projections (Appendix A) most of Cherry Creek will have been reclaimed in the near future such that the watershed model can be updated to include the projected benefits of stream reclamation.

3.5. Hydraulic Analysis of Cottonwood Creek Reclamation Design.

The success of the Cottonwood Creek Reclamation in Cherry Creek State Park in reducing phosphorus loads and concentrations is supported by monitoring data (see Section 3.3 above). The success of the project is also demonstrated by the public and the Parks support for the wildlife enhancements created by the design approach. As the result, the Cottonwood Creek project has become an Authority benchmark for comparing other stream reclamation projects

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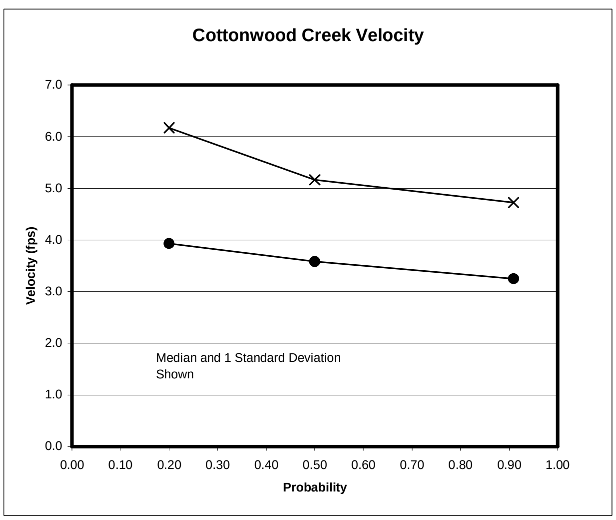
[19] WQCD July 2, 2007. *Water Quality modeling in Support of the Cherry Creek Reservoir Control Regulation.*
[20] Brown and Caldwell February 2009. *Cherry Creek Basin Watershed Phosphorus Model Documentation*.
[21] CCBWQA January 4, 2009. *Summary of Activities to Comply with Phased TMAL Requirements.*

that are tributary to Cherry Creek. Since Cherry Creek is a much larger stream system, the Authority investigated the Cherry Creek Stream Reclamation at Eco Park preliminary design as the basis for comparing stream reclamation projects within Cherry Creek itself. Initial results are encouraging and as more information is gathered, the Eco-Park project may become the baseline comparison for other Cherry Creek stream reclamation projects.

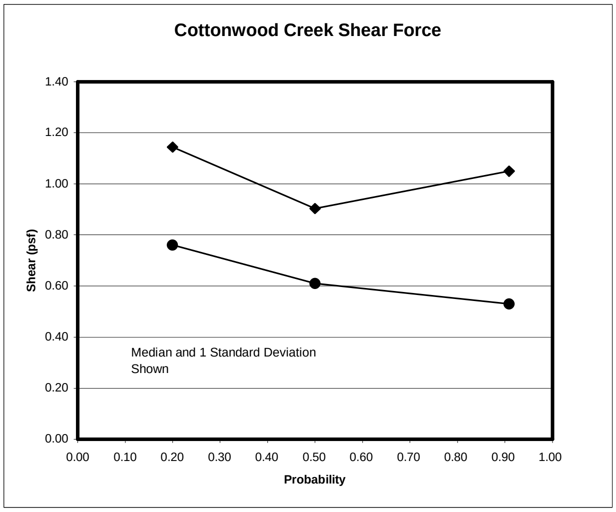
As such, the Authority developed a methodology for comparing tributary stream projects using hydraulic parameters for Cottonwood Creek described below. These hydraulic parameters are considered direct measures of water quality benefits:

1. A statistical analysis of velocity (fps), shear (lbs/sf), and power (lbs-f/s) was performed using the HECRAS backwater analysis prepared by the design engineer for the Cottonwood Creek project. Median and standard deviations were calculated for the mean-annual, 2- and, 5-year flood events. Graphics were prepared for each parameter and plotted versus flood probability and fitted with linear regression lines. Samples of the graphics are provided below along with a discussion of water quality benefits. For comparing projects, similar calculations would be made for velocity, shear, and stream power and plotted on the curves below. An assessment of the potential water quality benefits can then be made by evaluating where the mean and standard deviation values compare to Cottonwood Creek.

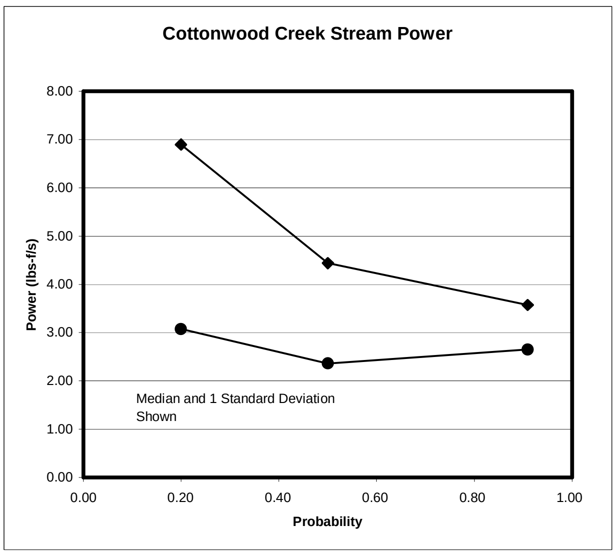
    a. The slower the velocity the greater the filtration time and the lower the erosive forces, which improves water quality.



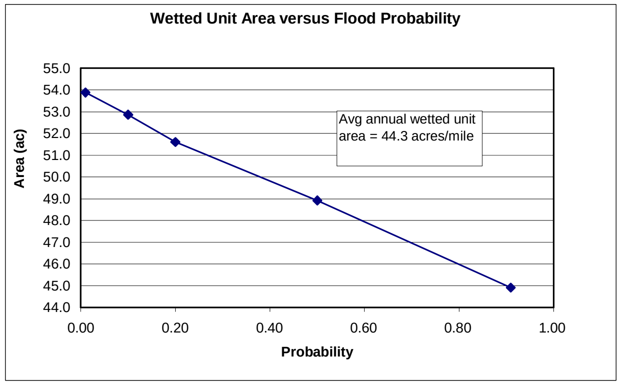
    b. The lower the shear force the less the sediment transport capacity, which reduces transport of pollutant loads.



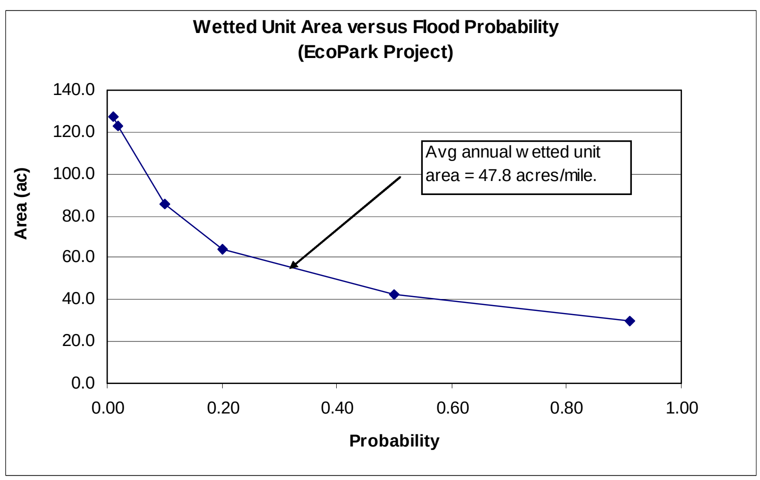
c. A channel is said to be "in regime" when the stream power is at its minimum. A channel in regime is considered stable, therefore, the lower the value the greater the water quality benefits.



2. Channel Wetted Area. The frequency of connection of channel flows to the riparian and floodplain area can be measured by the average annual wetted area, per unit length of channel. The higher the unit value the greater the water quality benefits. The parameter is determined by calculating the wetted area per mile of stream for multiple flood frequencies, such as the mean annual through the 100-year flood frequency events. These values are then plotted versus flood probability (see sample below). The area under the curve represents the average annual wetted area per stream mile. For comparing projects, similar calculations would be made and plotted on the curve below to calculate the average annual value and compare it to Cottonwood Creek. Also, areas that plot below the curve for any flood event suggest that the project may not provide similar water quality benefits as does Cottonwood Creek Reclamation.



3. Frequency of Bank Full Flow. The more frequent the channel flow overtops its banks and connects to the floodplain, the greater the potential for water quality benefits. Incised channels, like Cottonwood Creek before reclamation, rarely came out of its banks and connected to the floodplain. Now Cottonwood Creek is connected to the floodplain on a much more frequent basis, as illustrated by the figure above. The linear nature of the curve above shows that connection to the floodplain occurs gradually throughout the flood probability range without rapid changes in area for increasing flood event probability. By comparison, the figure below prepared based on preliminary design of the Eco Park reach of Cherry Creek shows a more rapid change in area starting around the 5-year event, which is likely the bank full flow frequency.



Another way to evaluate bank full flow is to inspect the graphical output for each cross section in HECRAS to get an idea at which frequency the channel becomes connected to the floodplain.

The hydraulic analysis for design of Cottonwood Creek prepared by the design engineer primarily focused on flow velocities during minor storm events since the design approach allowed connection to the floodplain on a very frequent basis (i.e.: less than the 2-year event). Since there were no regulatory constraints on the 100-year floodplain in Cherry

Creek State Park, the hydraulic analysis did not focus on precise delineation of rare flood events. Therefore, it is likely that the floodplain area for rare events is understated as some cross sections were truncated at the outer limits. To improve the hydraulic analysis for future projects, the HECRAS analysis should also consider water quality benefits when defining backwater cross sections.

Also, the Cottonwood Creek project had essentially no limitations on how wide the floodplain could be and, therefore connection to the floodplain occurs gradually throughout the flood frequency range. The Cherry Creek at Eco Park project does have floodplain width restrictions, which are likely reflected in the shape of the wetted area curve above.

4. Considerations for Prioritizing Projects

This chapter summarizes the current status of calculation procedures to evaluate the benefits of Stream Reclamation projects in the Cherry Creek watershed such that two or more projects can be compared or even prioritized for the Authority's annual CIP list. The procedures were developed during a series of TAC committee meetings beginning in 2009[22]. The guiding principals behind the evaluation procedure are:

- ✓ The primary basis for evaluating stream reclamation should be project cost weighed against the amount of phosphorus (P) immobilized by the project. Whereas the Authority's water quality focus is on nutrients and other pollutants, phosphorus is an effective measure of water quality.

- ✓ Benefit evaluation will require both *quantitative* and *qualitative* assessments due to the wide range of evaluation criteria developed by the committee some of which are not readily quantified.

- ✓ The TAC considered all reasonable evaluation criteria and believes the 12-criteria presented in Appendix D are reasonably complete and recommends these criteria be used to evaluate a proposed project's water quality benefits. Some of these criteria can be used to adjust cost per pound upward or downward, while other criteria will require a qualitative assessment. The discussion presented in Appendix E categorizes each criterion believed to be quantitative or qualitative measures, unnecessary criteria because it is accounted for elsewhere, is insignificant, or is part of a site-specific analysis performed by project proponent.

- ✓ Leveraging Authority funds by partnering with other agencies to construct stream reclamation (and other PRFs) is of primary importance to the evaluation process.

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[22] TAC committee meetings were held on December 3, 2009, March 30, 2010, Aril 30, 2010, June 29, 2010, and August 30, 2010.

