Alternative Analysis
Cherry Creek Reservoir West Boat Ramp
Parking Lot Water Quality Improvements

January 2012

Submitted to:

Cherry Creek Basin Water Quality Authority
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Introduction

Stormwater runoff from the Cherry Creek Reservoir west boat ramp parking lot currently discharges directly to the reservoir without any means of water quality treatment. Most of the flow from the parking lot enters the reservoir through a discharge pipe at the north end of the parking lot referred to in this report as Outfall 1 and the remainder drains down the boat ramp to a location referred to as Outfall 2. AMEC Earth & Environmental was contracted to prepare a pollution reduction facility water quality management plan for the west boat ramp parking lot. This consists of studying alternatives to collect and treat stormwater runoff from the parking lot from small, frequent storm events which is the runoff that typically transports the majority of the pollutants into waterways.

Hydrology

Runoff peak flow rates and stormwater volumes for three hydrologic subbasins analyzed in this study are displayed in the following table.

Table 1: Hydrology Results Summary

			Parking Lot	Boat Ramp	Boat Storage
	Area	(acres)	3.8	0.65	0.46
	Imp	(%)	75%	100%	100%
	t_c	(min)	13.4	5.0	5.0
2 year (P_1=0.95 in)	Q_{peak}	(ft^3/s)	4.8	1.9	1.3
	Volume	(ft^3)	3,828	558	393
5 year (P_1=1.35 in)	Q_{peak}	(ft^3/s)	7.2	2.7	1.9
	Volume	(ft^3)	5,778	801	567
10 year (P_1=1.55 in)	Q_{peak}	(ft^3/s)	8.8	3.1	2.2
	Volume	(ft^3)	7,075	939	666
100 year (P_1=2.60 in)	Q_{peak}	(ft^3/s)	16.9	5.5	3.9
	Volume	(ft^3)	13,586	1,644	1,164
WQCV = $a(0.91I^3 - 1.19I^2 + 0.78I) \times Area$	Volume	(ft^3)	3,337	945	673

Alternatives Analysis

Alternatives for removing pollutants from the parking lot and boat ramp stormwater runoff were analyzed and a recommended alternative was selected. The alternatives for improvements to Outfall 1 included:

- Water Quality Pond
  - Pipe only conveyance option
  - Pipe and swale conveyance option
- Proprietary BMP
  - Hydrodynamic separator
  - Filtration system

The alternatives evaluation included preparation of a matrix to rank the alternatives according to selected criteria and a weighting factor applied to each criteria. Improvements to Outfall 2 consisting of construction of a small water quality detention area at the existing pipe outfall were included in each alternative evaluated for Outfall 1. This report includes detailed descriptions of the estimated capital and maintenance costs as well as a description of decision criteria for the alternatives. The following table summarizes the estimated costs for the various alternatives studied.

Table 2: Cost Estimate Summary

Alternative	Capital Subtotal	Contingency & Other Costs	Present Worth O&M	Total Project Cost
Alternative 1-A	$147,803	$62,077	$18,665	$228,545
Alternative 1-B	$99,199	$41,664	$27,997	$168,860
Alternative 2-A	$126,991	$53,336	$410,621	$590,949
Alternative 2-B	$189,731	$79,687	$503,945	$773,363

The status quo or no-action alternative was also considered by the Authority prior to initiating the alternative analysis presented in this report. However, because of the direct water quality impacts from the discharge of polluted parking lot runoff into the reservoir, the Authority determined that corrective measures were necessary and incorporated the project into its 2011 capital improvement program.

Recommendation

Based on the analysis performed, the recommended alternative is Alternative1-B (water quality pond with pipe and swale option). This alternative consists of collecting and conveying stormwater runoff from the boat ramp parking lot to the existing water quality pond north of the boat storage area via a combination of pipe and open channel. Modifications to the existing pond outlet will be required. Removal of the existing Outfall 1 pipe and improvements to Outfall 2 are also included in the recommended alternative. Figures 2 and 3 in Appendix C show conceptual details of this alternative. This alternative is the most cost effective and fully meets current UDFCD criteria for water quality treatment BMPs.

The project was presented to the Technical Advisory Committee (TAC) on December 1, 2011. The TAC voted to accept AMEC's recommendation outlined above as the Selected Alternative. The following modifications should be considered during final design:

1. Investigate alternate trail and swale alignments to minimize disturbance area and trail-use impacts.

2. Consider the need for fencing the swale to protect and preserve the water quality function, while providing access for maintenance.