4.1. Reduction of Total Phosphorus

Phosphorus and nitrogen are frequently limiting factors for algal growth in water bodies which has a direct impact on beneficial uses of Cherry Creek Reservoir. The Clean Lakes Study for Cherry Creek Reservoir[23] concluded that both nitrogen and phosphorus limit algal growth at different times, but that only phosphorus should be targeted for control due to feasibility and effectiveness. More recent studies conducted for the Authority[24] have also demonstrated that Cherry Creek Reservoir is more often phosphorus limited, but can be co-limited and even nitrogen limited at times and, therefore, TP is the important variable that controls algal growth in the Reservoir[25].

Phosphorus comes in many forms but the dissolved or soluble reactive form is the most readily available for plant growth. However, many forms of phosphorus can become available to vegetation through chemical, biological, and physical processes making most forms of phosphorus important to water quality. In a disturbed watershed, particulate phosphorus is the dominant form resulting from land disturbances. In a stable watershed, such as one controlled by best management practices, dissolved phosphorus becomes the dominant form, even more so in effluent dominated stream systems. Because of the variability of dissolved and particulate phosphorus fractions, total phosphorus is believed to be a more stable parameter to evaluate stream reclamation and other PRFs.

The Authority has utilized reductions in total phosphorus as the primary metric for evaluating stream reclamation and PRFs, since a total maximum annual load (TMAL) for total phosphorus was established in 1984. Recent changes (2010) to the Reservoir standard and Control Regulation No. 72 eliminated the TMAL prompting the Authority to consider a broader range of nutrients and other pollutants when evaluating water quality in the watershed, including all forms of phosphorus, nitrogen, and other chemical, and biological constituents. However, for consistency, repeatability, and practicality, immobilization of total phosphorus continues to be the recommended primary metric for evaluating stream reclamation and other PRFs. The Authority is investigating the role played by the dissolved form of phosphorus and other pollutants that may also be used for evaluation in the future.

4.2. Basic Assumptions

a. The “approximate method” would be used by the Authority to conservatively evaluate water quality benefits. However, a project proponent can submit a “site specific analysis” to justify higher sediment and phosphorus loads – or other analytical variables - that exist or may exist in the future if the project is not implemented. It is anticipated that a site-specific analysis would show lower costs per pound of P.

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[23] Denver Regional Council of Governments 1984. *Cherry Creek Reservoir Clean Lakes Study.*
[24] Freshwater Research September 28, 2008. *Cherry Creek Reservoir Model and Proposed Chlorophyll Standard.*
[25] Ibid, p20.

b. Cottonwood Creek costs and benefits can be used as the “benchmark” for comparison with channels already degraded and McMurdo Gulch can be used as the benchmark for comparison of channels that are just showing signs of instability.

c. The Authority has used the following parameter values when evaluating stream reclamation benefits. These parameter values are recommended to be used when evaluating all stream reclamation projects so that results can be compared to historic projects. The parameter values can be adjusted based on project specific information, but the results should also be compared to the results using the baseline parameter values to maintain historic consistency.

   a. “Stream erosion rate”. Rate of 77-cy sediment/mile/year and a sediment density of 90-pcf.

   b. “Sediment phosphorus concentration”: 1.0 –lbs total P/ton of sediment.

   c. “Reclamation Efficiency”: 90% in reducing phosphorus loads

   d. a “P reduction benefit”. In lieu of specific information for items a, b, and c, the approximate method assumes that stream reclamation will reduce phosphorus loads by 90 lbs/mile/year.

   e. “Discount rate” for analysis. The Authority currently uses a 35-year time frame with a discount rate of 7% for calculating annual costs.

   f. a “Project life” which is a reasonable time frame for the project life, such as 35-years for consistency with the discount rate.

   g. a “Threshold cost” level for funding. Currently, the Authority uses $600 per pound per year as the maximum level for participating in a co-funded project.

   h. “baseline channel instability time”, which is the time it would take to first identify during the planning process a channel showing signs of instability to actual implementation of the reclamation measures.

4.3. Benchmark for Illustrations

To see how the proposed economic rating factors might work, the Cottonwood Creek Stream Reclamation Phase I and II project and the McMurdo Gulch projects are used for illustration purposes based on the following variables.

4.4. Example Economic Comparison

Baseline Comparison. Using two fictitious projects, (see Table 8A and 8B), an example economic comparison has been prepared for illustrative purposes. Project A is an example of a stream reach that has been seriously degraded while Project B is an example of a stream reach that just beginning to see substantive urbanization in the watershed. The information is for the "baseline condition" which means that the costs have not been adjusted and the water quality benefits are based on baseline conditions described above. The bold numbers are the input values whereas the remaining are calculations or other fixed baseline parameters.

Project A is clearly more expensive per pound of P ($1,343 versus $399) which is expected given the conditions. However, to prioritize the projects, the approach would be to assume both projects are "equal" at this point because:

- Stream Reclamation projects are recognized to be beneficial to water quality in the Reservoir, Cherry Creek and the watershed, as documented by this Stream Reclamation Report.

- Both projects have been previously evaluated at the conceptual level and have both been put on the "master list of PRFs". Therefore, these two projects are already considered good candidates for the Authority's CIP and it is just a case of prioritization.

Therefore, the prioritization process would evaluate increments in costs (quantitative) plus other qualitative criteria discussed above.

Table 8A- BASELINE COMPARISON - Project A - Baseline Condition

Item	Project A
Project Length (mi) =	**1.30**
Project Capital Costs =	**$ 1,950,000**
Project Cost per mile =	$ 1,500,000
Stream Reclamation Water Quality Benefits (lbs/mi/yr) =	**90**
Project Annual Water Quality Benefits (lbs/yr) =	117
Capital Recovery Factor (7% 35-years) =	**0.07723**
Annualized Capital Cost =	$ 150,600
Annual O&M Cost =	$ 6,500
Project Annual Unit Cost ($/lb) =	$ 1,343
Baseline Project Life (yr) =	**35**
Project Life Time Costs =	$ 2,177,500
Project Life Time Water Quality Benefits (lb) =	4095
Project Life Time Unit Costs ($/lb) =	$ 532

Table 8B- BASELINE COMPARISON - Project B- Baseline Conditions

Item	Project B
Project Length (mi) =	**1.30**
Project Capital Costs =	**$ 520,000**
Project Cost per mile =	$ 400,000
Stream Reclamation Water Quality Benefits (lbs/mi/yr) =	**90**
Project Annual Water Quality Benefits (lbs/yr) =	117
Capital Recovery Factor (7% 35-years) =	**0.07723**
Annualized Capital Cost =	$ 40,200
Annual O&M Cost =	$ 6,500
Project Annual Unit Cost ($/lb) =	$ 399
Baseline Project Life (yr) =	**35**
Project Life Time Costs =	$ 747,500
Project Life Time Water Quality Benefits (lb) =	4095
Project Life Time Unit Costs ($/lb) =	$ 183

4.5. Incremental Quantitative Analysis of Water Quality Benefits.

For the quantitative criteria, the process would involve three steps.

1. First, Table 8 above would be adjusted for the criteria as described above. For example, Criteria 1 allows costs adjustment for watershed planning costs to be recovered. For project A, the planning costs were $150,000, which is reflected in the table below.

2. Second, the changes in Project Annual Cost and Project Life Time Costs would be determined (see tables 9A and 9B below). For project A, the reductions in annual and life time costs are $99 and $37, respectively. Project B changes are 67 and 24, respectively.

Table 9A - Criteria 1 - Watershed Planning Credit - Project A

Item	Project A	Changes
Project Length (mi) =	**1.30**	$ -
Project Capital Costs =	**$ 1,800,000**	$ 150,000
Project Cost per mile =	$ 1,385,000	$ 115,000
Stream Reclamation Water Quality Benefits (lbs/mi/yr) =	**90**	$ -
Project Annual Water Quality Benefits (lbs/yr) =	117	$ -
Capital Recovery Factor (7% 35-years) =	**0.07723**	$ -
Annualized Capital Cost =	$ 139,000	$ 11,600
Annual O&M Cost =	$ 6,500	$ -
Project Annual Unit Cost ($/lb) =	$ 1,244	$ 99
Baseline Project Life (yr) =	**35**	$ -
Project Life Time Costs =	$ 2,027,500	$ 150,000
Project Life Time Water Quality Benefits (lb) =	4095	$ -
Project Life Time Unit Costs ($/lb) =	$ 495	$ 37

Table 9B - Criteria 1 - Watershed Planning Credit - Project B

Item	Project B	Changes
Project Length (mi) =	**1.30**	$ -
Project Capital Costs =	**$ 420,000**	$ 100,000
Project Cost per mile =	$ 323,000	$ 77,000
Stream Reclamation Water Quality Benefits (lbs/mi/yr) =	**90**	$ -
Project Annual Water Quality Benefits (lbs/yr) =	117	$ -
Capital Recovery Factor (7% 35-years) =	**0.07723**	$ -
Annualized Capital Cost =	$ 32,400	$ 7,800
Annual O&M Cost =	$ 6,500	$ -
Project Annual Unit Cost ($/lb) =	$ 332	$ 67
Baseline Project Life (yr) =	**35**	$ -
Project Life Time Costs =	$ 647,500	$ 100,000
Project Life Time Water Quality Benefits (lb) =	4095	$ -
Project Life Time Unit Costs ($/lb) =	$ 158	$ 24

3. The changes in annual and life time costs would be summarized in a separate table for each of the quantitative criteria. Table 10 was created to summarize the process and could be used during the annual CIP development to compare all stream reclamation projects. Note that this table is set up so that the "values" can

be adjusted and see the affects of the changes. Also the "cost adjustments" are *decreases* in annual and lift time costs.

Table 10 - Summary of Quantitative Evaluation Criteria

Project	Criteria	Value	Unit	Cost Adjustments	
				Annual $/lb	Life Time $/lb
Project A (degraded)	1 - Credit for Watershed Planning	150000	$	99	37
	2 - Credit for Proactive Project	0	years	0	0
	5 - Credit for Project Partners	200000	$	132	49
	Total Adjustments			231	85
Project B (proactive)	1 - Credit for Watershed Planning	100000	$	67	24
	2 - Credit for Proactive Project	10	Years	0	28
	5 - Credit for Project Partners	200000	$	132	49
	Total Adjustments			199	101

Examining Table 10 we see that, based on annual costs, Project A (degraded channel) rated higher for these three criteria, while Project B (proactive approach) rated higher based on life time costs. Therefore, either project could be considered a higher priority, depending on whether annual or life time costs receive greater weighting which can be addressed during the qualitative analysis below.

4.6. Qualitative Impact Analysis.

The next step in the prioritization process is to evaluate each project for the qualitative criteria. Of the 12 criteria suggested, numbers 10, 11, and 12 have been suggested as qualitative measures. Rather than develop fictitious projects, Cherry Creek at PJCOS will be considered Project A (degraded channel) and McMurdo Gulch will be considered Project B.

Presented in Table 11 below is an example of how the qualitative criteria might be applied to the two projects and includes assignment of "points" for each criterion. Points are numbers from 1 to 5 with 5 being the highest rating. The intention would be for TAC members and/or project proponents to provide their opinion on the assessment and assigned points which would then be discussed during a TAC prioritization meeting.

Discussion: The ecological benefits criterion appears to be unclear from the example since both projects, regardless of the current channel state, can be rated high for reasons provided. Perhaps the opinions of the TAC members might make this criterion more meaningful than suggested by this example or perhaps this criterion is unnecessary.