3. Consider using an inlet insert to trap trash or debris, and possibly oil and grease in storm runoff.

1.0 Introduction and Site Description

AMEC Earth & Environmental, Inc. (AMEC) has been retained by Cherry Creek Basin Water Quality Authority (CCBWQA) to prepare a pollution reduction facility (PRF) water quality management plan for the west boat ramp parking lot at the Cherry Creek Reservoir. This consists of exploring and evaluating alternatives to collect and treat runoff from the parking lot. The design and construction of water quality improvements at the west boat ramp parking lot will be considered a retro-fit project. The initial goal will be to meet or exceed the Urban Drainage and Flood Control District (UDFCD) criteria for water quality capture and treatment. However, existing site constraints may result in a system that provides a level of treatment somewhat less than outlined in the criteria. UDFCD guidelines outline runoff to be treated through the capture and slow release of the Water Quality Capture Volume (WQCV). The WQCV represents runoff from small, frequent storm events that have the greatest overall impact on the quality of the receiving waters. This report presents the concept-level design considerations and alternative evaluation for several alternatives including preliminary cost estimates.

Cherry Creek Reservoir is located in Greenwood Village, Arapahoe County, Colorado and the parking lot in question serves the boat ramp near the dam on the west side. The reservoir is located in Cherry Creek State Park. Colorado State Parks manages the parking lot and boat ramp. The dam and reservoir are owned and operated by the U. S. Army Corps of Engineers.

Under current conditions, the majority of the parking lot drains to the northeast to a single storm inlet that free flows to a pipe draining into the reservoir near the marina. This inlet will be referred to as Outfall 1. The existing pipe is a corrugated metal pipe that has sustained significant wear. Emergency repairs were made to the existing CMP earlier this year by State Park personnel. Alternatives developed as part of this study considered realignment of Outfall 1 to a point further east, away from the marina. Currently, when the capacity of the inlet is exceeded, flow from the parking lot is diverted through an existing curb cut and down the concrete path to the reservoir and does not reach the existing inlet. Modifications to the existing collection system were investigated to assure that first flush flows from the parking lot would be collected.

The remaining impervious area of the parking lot and boat ramp drains east down the ramp and is directed to a concrete rundown which directs flows into the reservoir on the north side of the boat ramp. This second outfall will be referred to as Outfall 2. See Figure 2 for outfall locations.

Several parking lot islands with mature trees and vegetation are in place in the parking lot, but do not serve to intercept runoff as the asphalt parking lot drainage is away from the islands.

The marina building is located at the north end of the west boat ramp parking lot. North or the marina is a boat storage area. A small water quality pond that currently collects and treats runoff from the boat storage area is located on the north side of the boat storage area. Small, frequent flows are contained in the pond and infiltrate, while larger less frequent runoff events are detained and discharged to the reservoir through a spillway. It is understood from discussions with Parks and Marina personnel that the pond was designed and constructed with the intent to provide 100-year storm event runoff detention for the boat storage area.