The watershed growth criterion is clearer in this example and would suggest that Project B be rated higher than Project A due to potential watershed growth at this time.

The offsite impacts example also suggest that the evaluation criterion is reasonable, but is still more subjective than the watershed growth criterion.

Table 11 - Summary of Qualitative Evaluation Criteria

Project	Criteria	Assessment	Assigned Points
Cherry Creek at PJOS	10 - Ecological Impacts	The channel has degraded to the point where habitat and vegetation are almost non existent which is evidence of poor water quality. Therefore, protecting this reach will achieve immediate ecological and water quality benefits.	5
	11 - Watershed Growth	Whereas Cherry Creek has seen rapid watershed growth, the continued growth upstream is already well past any "threshold" imperviousness such that impacts from continued growth may not have catastrophic results typical in headwater streams.	2
	12 - Offsite Impacts	Completing this section of Cherry Creek might stabilize the channel for a longer distance, by completing the segment. Whereas the impact at Arapahoe Road is uncertain, stabilization of the project reach may actually reduce sediment loads at Arapahoe Road and change the long term sediment dynamics reducing impacts on Valley Country Club. The rating reflects the uncertainty of the impacts due, in part, to lack of sediment analysis for the project	2
	Total		**9**
McMurdo Gulch	10 - Ecological Impacts	The channel is just beginning to erode the bed/banks, steepening the slope and reducing habitat and vegetation. Therefore, protecting this reach will prevent further ecological damage and preserve water quality.	5
	11 - Watershed Growth	McMurdo Gulch is experiencing rapid watershed growth and is likely at or near a threshold imperviousness meaning degradation will likely occur soon, resulting in significant channel degradation in the near future.	5
	12 - Offsite Impacts	The reach downstream of McMurdo Gulch is mostly stabilized by development such that McMurdo stabilization will reduce the potential for future sediment loads. The rating reflects that downstream impacts are expected to improve, not worsen	4
	Total		**14**

5. Conclusions

This report summarizes the TAC knowledge and understanding of the water quality benefits associated with stabilization and reclamation of streams systems within the Cherry Creek watershed. Conclusions from this investigation are provided below as answers to the questions presented in the introduction.

Stream reclamation is beneficial to water quality in the stream and in the Reservoir. Stream reclamation reduces sediment and other pollutant loads and concentrations, including phosphorus and nitrogen. Load and concentration reductions during base and storm flows conditions can occur by reducing flow velocities, providing greater areas for filtration and infiltration of stormwater and, to some extent, increases dissolved oxygen content. This finding is also supported by the several years of Authority water quality data collected to evaluate PRFs.

A more detailed analysis of the Authority's data for Cottonwood Creek further shows that stream reclamation projects can reduce phosphorus loads and concentrations to levels below the Authority's target flow-weighted concentration of 0.20 mg/l. The Cottonwood Creek data also suggest that stream reclamation may also reduce nitrogen loads and concentrations.

A literature search shows that stream reclamation is one of the more extensive practices used to improve water quality in streams and water bodies in total maximum daily load (TMDL) implementation plans. However, more monitoring data is needed to evaluate water quality benefits for stream reclamation projects.

This report documents two methodologies for evaluating stream reclamation projects, one based primarily on quantifying economic factors and the second based solely on hydraulic characteristics of the stream. Both methodologies are useful when evaluating a proposed project or for comparing project water quality benefits.

Comparison of the Authority's methodology (i.e.: cost-per-pound) for evaluating stream reclamation to agency methodologies in other parts of the US suggests that the Authority's methodology is consistent with and comparable to results obtained by others. By evaluating stream reclamation projects, as well as other PRFs, on a cost-per-pound basis, the Authority can select the most cost effective projects for implementation and can clearly show cost reduction benefits associated stabilizing a stream before the conditions get worse, as demonstrated by the McMurdo Gulch project.

Using hydraulic characteristics of the proposed stream reclamation design and comparing the results to the Cottonwood Creek Stream Reclamation within Cherry Creek State Park provides and a relatively simple way of comparing water quality benefits of stream reclamation projects. The methodology can be improved by developing more robust procedures.

Stream stabilization and reclamation were recognized in the early watershed plans as a watershed control method for Cherry Creek Basin to control phosphorus entering the Reservoir. Stream reclamation has been used extensively through out the country to protect and enhance water quality in stream systems and water bodies and is widely accepted best management practice to control pollutant loads. Stream reclamation has been and should continue to be a priority PRF for the Authority in the future.

6. Recommendations

6.1. Reevaluate Monitoring Program

The Authority is required by Control Regulation No. 72 to monitor the effectiveness of pollutant reduction measures and has therefore collected extensive chemical data to show water quality benefits of stream reclamation and other PRFs. The TAC recommends that the monitoring program be reevaluated and consider ecological assessments, not as a replacement to chemical monitoring, but as a way to improve our understanding of water quality benefits from stream reclamation and to include other, less direct measures of water quality.

> *"The restoration evaluation should usually focus on aquatic organisms and instream conditions as the "judge and jury" for evaluation restoration success….biological criteria detected an impairment in 49.8 percent of the situations where no impairment was evident with chemical criteria alone." (FISRWG 2000)*

6.2. Refine Phosphorus Reduction Calculation Procedure

The TAC recommends that the current procedures for calculating reduction in phosphorus loads be refined to incorporate more robust algorithms for a very complex process, particularly related to riparian and floodplain areas.

> *"While the importance of vegetation in streambank stabilization is widely acknowledged, the impacts are complex and have yet to be fully quantified." "Because riparian vegetation has a significant impact on stream stability and morphology, it has become an integral part of stream restoration designs*." (Center for TMDL and Watershed Studies)

6.3. Use Watershed Model to Estimate Benefits

The Authority developed a comprehensive watershed model that can predict long term trends in phosphorus loads into the Reservoir as part of the phased TMAL approach in the 2001 version of Control Regulation No. 72. The model can be used to estimate changes in phosphorus loads and flow-weighted concentrations for stream reclamation type projects, with some minor modifications to the algorithms, to help assess long-term water quality benefits particularly at the Reservoir. The TAC recommends further investigation into using the watershed model to evaluate stream reclamation, long-term benefits.

6.4. Refine Economic Evaluation Methodology

In the past, the Authority has evaluated PRFs, including stream reclamation, based primarily on cost-per-pound. Eleven additional evaluation criteria were developed by the TAC, both quantitative and qualitative as part of this process. The TAC recommends these criteria be refined and considered as a basis for prioritizing projects if required in the future.

6.5. Refine Hydraulic Evaluation Methodology

Further refine the methodology to compare water quality benefits of stream reclamation using the five channel hydraulic parameters presented in this report that are based on the design of Cottonwood Creek Stream Reclamation within Cherry Creek State Park.

APPENDIX A
2011 CIP Master List and 5-year CIP Program List

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

TABLE 1 - SUMMARY OF POTENTIAL POLLUTANT REDUCTION FACILITIES

REVISIONS FOR 2011 CIP

Date prepared: December 6, 2010

Color Code: Blue Project Completed Green: Planned for design/construction in 2011 See: "2011 CIP Notes" for changes to this Spreadsheet