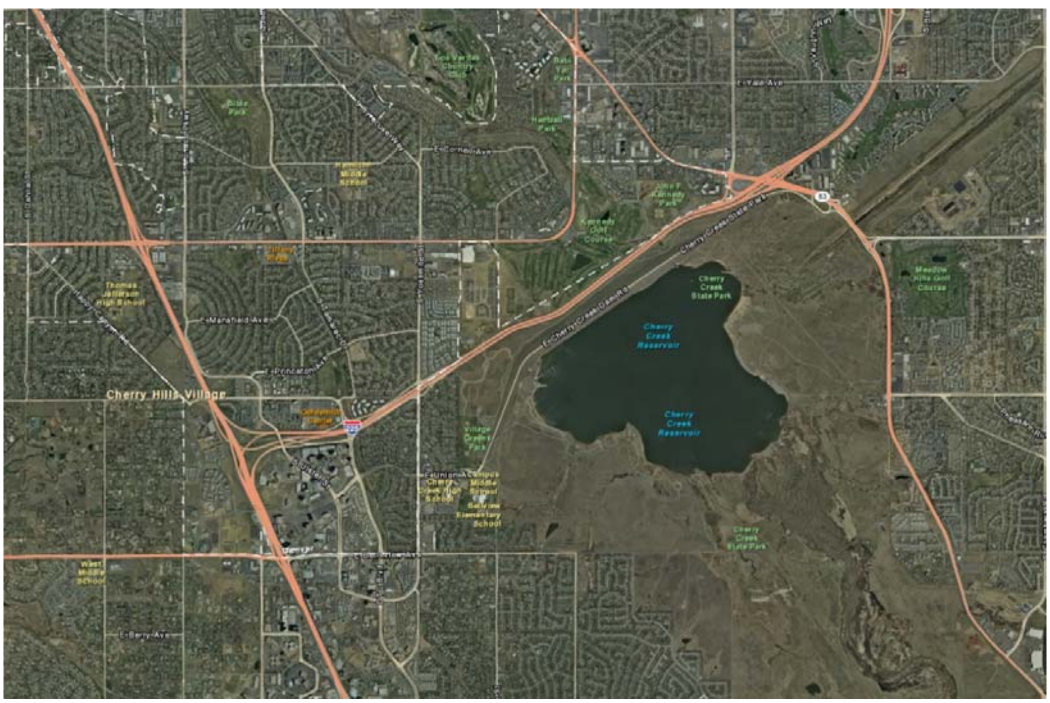


Figure 1: Cherry Creek Reservoir Location Map

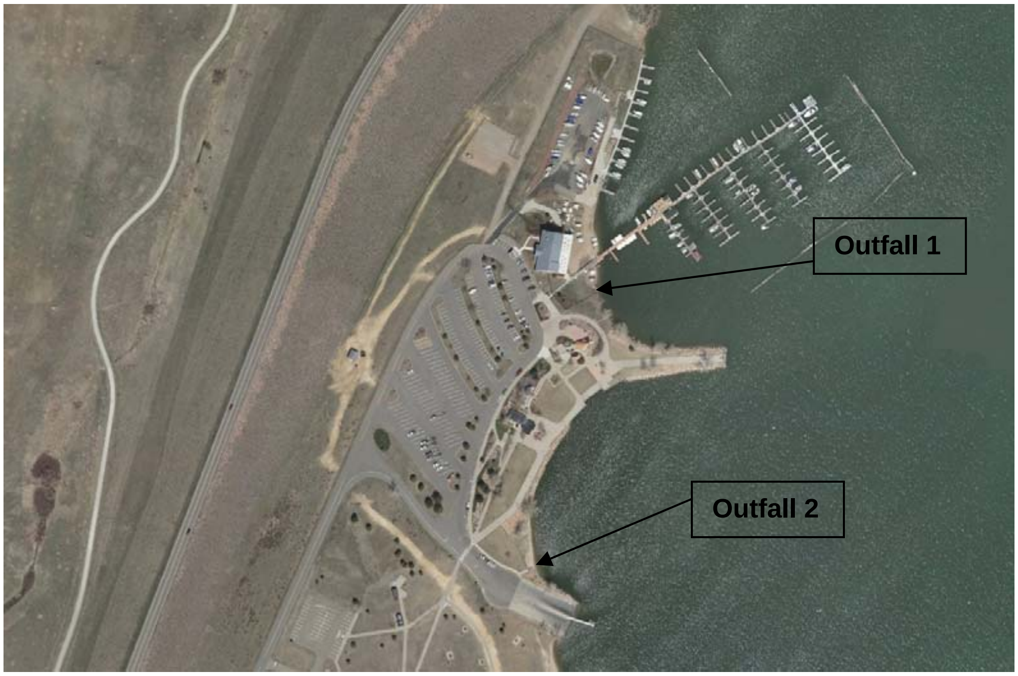


Figure 2: Cherry Creek West Boat Ramp Parking Lot

2.0 Hydrology

The rational method was used to analyze the hydrologic conditions of the boat ramp parking lot. The site was divided into subbasins comprising of the following:

Table 3: Hydrology Parameters

Subbasin	Area (acres)	Outfall	% Impervious	Impervious Area (acres)
Parking Lot	3.8	Outfall 1	75%	2.9
Boat Ramp	0.65	Outfall 2	100%	0.65
Boat Storage	0.46	WQ Pond	100%	0.46

The tool UD-Rational from UDFCD was used to calculate the peak runoff flow ($Q_{peak)}$ for various storm events. The UD-rational spreadsheets are included in Appendix A. The rational method inputs are as follows: (UDFCD vol 1)

- Area
- Percent Impervious

- NRCS Soil Type (Type D soils used for all basins)
- Design Return Period (2-yr, 5-yr, 10-yr and 100-yr)
- Runoff Coefficient – calculated using Denver area default values
- One-hour precipitation for design storm (P_1)
- Flow path lengths and slopes and land type to calculate Time of Concentration (T_c)

The results of the rational method hydrologic analysis are shown below in Table 4.