Proj. Designation	Project Title	Status	Description	Design Basis			Projected Loads			Projected Treatment			Cost Estimate (1000$)								Unit Cost ($/pound)		Note
				Trib. Area	Rate	Volume	Rate	Total	Source	Removal	lbs Removed		Capital	Land Acquisition	Water Augment[8]	Capital Replace[9]	O&M	Annual Cost @ 7%	CCBWQA Share (%)	CCBWQA Share ($)	w/o cost sharing	w/cost sharing	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
CCR-1	Reservoir Destratification (mixing)	Officially start-up April 2008	Use inlake mixing to minimize algae blooms, therefore chlorophyll a	369 sq. miles	n/a	n/a	n/a	n/a	n/a		810	lbs/season	$ 968				28	$ 103	100%	$968	$ 127	$ 127	
CCB-1	CCSP Wetlands	Prelim design prepared in 2003 (Ref 1, 8)	Restore 60 Acres of wetlands in multiple phases	369 sq. miles	3.5 cfs avg daily flow	1415 af/210 days	0.35 mg/l	1050 lbs/(210-day season)	Base flow		600	lbs/season	$ 1,928	$ -	$ -	$ -	19	$ 168	100%	$1,928	$ 280	$ 280	18
CCB-5.1	Cherry Creek Sediment Pond at Arapahoe Road	Feasibility study completed December 2006 (Ref 9). Not feasible at that time	Design and construct sediment pond	369 sq. miles		3600 cy sed/yr	14.6 mg/kg	92 lbs P/yr	base flow		85	lbs/year	$ 2,355	$ 50	$ -	$ -	$ 90	$ 275	18%	$424	$ 3,237	$ 583	1, 19
CCB-5.2	Arapahoe/Douglas County Line Stream Stabilization	Project completed w/o Authority participation	Local stream stabilization (L = 2700 ft)				100 lbs/mile	51 lbs P/yr	Storm Flow	90%	46	lbs/year	$ 1,062	$ -	$ -	$ -	1	$ 83	0%	$0	$ 1,799	$ -	
CCB-5.3	Cottonwood Bridge Stream Stabilization	Project completed by Parker w/o Authority participation	Local stream stabilization (L = 2700 ft)				100 lbs/mile	51 lbs P/yr	Storm Flow	90%	46	lbs/year	$ 436	$ -	$ -	$ -	2	$ 36	0%	$0	$ 773	$ -	
CCB-5.4	Cherry Creek Stream Stabilization at Main street (Parker)	Conceptual design by UDFCD identified priority 1	Local stream stabilization (L = 4000 ft)				100 lbs/mile	75 lbs P/yr	Storm Flow	90%	68	lbs/year	$ 1,776	$ -	$ -	$ -	1	$ 138	11%	$200	$ 2,026	$ 228	2
CCB-5.5	Stroh Road Stream Stabilization	Project completed by Parker w/o Authority participation	Stream stabilization (L = 5000 ft)				100 lbs/mile	95 lbs P/yr	Storm Flow	90%	85	lbs/year	$ 218	$ -	$ -	$ -	1	$ 18	25%	$55	$ 209	$ 52	
CCB-5.6	Cherry Creek Stream Stabilization at Lincoln Avenue (Parker)	Conceptual design by UDFCD identified priority 3	Local stream stabilization (L = 2350 ft)				100 lbs/mile	45 lbs P/yr	Storm Flow	90%	40	lbs/year	$ 1,447	$ -	$ -	$ -	1	$ 112	21%	$304	$ 2,810	$ 590	2
CCB-5.7	Cherry Creek Stream Stabilization at Eco-Park (Arap County)	Authority partner in funding of design in 2010	Local stream stabilization (L = 6540 ft)				100 lbs/mile	123 lbs P/yr	Storm Flow	90%	110	lbs/year	$ 2,851	$ -	$ -	$ -	$ 1	$ 220	30%	$855	$ 2,004	$ 601	2
CCB-5.8	Cherry Creek Stream Reclamation U/S Arapahoe Rd (Aurora)	Conceptual design by UDFCD identified. CDOT considering bridge replacement	Local stream stabilization (L = 1675 ft)				100 lbs/mile	32 lbs P/yr	Storm Flow	90%	29	lbs/year	$ 518	$ -	$ -	$ -	1	$ 41	25%	$130	$ 1,410	$ 352	2
CCB-5.9	Cherry Creek Stream Stabilization at 12-Mile Park (CCSP)	Design started in 2010	Local stream stabilization (L = 3000 ft)				100 lbs/mile	57 lbs P/yr	Storm Flow	90%	51	lbs/year	$ 625	$ -	$ -	$ -	1	$ 49	100%	$625	$ 963	$ 963	2, 20
CCB-5.10	Cherry Creek Stream Stabilization at PJCOS (Vermillion Creek.)	Design completed by PJMD. Authority is funding partner in design	Local stream stabilization (L = 5100 ft)				100 lbs/mile	97 lbs P/yr	Storm Flow	90%	87	lbs/year	$ 3,730	$ -	$ -	$ -	$ 2	$ 289	18%	$671	$ 3,324	$ 598	
CCB-5.11	Cherry Creek Stream Stabilization at Norton Open Space	Conceptual design by UDFCD identified priority 3	Local stream stabilization (L = 2200 ft)				100 lbs/mile	41 lbs P/yr	Storm Flow	90%	38	lbs/year	$ 900	$ -	$ -	$ -	1	$ 70	28%	$252	$ 1,850	$ 518	2
CCB-5.12	Cherry Creek Stream Stabilization at Pine Lane	Project completed by Parker w/o Authority participation	Local stream stabilization (L = 1500 ft)				100 lbs/mile	28 lbs P/yr	Storm Flow	90%	26	lbs/year	$ 500	$ -	$ -	$ -	1	$ 40		$0	$ 1,519	$ -	
CCB-5.13	Cherry Creek Stream Stabilization at Shop Creek Trail	Preliminary design completed in 2010 (Ref 12).	Local Stream Stabilization (L = 2000 ft)				100 lbs/mile	38 lbs P/yr	Storm Flow	90%	34	lbs/year	$ 675	$ -	$ -	$ -	$ 1	$ 53	100%	$675	$ 1,558	$ 1,558	
CCB-5.14	Cherry Creek Stream Reclamation - Arapahoe Rd to Piney Creek	Conceptual design by UDFCD in Master Plan	Local stream stabilization (L = 5000 ft)				100 lbs/mile	95 lbs P/yr	Storm Flow	90%	85	lbs/year	$ 7,000	$ -	$ -	$ -	$ 1	$ 540	10%	$700	$ 6,353	$ 635	
CCB-5.15	Cherry Creek Stream Reclamation at Country Meadows	New project by Town of Parker and Douglas County	Local stream stabilization (L = 4000 ft)				100 lbs/mile	76 lbs P/yr	Storm Flow	90%	68	lbs/year	$ 1,100	$ -	$ -	$ -	$ 1	$ 86	20%	$220	$ 1,260	$ 252	
CCB-6.1	Piney Creek Stream Stabilization - Project 1	Authority funded $118,000 Arapahoe County in 2002.	Restore 5200 lf upstream of Parker Road	22.9 sq. miles	n/a	n/a	100 lbs/mile	100 lbs/year	Storm Flow	90%	90	lbs/year	$ 997	$ -	$ -	$ -	$ 10	$ 87	13%	$130	$ 969	$ 126	
CCB-6.2	Piney Creek Stream Stabilization - Project 2 U/S Buckley Rd	Project completed w/o Authority participation	Reclaim 1700 lf upstream of Buckley Road				100 lbs/mile	32	Storm Flow	90%	28.8	lbs/year	$ 998	$ -	$ -	$ -	1	$ 78	12%	$120	$ 2,703	$ 324	
CCB-7.1	McMurdo Gulch (Castle Rock)	Final design completed in 2010. Authority IGA provided $430,000 in 2010	Stream Reclamation (L = 15,000 lf)				100 lbs/mile	300	Storm Flow	90%	270	lbs/year	$ 1,562	$ -	$ -	$ -	5	$ 125	41%	$640	$ 464	$ 190	
CCB-8	Limestone Filter Enhancement	Specific project not identified	Construct limestone filter bed downstream of retention pond	640 acres	n/a	10.7 af/year/sq mile	427 lbs/sq mile	427 lbs/sq mile	Base and storm flow		85	lbs/year/mi^2	$ 943		$ -	$ 595	$ 1	$ 119	43%	$405	$ 1,398	$ 601	
CCB-11	Advanced Water Treatment Plant	Conceptual design prepared	Construct 2 MGD AWT plant on Cottonwood Creek to treat Cherry Creek and Cottonwood Creek flows.	3 cfs	2-MGD	2260 aft/year	0.21 mg/l average influent	0.03 mg/l effluent	Base flow and groundwater	90%	1096	lbs/year	$ 4,593	unknown	unknown		$ 69	$ 423	100%	$4,593	$ 386	$ 386	11
CCB-12	Bowtie Property PRF	Purchase completed 2003	Stabilize confluence (Ph I) and construct sediment pond (Ph 2)	22 sq. mi	2-year flood	300 af	500 mg/l P per ton of sed	85 ton sed w/85 lbs P	base flow and minor flood	70% pond 65% wetlands	235	lbs/year	$ 826	$ 300	$ 63	$ 1.8	$ 6	$ 95	100%	$826	$ 404	$ 404	2
CCB-12.1	Expanded Bowtie Project	No action to date	Constructed Wetlands u/s Bowtie Property in Cherry Creek	369 sq mi	3.5 cfs avg daily flow	1415 af/210 days	0.35 mg/l	1050 lbs/(210-day season)	Base flow	60%	150	lbs/season	$ 235	$ 200	$ 80	$ -	$ 7	$ 47	100%	$235	$ 311	$ 311	
CCB-13.1	Cottonwood\Peoria Wetlands Pond	Completed 2003. Restorative maintenance required in 2009	Joint funded project with UDFCD, GWV, Arapahoe County	8.3 sq. mi					base and flood flows		363	lbs/year	$ 1,636	$ -	$ -	$ -	$ 5	$ 131	12%	$196	$ 361	$ 43	2
CCB-13.2	Cottonwood Stream Reclamation	Phase I completed in 2004. Phase II completed June 2008 (Ref 2)	11,600 lf of stream reclamation from Peoria to Perimeter Rd. Pond	8.3 sq. mi					base and flood flows		730	lbs/year	$ 2,200	$ -	$ -	$ -	$ 55	$ 224	100%	$2,200	$ 307	$ 307	2
CCB-13.3	Cottonwood Creek Stream Stabilization at Easter Avenue	Authority contributed $338,000 for construction in 2010.	2,600 lf of stream reclamation from Easter Ave to Briarwood Ave				100 lbs/mile	50 lbs/yr	Storm Flow	90%	45	lbs/year	$ 1,350	$ -	$ -	$ -	$ 1	$ 105	25%	$338	$ 2,332	$ 584	2
CCB-13.4	Peoria Trib B/Airport East and West Pond (Outfall C-1)	Cottonwood Creek Master Planned Improvements	Retrofit existing detention ponds for EURV	0.35- sq mi			400 lbs/mi2	140 lbs/yr	Base and storm flow	40%	56	lbs/yr	$ 523	$ -	$ -	$ -	$ -	$ 40	25%	$131	$ 719	$ 180	
CCB-14	Belleview Wetlands	Co-funding opportunity with USACE on indefinite hold	Retrofit existing develop. w/wet detention pond	235 Ac SF Resid			400 lbs/mi^2	145 lbs/year	Base and storm flow	50%	70	lbs/year	$ 210	$ -	$ -	$ -	$ 2	$ 18	100%	$210	$ 260	$ 260	2
CCB-15	Surface Water Reuse at Cherry Creek Vista	Supplemental water not available. Project on indefinite hold.	Use water from Cottonwood Creek to irrigate 10-acres		2.92 af/ac-yr	29.2 af/yr	0.20 mg/l	15.9 lbs/yr	base flow	80%	13	lbs/year	$ 50	$ -	$ -	$ -	$ -	$ 3.85	100%	$50	$ 303	$ 303	
CCB-16	Stream Corridor Preservation	No projects identified in 2010	Partner with others to purchase property or conservation easements along Cherry Creek										0						100%				1
CCB-17.2	Reservoir Shoreline Stabilization Mountain Loop Trail	Final design completed in 2010.	CCSP Recreation sites: Mountain, Lake and Cottonwood Creek Loops							Note 16	54	lbs/yr	$ 786	$ -	$ -	$ -	$ 5	$ 66	100%		$ 1,213	$ 1,213	1
CCB-17.3	West Boat Ramp Parking Lot WQ Improvements	No design prepared to date.	Provide water quality treatment of parking lot runoff.	To Be Determined			To Be Determined			To Be Determined				To Be Determined							To Be Determined		1

CCB-15	Surface Water Reuse at Cherry Creek Vista	Supplemental water not available. Project on indefinite hold.	Use water from Cottonwood Creek to irrigate 10-acres		2.92 af/ac-yr	29.2 af/yr	0.20 mg/l	15.9 lbs/yr	base flow	80%	13	lbs/year	$ 50	$ -	$ -	$ -	$ -	$ 3.85	100%	$50	$ 303	$ 303	
CCB-16	Stream Corridor Preservation	No projects identified in 2010	Partner with others to purchase property or conservation easements along Cherry Creek										0						100%				1
CCB-17.2	Reservoir Shoreline Stabilization Mountain Loop Trail	Final design completed in 2010.	CCSP Recreation sites: Mountain, Lake and Cottonwood Creek Loops							Note 16	54	lbs/yr	$ 786	$ -	$ -	$ -	$ 5	$ 66	100%		$ 1,213	$ 1,213	1
CCB-17.3	West Boat Ramp Parking Lot WQ Improvements	No design prepared to date.	Provide water quality treatment of parking lot runoff.	To Be Determined			To Be Determined			To Be Determined				To Be Determined							To Be Determined		1
CCB-18	ISDS Sewer Service	No action to date	Provide Sewer Service for ISDS Areas	To Be Determined			To Be Determined			To Be Determined				To Be Determined							To Be Determined		1
													$ 62,741						***$ 23,303***				

Basis for Analysis

(A) Unit cost of phosphorus removal based on annualized cost of completed project over 35 years at 7% interest rate.

(B) All projects identified provide for additional phosphorus immobilization beyond minimum requirements, unless noted otherwise.

NOTES:
1. Assumed that augmentation for consumptive use not required
2. Augmentation for naturally established wetlands not required (assumption)
8. Water costs at $ 2,500 per acre foot
9. Present worth of capital replacement
11. Land acquisition and water augmentation not defined. CWSD\ACWWA JWPP project influenced scope of project.
15. Estimate based on costs for similar work along East Shoreline dating back to 1996
16. Benefit approximated based on other shoreline projects and estimates
18. SEO opined that ET must be augmented. Also, recent Reservoir fluctuations may render project infeasible. Placed on indefinite hold.
19. Technical feasibility may change with CDOT bridge replacement and Valley Country Club assistance
20. Joint project with CCSP. Integrate design with Dog Park uses and improvements. Estimate based on similar stream stabilization projects

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9. TetraTech December 2006. *Design of Cherry Creek Sediment Basin and Stream Stabilization.*
10. Brown and Caldwell Feb 2007. *Shop Creek Wetlands Pollutant Reduction Facility Wetland Assessment*
11. PBSJ October 2006. *Draft McMurdo Gulch Major Drainageway Master Plan*
12. Brown and Caldwell 2010. *Cherry Creek Stream Reclamation at Shop Creek Trail.*

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

TABLE 2 - SUMMARY OF RECOMMENDED POLLUTANT REDUCTION FACILITIES

2011 - 2015 BUDGET PROJECTIONS (1000$)

November 8, 2010

See "2011 CIP Notes" for revisions to this Spreadsheet. Previous CIP projects included in Spreadsheet if ongoing during the 5-year projection

		Project Budget						Previous Expend.	Residual PRF Costs	Proposed 2011 Budget					Proposed 2012 Budget	Proposed 2013 Budget	Proposed 2014 Budget	Proposed 2015 Budget
Project No.	Project Title	Capital[1]	Land	Total	O&M	Authority Portion	Authority Portion	Note 11		Design[6]	Capital	Land	Water	Total	Total	Total	Total	Total
CCB-5.1	Cherry Creek Sediment Pond at Arapahoe Road[4]	$ 2,355	$ 50	$ 2,405	$ 90	$ 433	18.0%	$ 70	$ 363	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 363
CCB-5.4	Cherry Creek Stream Reclamation at Mainstreet (Parker)[17]	$ 1,776	$ -	$ 1,776	$ 1	$ 200	11.3%	$ -	$ 200	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 200	$ -
CCB-5.6	Cherry Creek Stream Reclamation at Lincoln Avenue (Parker)[17]	$ 1,447	$ -	$ 1,447	$ 1	$ 304	21.0%	$ -	$ 304	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 20	$ 284
CCB-5.7	Cherry Creek Stream Reclamation at Eco-Park (SEMSWA)	$ 2,851	$ -	$ 2,851	$ 1	$ 855	30.0%	$ 50	$ 805	$ -	$ 403	$ -	$ -	$ 403	$ 402	$ -	$ -	$ -
CCB-5.8	Cherry Creek Stream Reclamation U/S Arapahoe Rd (Aurora)	$ 518	$ -	$ 518	$ 1	$ 130	25.0%	$ -	$ 130	$ -	$ -	$ -	$ -	$ -	$ -	$ 130	$ -	$ -
CCB-5.9	Cherry Creek Stream Reclamation at 12-Mile Park	$ 518	$ -	$ 518	$ 1	$ 518	100.0%	$ 97	$ 421	$ -	$ -	$ -	$ -	$ -	$ 100	$ 321	$ -	$ -
CCB-5.10	Cherry Creek Stream Reclamation at PJCOS (Vermillion Creek, PJMD)	$ 3,730	$ -	$ 3,730	$ 2	$ 671	18.0%	$ 56	$ 615	$ -	$ 615	$ -	$ -	$ 615	$ -	$ -	$ -	$ -
CCB-5.11	Cherry Creek Stream Reclamation at Norton Open Space[17] (Parker)	$ 900	$ -	$ 900	$ 1	$ 252	28.0%	$ -	$ 252	$ -	$ -	$ -	$ -	$ -	$ 30	$ 222	$ -	$ -
CCB-5.13	Cherry Creek Stream Reclamation at Shop Creek Trail	$ 675	$ -	$ 675	$ 1	$ 675	100.0%	$ -	$ 675	$ -	$ -	$ -	$ -	$ -	$ 90	$ 585	$ -	$ -
CCB-5.14	Cherry Creek Stream Reclamation - Arapahoe Rd to Piney Creek	$ 7,000	$ -	$ 7,000	$ 1	$ 700	10.0%	$ -	$ 700	$ 25	$ -	$ -	$ -	$ 25	$ 25	$ 650	$ -	$ -
CCB-5.15	Cherry Creek Stream Reclamation at Country Meadows	$ 1,100	$ -	$ 1,100	$ 1	$ 220	20.0%	$ -	$ 220	$ 20	$ -	$ -	$ -	$ 20	$ 200	$ -	$ -	$ -
CCB-7.1	McMurdo Gulch Stream Reclamation (Castle Rock)	$ 1,562	$ -	$ 1,562	$ 2	$ 640	41.0%	$ 430	$ 210	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CCB-12.1	Bowtie Phase I	$ 616	$ 450	$ 1,066	$ 6	$ 1,066	100.0%	$ -	$ 1,066	$ -	$ -	$ -	$ -	$ -	$ -	$ 50	$ 500	$ 516
CCB-13.3	Cottonwood Creek Stream Reclamation at Easter Avenue (SEMSWA)	$ 1,350	$ -	$ 1,350	$ 1	$ 338	25.0%	$ 338	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
CCB-13.4	Peoria Trib B/Airport East and West Pond (Outfall C-1)	$ 523	$ -	$ 523	$ -	$ 131	25.0%	$ -	$ 131	$ 25	$ -	$ -	$ -	$ 25	$ 15	$ 91	$ -	$ -
CCB-16	Stream Corridor Preservation[2]	$ -	$ 500	$ 500	$ -	$ 500	100.0%	$ -	$ 500	$ -	$ -	$ 250	$ -	$ 250	$ 100	$ 100	$ 100	$ 100
CCB-17.2	Reservoir Shoreline Stabilization Mountain Loop Trail	$ 786	$ -	$ 786	$ 1	$ 786	100.0%	$ 80	$ 706	$ -	$ 706	$ -	$ -	$ 706	$ -	$ -	$ -	$ -
CCB-17.3	West Boat Ramp Parking Lot WQ Improvements	$ 140	$ -	$ 140	$ 1	$ 140	100.0%	$ -	$ 140	$ 13	$ 127	$ -	$ -	$ 140	$ -	$ -	$ -	$ -
CCB-18	ISDS Sewer Service[18]	$ 350	$ -	$ 350	$ -	$ 350	100.0%	$ -	$ 350	$ -	$ -	$ -	$ -	$ -	$ 100	$ -	$ 250	$ -
	SUB-TOTALS	$ 28,196	$ 1,000	$ 29,196	$ 112			$ 1,121	$ 7,788	$ 83	$ 1,851	$ 250	$ -	$ 2,184	$ 1,062	$ 2,149	$ 1,070	$ 1,263

	OPERATIONS AND MAINTENANCE																	
	Rehabilitation Categories																	
OM-1	Restore Cottonwood Wetlands Pond	$ 341	$ -	$ -	$ 341	$ 341	100.0%	$ 30	$ 311	$ -	$ 311	$ -	$ -	$ 311	$ -	$ -	$ -	$ -
OM-8	Cottonwood/Peoria sediment removal[14]	$ 24	$ -	$ -	$ 24	$ 6	25.0%	$ -	$ 6	$ -	$ -	$ -	$ -	$ -	$ 24	$ -	$ -	$ 24
	SUB-TOTALS	$ 365			$ 365			$ 30	$ 317	$ -	$ 311	$ -	$ -	$ 311	$ 24	$ -	$ -	$ 24
	Restorative Categories																	
OM-14	PRF weed control in CCSP[7]	$ -	$ -	$ -	$ 51	$ 51	100.0%	$ -	$ 51	$ -	$ -	$ -	$ 51	$ 51	$ -	$ -	$ -	$ 10
OM-6	Interpretive Signage restore	$ -	$ -	$ -	$ 15	$ 8	50.0%	$ -	$ 8	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 8
	SUB-TOTALS	$ -			$ 66			$ -	$ 59	$ -	$ -	$ -	$ 51	$ 51	$ -	$ -	$ -	$ 18
	Routine Categories																	
OM-7	Reservoir Destratification	$ -	$ -	$ -	$ -	$ -	100.0%	$ -	$ -	$ -	$ 53	$ -	$ -	$ 53	$ 53	$ 53	$ 53	$ 53
OM-15	Tower Loop Repairs	$ 25	$ -	$ -	$ 25	$ 25	100.0%	$ -	$ 25	$ -	$ 25	$ -	$ -	$ 25	$ 15	$ 15	$ 15	$ 15
	SUB-TOTALS	$ -	$ -	$ -	$ -			$ -	$ -	$ -	$ 53	$ -	$ -	$ 78	$ 68	$ 68	$ 68	$ 68
	SUB-TOTAL O&M	$ 365	$ -	$ -	$ 431			$ 30	$ 376	$ -	$ 364	$ -	$ 51	$ 440	$ 92	$ 68	$ 68	$ 110
	GRAND TOTAL	$ 28,561	$ 1,000	$ 29,196	$ 543			$ 1,151	$ 8,163	$ 83	$ 2,215	$ 250	$ 51	$ 2,624	$ 1,154	$ 2,217	$ 1,138	$ 1,373

NOTES:

1 Includes engineering, administration, and contingency
2 Specific project not identified. Budget based on available funds. Cost of land/water purchase unknown. $100k used as "place holder".
4 Total CIP = $4,278M. Budget for stream reclamation portion of project partnering with local government after u/s Cherry Creek stabilization measures in place
6 Includes technical feasibility, design, construction observation and administrative costs
7 Authority 100% responsible for weed control in CCSP up to 5-years from project completion. Thereafter, Authority equally shares cost w/CCSP.
11 Accumulative expenditures for the project, based on previous years accounting and estimate of current year expenses
14 Assume Authority provides 25% of funds, with remaining under UDFCD cost sharing with SEMSWA for O&M
17 Time line based on CIP projections. Parker requested Assistance funds of $200k for CCB-5.4 and $150k for CCB-5.11
18 Capital costs and potential benefits unknown.

APPENDIX B
Summary of Procedures to Calculate Phosphorus Reduction Benefits

The Authority has used two different approaches to estimating the benefits of stream stabilization and reclamation. One method, Approximate Method, relied on erosion data from a TMDL study in Michigan[26], which provided historic erosion rates for similar soils over a period of several years. This method only estimates annual benefits from reduced erosion, and therefore phosphorus, in the main channel. No phosphorus reduction benefits from new riparian vegetation or more frequent connection to the floodplain is accounted for in the Approximate Method.

The second method used project specific data for Cottonwood Creek to estimate the erosion that has occurred over time, as well as additional phosphorus reduction benefits of riparian vegetation and more frequent floodplain inundation. The site specific method has been found to result in higher phosphorus loads per mile of stream – therefore greater phosphorus reduction benefits - than the Approximate Method. The greater benefits are because actual erosion rates are used and because additional benefits from riparian vegetation filtration and flood inundation are included. However, the Approximate Method is typically used in the annual CIP projections because site specific data is often lacking at the time the budgets are prepared. Data used and assumptions made for each of these calculation methods is provided below.

Approximate Method.

To evaluate water quality benefits from stream stabilization, the Authority previously investigated[27] the erosion characteristics of Sycamore Creek in Michigan, which measured bed and bank erosion over a period of time. Potential phosphorus loads from eroding streams have been estimated based on measurements of phosphorus content of soils, and erosion rates of urban streams. Measurements used (also see Table 1) and assumptions made include the following.

- Measured phosphorus concentrations in streambed soils varied from 310 to 580 mg/Kg (0.6 to 1.2- lbs/ton) of soil[28]. Phosphorus concentrations were also reported at 2 pounds per cubic yard[29] based on soils samples along Cherry Creek Reservoir. Bed and bank sediment samples from Cottonwood Creek at Easter Avenue obtained by the Authority and tested for phosphorus content by GEI in 2008 contained approximately 1.4-lbs/ton of phosphorus. Sediment removed from the Cottonwood Peoria wetlands pond in 1998 was tested and resulted in a phosphorus content of 1.3 to 1.6 lbs/ton of sediment. The value

[26] U.S. Environmental Protection Agency 1992. *TMDL Case Study Sycamore Creek Michigan/*
[27] Cherry Creek Basin Water Quality Authority June 2000. *Cherry Creek Watershed, Colorado Watershed Plan 2000.* Appendix M, page 3-4.

of one pound of phosphorous per ton of sediment has been used for consistency with previous samples in Cherry Creek and for conservatism.