Table 4: Rational Method Hydrology Results

		Q_{peak} Rational Method		
		Parking Lot	Boat Ramp	Boat Storage
Q_{peak} 2-year	(ft^3/s)	4.8	1.9	1.3
Q_{peak} 5-year	(ft^3/s)	7.2	2.7	1.9
Q_{peak} 10-year	(ft^3/s)	8.8	3.1	2.2
Q_{peak} 100-year	(ft^3/s)	16.9	5.5	3.9

Table 5 shows the volumes calculated using UDFCD empirical equations for the sizing of on-site detention storage volumes. (UDFCD vol 2). The use of empirical equations is applicable to for the smaller basin sizes (less than 90 acres) being studied in this analysis. The empirical equations provide preliminary estimates for on-site detention facility sizing and are considered an acceptable methodology for alternatives analysis.

Table 5: Runoff Volume Summary

			Volume = K_iA		
			Parking Lot	Boat Ramp	Boat Storage
5-year	K_5*	-	0.055	0.074	0.074
	Volume	(ft^3)	9,121	2,105	1,490
10-year	K_{10}*	-	0.069	0.093	0.093
	Volume	(ft^3)	11,479	2,636	1,866
100-year	K_{100}*	-	0.132	0.172	0.172
	Volume	(ft^3)	21,829	4,859	3,438
WQCV		(ft^3)	3,337	945	673
* From UDFCD empirical equations					

3.0 Alternatives Analysis

A site-walk was held on July 19th 2011 to review existing conditions and discuss potential alternatives. Based on observations during the site-walk, it was determined that a porous landscape detention option would not be included in the alternatives analysis. This alternative would require removal of significant trees and landscaping and would require construction of retaining walls and extensive regarding. Therefore, this alternative was considered to have too great an impact on Park facilities. Based on the site review, two separate alternative approaches were carried forward for analysis of water quality improvements to the parking lot. These alternatives include: water quality pond and proprietary BMP.

3.1 Outfall 1

3.1.1 Water Quality Pond

Stormwater runoff from the boat ramp parking lot would be directed to the existing water quality pond north of the boat storage area and this pond would be modified to treat the additional runoff. Modifications would be made to the pond to increase the detention volume by raising the embankment on the reservoir side and adding an outlet structure for a controlled release.

Existing conditions of the water quality pond provide storage for the 100-year runoff of the boat storage area. The proposed modifications for the pond would continue to provide storage for at least this volume and include a controlled release of the additional volume. Thus, the existing purpose of the pond would be maintained.

The table below lists the volume available in the existing boat storage pond with one foot of freeboard. The existing pond provides more than adequate storage volume for the 100-year runoff from the boat storage area. The remaining volume provided by the existing pond will provide more than adequate detention capacity for the water quality capture volume (WQCV) from the west boat ramp parking lot and boat storage area. The outlet structure should be designed to slowly release the entire volume above the 100-year boat storage volume of 3,438 ft^3.

If desired, additional storage volume could be attained in the pond by setting the outlet structure release point higher than the existing outlet elevation of 5,556.34. Depending on the desired volume, the pond may require additional grading including raising the embankment. Evaluation of the potential detention volume available at the existing pond is outside the scope of this study.

Table 6: Existing Boat Storage Pond Volumes

Existing Outlet Elev	1' Freeboard	Volume Available	Required 100-yr Detention Volume	Excess Storage Volume
feet	Feet	(ft^3)	(ft^3)	(ft^3)
5,556.34	5,555.34	10,139	3,438	6,701

Conveyance of the stormwater runoff from the parking lot to the water quality pond was considered. A pipe option and a pipe/swale option were considered. An 18" pipe could convey the flow from the parking lot to the pond. Or the pipe could convey flows part-way and outfall into an open channel swale that would empty into the pond. One benefit to this option is that a grass-lined swale would provide additional water quality treatment of the storm water runoff. As long as a minimum slope of 1% is maintained in the pipe, the 18" RCP will have a full flow discharge capacity of approximately 10.5 ft^3/sec. The proposed inlets needed for the improved collection system in the parking lot include replacing the existing curb inlet at the north east corner and adding two curb inlets upstream to prevent flow from bypassing the collection system. These three inlets have more than adequate capacity to capture the first flush runoff. The capacity of the pipe will control the amount of runoff reaching the pond. The existing water quality pond with minor modifications to the outlet structure would have capacity to store the runoff volume produced by this storm. See Appendix A for calculations of inlet capacity as well as pipe capacity.