- Measured erosion rates in Sycamore Creek Michigan (USEPA, 1992) for sandy, silty clay loam soils were approximated at 77 cubic yards per mile of stream (both bed and banks).

- The dry density of sediment was assumed between 80 to 90 pounds per cubic foot (pcf). Using 90 pcf the following table compares estimated stream erosion rates for Cottonwood Creek in Cherry Creek State Park[30], Cottonwood Creek between Easter Avenue and Briarwood Avenue[31], Ward Branch in Missouri (Dove 2009), and Stroubles Creek in Virginia (Virginia Tech 2006).

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 comparison suggests that when bank sloughing (or wasting) occurs, which is the case for Cottonwood Easter to Briarwood, 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.

- Erosion of Watershed Soils. Measurements by Halepaska[32] show that typical watershed soils have phosphorus (orthophosphate) concentrations of up to 3.9 mg/kg with an average of 1.5 mg/kg. The origin of all inorganic orthophosphate is the class of minerals known as apatites.[33] As phosphorus moves through the drainage system toward the Reservoir, the concentrations in the soils increase, a phenomenon known as pollutant enrichment[34], which helps maintain a phosphorus source in sediment for many years.

The projected phosphorus loads were found to vary from 51 to 151 pounds per mile of stream. A value of 100-pounds per mile was used in projecting load reductions and is considered a reasonable approximation of annual loads from unstable stream systems. The value of 100-pounds per mile per year has been the basis for estimating benefits of stream stabilization - and

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[28] J. C. Halepaska & Associates December 9, 1999. *Cherry Creek Basin Soil Analysis Results*. Appendix D, Watershed Plan 2000

[29] CH2MHill 1997. *Nonpoint Source Evaluation*

[30] William P. Ruzzo, PE, LLC September 5, 2003. *Cherry Creek Corridor Master Plan – Estimate of Phosphorus Reduction from Stream Reclamation.*

[31] William P. Ruzzo, PE, LLC September 1, 2010. *Cottonwood Creek Erosion History – Easter Avenue to Briarwood Ave.*

[32] Halepaska 1999.

[33] Novotny and Chesters, 1981. *Handbook of Nonpoint Pollution Sources and Management*, p 221.

[34] Ibid, p 215

cost per pound of phosphorus immobilized - for Authority projects since 2000. This rate would be classified as being between "slight" (50-tons/mile) and "moderate" rates (150-tons/mile) for stream bank erosion, based on a sediment budget for another watershed[35].

Site Specific Method

Calculations of phosphorus immobilization resulting from stream reclamation are divided into three parts: reduction in sediment and phosphorous loads from (a) the stream bed and bank, (b) riparian wetland areas, and (3) floodplain area. To illustrate the calculation process, information available for Cottonwood Creek was used in the following discussion. Calculations are provided in Table 2.

Stream Bed and Banks. Stream erosion rates in Cottonwood Creek were estimated to be about 150 cubic yards per mile of stream per year. This estimate was based on an old concrete irrigation diversion structure, which was preserved during reclamation construction and whose remnants are still visible today. Prior to reclamation, the crest of the diversion structure was well above the channel invert suggesting that as much as 5- to 7-feet of erosion had taken place over many years. Research into the history of the area showed that there were several small truck farms in the area in the 1930 to 1940 era which provided a time-frame for the erosion period.

Riparian Wetland Areas. Phosphorus immobilized by riparian wetland areas was calculated using the first-order exponential decay model that accounts for water gains and losses (i.e.: precipitation, ET, and infiltration) developed by Kadlec and Knight[36]. The analysis accounted for inflow concentrations, hydraulic loading rates, site-specific climatic data, and assumed irreducible concentrations to calculate effluent concentrations[37]. Data used for Cottonwood calculations are:

Area, acres	20
Average flow, cfs	2.3
Inflow P, mg/l	0.10
First-order removal rate, m/yr	12.1
Irreducible effluent concentration, mg/l	0.02
Rainfall P concentration, mg/l	0.025

Based on an increased riparian area of 20 acres, the riparian area is expected to immobilize an additional 200 pounds of phosphorus per year, or around 10-lbs P per year per acre

[35] FISRWG Revised October 2000. *Stream Corridor Restoration Principles, Processes, and Practices*. Page 8-57.
[36] Robert Kadlec, Robert Knight, 1996. *Treatment Wetlands*
[37] Muller Engineering January 2003. *Feasibility Estimates for Cottonwood Creek Stream Stabilization Project.*

Floodplain Area.

By increasing the frequency of over-bank flooding, sediments (and attached phosphorus) are deposited by gravity in additional to filtration by vegetation. The amount of sedimentation that takes place was calculated using dynamic settling equations suggested by equation 8 in EPA[38]. This equation accounts for particle settling velocity and rate of applied flow divided by the surface area (i.e. hydraulic loading rate, ft/hr).

Sediment concentration in flood flows used in the analysis is 500-mg/l based on Cherry Creek Basin Water Quality Authority monitoring data. The fraction of various size particles in the suspended sediment was based on data provided in the Nationwide Urban Runoff Program[39]. Suspended particles with a settling velocity less than 1-foot per second (i.e.: diameters less than 0.01 mm) were assumed to remain suspended.

To estimate overflow rate required a number of steps and assumptions, which are summarized below:

1. The CUHP/SWMM model for Cottonwood Creek was obtained from the UDFCD. The storm input was modified to reflect an SCS Type II distribution for a 24-hour general storm. The general storm was considered more representative of longer duration flooding in the overbanks, rather than the shorter, but more intense, 2-hour storm used for peak flow estimates. Hydrographs were generated for the 2-, 5-, 10-, 50- and 100-year events with future development.

2. Overflow hydrographs were developed for each flood event, assuming flooding occurs when the main channel exceeds approximately 300-cfs. These hydrographs were integrated to obtain overflow volume and averaged over the duration of the overflow hydrograph. This approach produced overflow duration that ranged from about 4-hours for the 2-year event to over 8-hours for the 100-year event.

3. Observations of flooding in Cottonwood Creek suggest that during wet spring periods, such as during 1998, 1999, and 2000 where flows exceeded 10-year means, high flows in the creek can last sometimes for days or weeks. These observations support an upward adjustment of flood flow duration. However, lacking long term high-flow data, only a moderate adjustment was considered reasonable (i.e.: over flow duration was multiplied by 2). This assumption did not increase the runoff volume, only the duration, which therefore divided the over-flow rate in half.

4. The resulting overflow rates varied from 0.5-ft/hr for the 2-year to 1.1 ft/hr for the 100-year. These values are much lower than rates used in the primary treatment design for wastewater systems, which range from 4 to 7-ft per hour.

Settling calculations were then performed for each particle size fraction for each flood event to determine the tons of sediment deposited during each event, using the sediment density of 500 mg/l and the volume of overflow. The phosphorus concentrations in Cherry Creek

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[38] US EPA 1986a. *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality*.
[39] US EPA 1986b. Nationwide Urban Runoff Program

sediment have been measured by Halepaska and range from 310- 580-mg/kg (0.62 to 1.16 lbs P/ton of sediment). An average value of 1.0-lb P/ton of sediment deposited was used in the analysis.

The final step was to integrate the phosphorus loads for each flood frequency to develop an average annual value. Using this approach resulted in approximately one-pound of phosphorus deposited per acre per year.

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
TECHNICAL ADIVSORY COMMITTEE

Table 1 - MEASURED VALUES

PRECIPITATION

Mean Watershed Precipitation (in)		Maximum Annual Precipitation (in)
At Reservoir	13.3	22
At Palmer Divide	18	33

Annual Runoff Producing Precipitation (regional statistics)	
number of runoff productive events (in)	32
average runoff producing event (in)	0.43
Average annual runoff producing precip (in)	13.8

STORM RUNOFF COEFFICIENTS

Note: These coefficients apply to minor storms (I.e.: 2-year or less frequent)
The coefficients are used in estimating mean runoff volume by UDFCD

Land Use	% Imperv	Rv
Indust.	85	0.67
Commer.	83	0.65
Resid (low den)	20	0.17
Resid (med den)	45	0.31
Resid (high den)	65	0.45
Undev	0	0.04

EVENT MEAN CONCENTRATIONS (mg/l)

Note: EMC's represent mean values as reported by UDFCD

Land Use	Total P	TSS
Industrial	0.43	399
Commercial	0.42	225
Residential	0.65	240
Undeveloped	0.40	400

MEASURED STREAM PHOSPHORUS CONCENTRATIONS (mg/l)

	SRP	Total P	Comments
Cherry Creek & alluvium	0.15 to 0.25		SRP represents about 80% of total
Cottonwood (base flow)		0.1 to 0.2	Flow to reservoir
Cottonwood (storm peaks)		0.3 to 0.8	Flow to reservoir
Shop Creek		0.16	Flow to reservoir

PHOSPHORUS CONTENT IN SOILS

	Range		Average		Note
Stream bed measurements (Halepaska)	310	580		mg/kg	
Soil Measurements (Halepaska)	0	3.9	1.5	mg/kg	
Soil Measurements (CSU Extension)	1	60	8	mg/kg	
Bank measurements (CH2MHill)			2	lbs/cy	
Bed measurements at Arapahoe Rd (Ttech)	10.5	41.4	14.7	mg/kg	
Cottonwood\Peoria Sediment (GEI)	640	810	743	mg/kg	Extrac P = 3 mg/kg
Stream bed measurements (Halepaska)	0.6	1.2		lbs/ton	
Soil Measurements (Halepaska)	0.0	0.0	0.0	lbs/ton	
Soil Measurements (CSU Extension)	0.0	0.1	0.0	lbs/ton	
Bank measurements (CH2MHill) @ 80 pcf			1.9	lbs/ton	
Bed measurements at Arapahoe Rd (Ttech)	0.0	0.1	0.0	lbs/ton	
Cottonwood\Peoria Sediment (GEI)	1.3	1.6	1.5	lbs/ton	

Soil Erosion Rates:

Assume Sediment Density =	90	pcf		
Sycamore Creek TMDL =	77	cy/mile/year =	94	tons/mile/year
Cottonwood Creek estimate =	150	cy/mile/year =	182	tons/mile/year
Ward Creek (Stormwater July/August 2009) =	610	Tons/mile/year		

Table 2

ESTIMATION OF PHOSPHORUS REDUCTION FROM STREAM RECLAMATION FOR LOWER COTTONWOOD CREEK SBS PROJECT

STEPS

1. Use HECRAS to determine WSP for various flood frequencies. Elect to printout left/right overbank surface areas and left/right overbank volume. Record values below.
2. Determine the "bank full" discharge for the main channel. Record value below.
3. Using the "hydrographs" worksheet, estimate the over flow duration in years by subtracting bankfull discharge from the hydrograph and recording the beginning and ending times.
4. Adjust flow duration for CCSP observations of flooding events:
   a.. Has occurred 2-3 times per year
   b. Duration from 8-12 hours.
5. Calculate the hydraulic loading rate (HLR) defined as q = Q/A.in meters/year. The analysis assumes that the flood frequency occurs only once during the year. Then Q = af/year/ac is converted to meters/year
6. Analyze the Cottonwood Creek data to estimate the P-concentration during flood events.
7. Use the Knight/Kadlec first order aerial rate equation ($Co = Ci * e^{(-k/q)}$) to calculate the change in concentration due to overbank flooding.
8. Calculate the P immobilized by multiplying the change in P concentration times the overbank flooding volume.
9. Plot Del P versus flood probability and integrate the area under the curve to get average annual Del P.

VARIABLES

Q_{bf} = Cfs. Banfull Discharge = 300
Q_{ob} = cfs. Average overbank flow discharge
A = Acres. Flooded area outside of main channel
k = 10 meter/year. First order aerial rate equation constant.
Ci = mg/l. P concentration of flood in overbank, based on Cottonwood Creek measurements
Q_{mc} = af. Main channel flow
Q = af/year. Volume of hydrograph that "floods" the overbank
q = meters/year. Hydraulic Loading Rate
Co = mg/l. P concentration of flow that leaves the flooded area.
Del P = pounds of P immobilized
Duration Factor = Adjustment of over bank flooding duration based on observations = 2 times

HECRAS OUTPUT SUMMARY

Flood Frequency	Flooded Area (acres)			Flooded Volume (af)			Vol/Area (feet)	OB Flood Duration (hours)		q = HLR	
	(LOB)	(ROB)	(total OB)	(LOB)	(ROB)	(total OB)		Hydrog.	Observ.	(m/year)	(ft/hour)
100			98			900	9.2	8.3	16.7	1472	1.10
50			96			727	7.6	8.0	16.0	1264	0.95
10			94			459	4.9	6.0	12.0	1086	0.81
5			92			355	3.9	5.0	10.0	1031	0.77
2			90			216	2.4	4.3	8.7	740	0.55
1.1			0			0	0	0.0	0.0	0	0

COTTONWOOD CREEK P-CONCENTRATION DURING FLOODING

Data review:
1. Total P concentrations are higher during storm events than base flow
2. Total P concentration often reach 0.6 or greater for flows less than 100 cfs.
3. Total P concentration can exceed 1 mg/l

PHOSPHORUS LOAD REDUCTION CALCULATIONS

Flood Frequency (years)	Flood Probability	Ci	Co	Del P	Integrated Area (lbs)
100	0.01	1.10	1.09	18	-
50	0.02	1.00	0.99	16	**0.2**
10	0.1	0.90	0.89	10	**1.0**
5	0.2	0.80	0.79	7	**0.9**
2	0.5	0.70	0.69	6	**1.9**
1.1	0.91	n/a	n/a	0	**1.1**

TOTAL **5**

APPENDIX C
Annotated Bibliography

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
Stream Reclamation Annotated Bibliography

Author Organization	**Title**	**Notes**
Berg, Joe September 2009	"Baseflow Stream Channel Design: An Approach to Restoration that Optimizes Resource Values and Ecosystem Services." Water Resources IMPACT. Vol 11 No 5.	1. "*Kaushal et al (2008) documented that stream restoration projects that were hydrologically connected to their floodplains had increased rates of denitrification relative to restored streams that were not as well reconnected to their floodplains*." 2. "*Higher denitrification rates, a permanent type of nitrogen removal, occur in headwater streams as a function of greater channel surface area to water volume…The nitrogen processing literature points to an integrated stream and riparian zone.*" 3. "*By reconnecting the channel to the riparian zone or floodplain to deliver the elevated flows to these vegetated systems, society capitalizes on natural floodplain functions critical to ecosystem health…*"
Center for TMDL and Watershed Studies. Ca 2000	"Stream Restoration" Website	1. "*While the importance of vegetation in streambank stabilization is widely acknowledged, the impacts are complex and have yet to be fully quantified*." 2. "*Because riparian vegetation has a significant impact on stream stability and morphology, it has become an integral part of stream restoration designs.*"
Center for Watershed Protection, *Watershed Protection Techniques,*	Irreducible Pollutant Concentrations Discharged from Stormwater Practices, 2(2): 369-372, Technical Note #75	1. "*The data suggests that a background storm phosphorus concentration of 0.15 to 0.25 mg/l is probably the lowest concentration that can be achieved through stormwater treatment, even when stormwater practices are widely applied and maintained*."
Dean, Cornelia June 24, 2008	"Follow the Silt", New York Times	1. "Most agencies want to spend the money making things happen and not spend the money finding out if they work," Dr. Dietrich said. 2. "And some critics say restoration to some pristine ideal is simply impractical". 3. "But he, too, has his critics. Dr. Montgomery called Dr. Rosgen's classification "a very clever system" but said it was wrong to think that "just by knowing what channel type you have you would know what to do."
Dove, Eric, Rodgers, Kasi, and Keener, Matt 2009	"The Value of Protecting Ozark Streams". Stormwater, Vol 10 No 5.	1. "*This study has shown that stream restoration can be one of the most cost-effective methods of preventing phosphorus from entering lakes*." 2. Provided cost per foot of stream, tons/ac/year sediment, sediment tons /1000 ft of stream, P concentrations in sediment, lbs P/1000ft/year, and cost/lb P/year for Ward Branch in Springfield Missouri. 3. Information used in Ruzzo presentation at the 2009 Stewardship Conference.
Federal Interagency Stream Restoration Working Group (FISRWG) 2000.	Stream Corridor Restoration Principles, Processes, and Practices.	1. "*The quality of water in the stream corridor is normally a primary objective of restoration, either to improve it to a desired condition, or sustain it.*" 2. "*Reaeration is the primary route for introducing oxygen into most waters...Stream Restoration techniques often take advantage of these relationships, for instance by the installation of artificial cascades to increase reaeration.*" (Stream reclamation measures include riffle/pool complexes and drop structures)

Author Organization	Title	Notes
		3. *"As the salinity of water increases, the [DO] saturation concentration decreases"*. (Stream reclamation can reduce sediment in the water, reducing salinity) 4. *"The restoration evaluation should usually focus on aquatic organisms and instream conditions as the "judge and jury" for evaluation restoration success….biological criteria detected an impairment in 49.8 percent of the situations where no impairment was evident with chemical criteria alone."* (argument for habitat and EPT assessments-biological-as a measure of water quality, consistent with the CWA) 5. Other valuable information in report.
Johnson, Mike January 2011	"Nutrient Reduction Into Watershed from Point Sources and Non-Point Sources", *Rumbles*	1. Compared annual cost per pound of phosphorus between point and non-point source nutrient control approaches.
Kaushal, Sujay S. et. al 2006.	"Land Use Change and Nitrogen Enrichment of a Rock Mountain Watershed", *Ecological Applications, 16(1).*	2. "*Headwater streams experiencing residential development may be particularly susceptible to N enrichment."*
Kaushal, Sujay S. et. al 2008.	"Effects of Stream Restoration on Nenitrification in an Urbanizing Watershed". *Ecological Applications, 18(3)*	1. "*Our results suggest that stream restoration designed to "reconnect" stream channels with floodplains can increase denitrification rates…"* 2. Results based on monitoring data.
McKergow, Lucy A. et. al. September 2002.	"Before and After Riparian Management: Sediment and Nutrient Exports from a Small Agricultural Watershed, Western Australia". Journal of Hydrology 270 (2003):253-272.	1. *"Riparian management had limited impact on total phosphorus (TP) concentrations or loads, but contributed to a change in phosphorus (P) form. Before improved riparian management, around half of the P was transported attached to sediment, but after, the median filterable reactive P (FRP) to TP ratio increased to 0.75."* 2. Results for P attributed, in part, to low P retention type soils.
NRCS	Watershed Condition Series, Technical Note 1 Biotic Condition Indicators for Water Resources	1. Index of Biotic Integrity (IBI) fish productivity 2. Habitat assessment, such as corridor width, vegetation, in-stream features. 3. EPT (mayfly, stonefly, caddis fly) assess land use and water quality using benthic macro-invertebrates which are sensitive to water quality
NRCS, 1999.	Assessing Conditions of Riparian Wetland Corridors at the Areawide Level	1. Use "proper functioning condition" (PFC) methodology for large area stream corridor assessments to determine "health of riparian-wetland area conditions".
Nichols, Mary and Green, Douglas 2007	"Regional Perspectives of Stream Restoration: Stream Restoration in the Semi-Arid West". Stream Restoration Networker. Vol 1 Issue 1	1. "*There are two major challenges to stream restoration in the Southwest: using stream restoration practices from other regions and determining project success or failure based on varying monitoring protocols."* 2. "*Because of the high flow variability, bankfull features may not be appropriate design features."* 3. "*Efforts to create specific channel forms may not result in restored geomorphic processes, especially in flashflood dominated hydrologic regimes*."

Author Organization	Title	Notes
http://wildfish.montana.edu	"Common Problems Addressed in Stream Restoration"	Study concluded that majority of restoration projects had one or more of the following objectives: enhance water quality, manage riparian zones, and stabilize stream banks.
Shields, F. Douglas et al. 2003	"Design of Stream Restoration", <u>Journal of Hydraulic Engineering</u>, ASCE	1. "*Although the number and scope of stream restoration projects are increasing, designs for these projects are often weak in hydraulic engineering*." 2. "*All stream restoration projects require some level of sedimentation analysis to reduce the risk of undesirable outcomes*."
Sudduth, E.B. and Meyer, J.L. 2006.	Effects of Bioengineered Streambank Stabilization on Bank Habitat and Macroinvertebrates in Urban Streams". <u>Environmental Management</u> Vol 38, No. 2, pp. 218-226	*1.* "*…results suggest that bioengineered bank stabilization can have positive effects on bank habitat and macroinvertebrate communities in urban streams, but it cannot completely mitigate the impacts of urbanization.* *2.* Reference for developing ecological monitoring parameters.
Tomer, M.D. et. al. 2007	"Spatial Patterns of Sediment and Phosphorus in a Riparian Buffer in Western Iowa" <u>Journal of Soil and Water Conservation.</u> 62.5 (Sept-Oct 2007):329(10).	*1. "In agricultural landscapes, riparian buffers have the capacity to trap and remove a variety of contaminants including sediment, nutrients, pesticides, and pathogens"* *2. "Despite the non-uniform nature of runoff pathways, the buffer appeared to trap sediment effectively."*
Trimble, Stanley W. November 21, 1997	"Contribution of Stream Channel Erosion to Sediment Yield from Urbanizing Watershed" <u>Science Magazine, Vol. 278, p1442-1444</u>	*1.* "*…channel erosion furnished…about two-thirds of sediment yield. Thus, because channel erosion can be a major source of sediment yield from urbanizing areas, channel stabilization should be a priority in managing sediment yield."* 2. "*Additionally, much less is known about geomorphologic effects of urbanization in arid regions than in humid regions*."
Virginia Tech. May 24, 2006.	Upper Stroubles Creek Watershed TMDL Implementation Plan, Montgomery County, Virginia.	1. TMDL for sediment. Two major sources, channel erosion, and agriculture. 2. Based TMDL on protective habitat for benthic macro-invertebrates using "Rapid Bio-assessment Protocol II and EPA's Stressor Identification Guidance Document." 3. Provided cost per foot of stream, tons/ac/year sediment, sediment tons /1000 ft of stream, P concentrations in sediment, lbs P/1000ft/year, and cost/lb P/year.
Williamson, R.B. et. al.	"Watershed Riparian Management and Its Benefits to a Eutrophic Lake" <u>Journal of the American Water Resources Association,</u> January/February 1996.	1. Results support watershed, non-point source control methods as effective in reducing watershed pollutant loads.
Wynn, T. and Mostaghimi, S. August 1, 2006.	"The Effects of Vegetation and Soil type on Streambank Erosion, Southwestern Virginia, USA". <u>Journal of the American Water Resources Association. pp 69-82</u>	1. "*The most significant factor determining soil erosion rate in this study was bulk density (BD)"* 2. "*Study results provided evidence that the interaction of stream and soil chemistry significantly influenced streambank erosion.*

APPENDIX D
Stream Reclamation Rating Criteria and Rationale

CHERRY CREEK BASIN WATER QUALITY AUTHORITY

Stream Reclamation Evaluation Criteria and Rationale

#	Evaluation Criteria	Approach	Rationale
1	Is the project part of an overall watershed plan that includes sub-regional and source control BMPs?	Quantitative	Emphasizes that stream reclamation is just part of the overall strategy which must include other watershed controls, including source, runoff volume and rate control measures.
2	Is the project proactive such that "future" water quality problems will be addressed before they occur?	Quantitative	Addressing stream erosion problems when growth is just starting saves money but also reduces the sediment/nutrient loads that reach the stream & Reservoir likely many years before the problem gets more severe (i.e.: many lbs P for many years) and more costly.
3	What is the expected time frame to begin to see benefits at the Reservoir?	Unnecessary	Recognizes that CR-72 measures success at the Reservoir by the Chl a standard so that lower watershed measures that respond quicker and maintain Chl a levels maybe higher priority. The time frame is approximated by groundwater flow rate at 3-years mile or surface flow at 1.5-fps. However, analysis has shown this criteria to be irrelevant to stream reclamation.
4	Is cost per pound of P less than $600 without partners?	Quantitative	Cost per pound <$600 suggests that project design is cost effective OR that the project is proactive by addressing the problem before the stream degrades to poor or worse conditions.
5	Are there funding partners such that the cost/pound is less than $600?	Quantitative	Funding partners reduces cost to Authority allowing for more cost sharing on other projects, as well as good will generated through cooperation between agencies.
6	Is the cost per mile less than $1M	Unnecessary	Cottonwood Creek was severely eroded over many years such that the cost/mile was over $1M, whereas McMurdo Gulch is expected to be around $0.5M/mile since growth in McMurdo is in the initial stages. The cost/mile also reflects property availability and creativity in design approach. However, this economic measure is readily obtained from other criteria and would be redundant.
7	Is the existing stream/channel degraded to such an extent that high phosphorus concentrations (i.e.: > 0.20-mg/l) during base/storm flows are likely?	Site Specific Analysis by Proponent	0.20-mg/l P or less is a watershed goal. If the existing channel reach produces higher concentrations, than the reach is high priority. If the source of high P concentrations is upstream, then the project is lower priority. This criteria can be part of an analysis by project proponents.
8	Is it design such that the proposed reclamation plan likely reduces phosphorus concentrations to < 0.20-mg/l ?	Site Specific Analysis by Proponent	The Chl a correlation with external P suggests high priority for this metric. This criteria can be part of an analysis by project proponents.
9	Is there at least one year of monitoring data showing P concentrations into and out of the project reach are above 0.20-mg/l?	Site Specific Analysis by Proponent	Having some data to support the project is important.
10	Is there evidence or data demonstrating poor ecological channel and riparian habitat conditions currently exist?	Qualitative	Poor ecological conditions is an indication of that water quality conditions are also poor even if high P concentrations are not prevalent.
11	Is there significant watershed growth potential that would accelerate the need for stream reclamation?	Qualitative	Significant growth in the watershed can rapidly accelerate channel degradation.
12	Is it likely that stabilization of the project reach will have downstream impacts?	Qualitative	It is possible that stabilization of the Arapahoe County reach upstream of PJCOS may have accelerated erosion of the PJCOS reach by reducing the sediment supply available to the PJCOS reach. If this were the case, then the sediment demand in the PJCOS reach would be satisfied by increased erosion in the PJCOS reach.

APPENDIX E
Evaluation of Economic Rating Criteria

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
Economic Evaluation of Rating Criteria

Criteria 1 – Watershed Planning (Quantitative**)**.

An entity that prepares a watershed plan that includes watershed water quality controls could receive credit for the cost of the watershed plan that reduces the total cost of the project used in the economic analysis.

Discussion: A well executed master plan provides a level of confidence of the projects technical feasibility, relationship to the rest of the watershed, water quality benefits, and probable costs.

Illustration: Assume that monetary credit of $100,000 is allowed for the Cottonwood Creek master plan which identifies the actual project. This amount would reduce the Project Capital Cost to $2,300,000 resulting in an Annual Unit Cost per pound of $1008 (from $1047) and the Life Time Unit Cost to $443 (from $457).

Criteria 2 – Proactive Projects (Quantitative).

Economic benefits from proactive projects are achieved in three ways. First, a proactive project reduces project overall costs, as illustrated by the Cottonwood Creek and McMurdo Gulch examples and which is accounted for in the cost/pound calculation. Second, proactive projects reduce future phosphorus loads for the life of the project, which is accounted for in the lifetime value of P reduction in the same way as non-proactive projects. Third, proactive projects also reduce phosphorus loads during the time it would have taken to identify the instability of the channel during planning efforts and actual implementation of the reclamation project.

- Life Time Unit Cost = ("Life Time Cost) / (("baseline project life" plus "baseline channel instability time frame") x ("Lifetime water quality benefits"))

Discussion. Although highly variable and somewhat subjective, the baseline instability time frame reflects the planning and design process which can take 10- to 15-years. For conservatism, a value of 10-years is suggested for the economic analysis.

Illustration. For being proactive, McMurdo Gulch could add up to 10-years to its lifetime value, which is calculated by: Life Time Unit Cost = ($2,750,000) / ((35-years plus 10-years) x (270-lbs)) = $226/lb. This credit reduces life time unit cost from $259 to $226/lb.

Criteria 3 – Reservoir Related Time Frame (Unnecessary).

The time for surface flows to reach the Reservoir from the downstream end of a project can be estimated using base flow velocities calculated from HECRAS analysis, called "time delay". Surface flow rates would be used since stream reclamation benefits are primarily associated with surface runoff. The calculation method is similar to Criteria 2.

- Life Time Unit Cost = ("Life Time Cost) / (("baseline project life" minus "surface flow travel time") x ("Lifetime water quality benefits"))

Discussion: Although stream reclamation in the upper watershed is beneficial to Cherry Creek and the watershed, the Reservoir water quality standard has been the primary measure of water quality since there is an in-lake chlorophyll *a* standard. Therefore, this "adjustment' attempts to account for the number of years to see "benefit" at the Reservoir in terms of reduce nutrient loads and chlorophyll concentrations.

Illustration: Calculation of the surface travel time for McMurdo Gulch resulted in a time delay less than a week. Therefore, this adjustment does not appear to be necessary for the economic analysis since the minimum evaluation time frame is annual. If the time frame adjustment was based on groundwater flow rates, than the number of years to see changes at the Reservoir would 60-years, which is beyond the evaluation time frame for watershed projects (i.e.: 35-years).

Criteria 4 – Cost per Pound of P (Quantitative)**.**

This criterion is the standard calculation used by the Authority since 2001 to identify, prioritize, and establish levels of funding assistance for cost-shared CIP projects. Two unit costs are evaluated, annual unit cost and life time unit costs.

- Annual Unit Cost = ("project capital cost" plus PW[40] of "annual cost") / (Project annual water quality benefits)

- Life Time Unit cost = ("project life time cost") / ("Life time water quality benefits")

Discussion: The TAC committee recommends that these unit costs be used to evaluate future stream reclamation projects for consistency and comparability to past projects.

Illustration: See Table 7 – Baseline Comparison.

Criteria 5 – Funding Partners (Quantitative)**.**

Funding partners reduce the Authority's project costs, so the economic analysis is based on the Authority's contribution.

Discussion: The Authority funds available for stream reclamation (or for other Authority CIP or initiatives) are limited. Therefore, if the Authority has a funding partner for a project, it not only reduces the Authority costs but makes funds available for other projects as well. However, it is still important to calculate the unit costs without funding partners, since it does represent a "cost to society", which is also important in the overall assessment of a project.

Illustration: If funded entirely by the Authority (or Castle Rock), the McMurdo Gulch project annual unit cost would be $511/lb and life time unit cost would be $259/lb (see Table 7). The IGA with Castle Rock provides $430,000 in cost-sharing funds, which reduces annual unit cost to $389/lbs and life time unit costs to $214/lb.

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[40] PW = present worth

Criteria 6 – Cost per Mile (Unnecessary)**.**

This economic measurement is readily obtained from the results of the above calculations. However, it use is more likely related to a "reasonableness" check and is not recommended as an upward or downward adjustment in the economic analysis.

Criteria 7 – Channel Degradation as measured by P Concentrations (Site Specific Analysis)**.**

This criterion can be included in the economic evaluation through a site specific analysis of P concentrations.

Discussion: It may be possible to convert 90-lbs P per mile per year into a flow weighted "baseline concentrations" based on minor flows in Cherry Creek, or use the Cottonwood Creek data before and after reclamation to establish site specific flow weighted concentrations. Therefore, if a project reach has higher flow weighted discharge concentrations than the baseline or Cottonwood Creek "pre-project flow weighted concentrations", then it means that more phosphorus is being generated by the project than the typical assumed, which means more economic benefits in P reduction. This analysis could either be performed as part of the proponent's site-specific analysis, or by the Authority as a pre-evaluation step for consideration of a project in the same manner as soil phosphorus concentrations are analyzed.

Criteria 8 – Channel Improvements as measured by P Concentrations (Site specific Analysis)**.**

A separate calculation of economic benefits would not be required, as this criterion would be accounted for in the calculations prepared for Criteria 7.

Criteria 9 – Monitoring Data (Site specific analysis)**.**

A separate calculation of economic benefits would not be required, as this criterion would be accounted for in the calculations prepared for Criteria 7 if performed by the project proponent. If available, the data can be submitted by the proponent and used by the TAC in the prioritization evaluation.

Criteria 10 – Ecological Benefits (Qualitative)**.**

It is believed that calculating economic benefits related to ecological conditions may be too problematic or more subjective than desired. Therefore, this criterion is not included in the economic calculations. However, it is also believed that evaluating ecologic benefits of stream reclamation is a worthwhile effort on the part of the Authority.

Illustration: See example economic comparison section below.

Criteria 11 – Rapid Watershed Growth (Qualitative)

Significant growth in the watershed can rapidly accelerate channel degradation.

Discussion: If land use projections show that growth in a tributary watershed is imminent, as measured by an increase in impervious area, than the reclamation should be a high priority.

Whereas this criterion might be more readily identified for a watershed tributary to Cherry Creek, assessment of a Cherry Creek reach for rapid growth may not be practical.

Criteria 12 – Sequence of Channel Reclamation (Qualitative)

There is evidence in Cherry Creek that stabilization of an upstream reach may have negative impacts on downstream channel reaches, as suggested by the rapid degradation (just a few years) of the one mile reach south of Bronco's Parkway, called Parker Jordan Open Space (PJCOS) and another stream reach Parker.

Discussion: It is possible that stabilization of the Arapahoe County reach upstream of PJCOS may have accelerated erosion of the PJCOS reach by reducing the sediment supply available to the PJCOS reach. If this were the case, then the sediment demand in the PJCOS reach would be satisfied by increased erosion in the PJCOS reach. Often the approach in flood control is to start at the downstream reach and move upstream with stabilization. However, due to many factors, this approach has not been practical in Cherry Creek and, as the result; there are unstable reaches in between stream reclamation projects that might be negatively impacted by the piecemeal approach. Therefore, if a project connects existing stabilized reaches of a channel, there may be some basis for assigning it a higher priority.

APPENDIX F
Interim Report Amendments