3.1.2 Proprietary BMP

Several proprietary BMP options were considered to install directly at Outfall 1 to treat runoff before emptying into the reservoir. The two companies that were considered for comparison purposes are CONTECH® and Imbrium®. Both companies provide similar products as do other stormwater treatment technologies that could also be explored if selected as the preferred treatment method alternative.

3.1.2.1 Hydrodynamic Separator

CDS© (Contech) and Stormceptor© (Imbrium) are both industry leading products that are proven to remove pollutants from stormwater. The hydrodynamic separator technology uses centrifugal motion of the water passing through the structure to separate floatable pollutants and some sediments. Maintenance on the hydrodynamic separator option would include periodic removal of accumulated sediment and pollutants from the catchment chamber. This would likely be done by a vacuum truck and it is estimated the maintenance interval would be at least yearly.

3.1.2.2 Filter

Stormfilter© (Contech) and Jellyfish© (Imbrium) are the filter options that were explored for treatment of the parking lot runoff. This option uses a filter to remove particles from stormwater as in flows through the device. The filter technology is able to remove much smaller particles than the hydrodynamic separator technology with a result of cleaner stormwater released into the reservoir. The maintenance required would be removal and replacement of the filter cartridges. The maintenance interval would be dependent on pollutant loads in the stormwater.

3.2 Outfall 2

Runoff from the boat ramp is collected and discharged into the reservoir on the north side of the ramp. It is proposed that a small catchment area be constructed to retain runoff before discharging into the reservoir. Using 36 inch boulders and strategically planted willow vegetation, the runoff would pond and sediments would be removed by settlement and infiltration. This is intended to have minimal impact on the existing shoreline and would provide pollutant removal. The treatment proposed is similar to that constructed at the east side boat ramp parking lot.

Conceptual level design layouts were prepared for the following alternatives:

- Outfall 1
    - Alternative 1-A Water Quality Pond with Pipe to Pond
    - Alternative 1-B Water Quality Pond with Pipe to Swale to Pond
    - Alternative 2-A Proprietary BMP Hydrodynamic Separator
    - Alternative 2-B Proprietary BMP Filtration System

- Outfall 2 Improvements

Required improvements to the existing storm drain collection system consisting of two additional inlets, 18” RCP and manholes are included in all Outfall 1 alternatives. Reconstruction of a new outfall pipe is also included in all Outfall 1 alternatives 2-A and 2-B. Conceptual design of Outfall 2 did not included alternatives, per direction from the CCBWQA.

4.0 Cost Estimate

Conceptual level opinion of probable cost estimates were prepared for the four alternatives at Outfall 1 and for the proposed improvements at Outfall 2. Unit costs were obtained from UDFCD Cost Estimator, CDOT Cost Data and in-house cost data. A 25% contingency is included in each cost estimate along with estimated costs for Final Design Services, Construction Services and Administrative costs. Annual operations and maintenance costs were estimated based on UDFCD guidelines and information provided by the proprietary BMP suppliers. Present worth values for the annual operations and maintenance costs were calculated assuming an interest rate of 4% and a total lifespan of each alternative of 35-years. The alternative costs are shown in the following tables.

Table 7: Cost Estimate Alternative 1-A Pipe to Pond

Item No	Description	Unit	Unit Cost (USD)	Quantity	Cost
1	18" RCP	LF	$ 60	833	$ 49,980
2	Remove Asphalt Paving	SY	$ 8	109	$ 875
3	Asphalt Patch	SY	$ 40	109	$ 4,373
4	18" FES + Outlet Protection	LS	$ 1,100	1	$ 1,100
5	Pond Grading	LS	$ 10,000	1	$ 10,000
6	Pond Outlet Structure	LS	$ 10,000	1	$ 10,000
7	Curb Inlet	LS	$ 4,500	1	$ 4,500
8	Area Inlet	LS	$ 4,500	2	$ 9,000
9	Manhole	LS	$ 2,000	5	$ 10,000
10	Outfall #2 Water Quality	LS	$ 3,375	1	$ 3,375
11	Cut/Cap/Fill Abandon CMP	LF	$ 26	150	$ 3,900
12	Pond Maintenance Access	LF	$ 14	50	$ 700
13	Erosion Control	LS	$ 10,000	1	$ 10,000
14	Mobilization/Demobilization	LS	$ 15,000	1	$ 15,000
15	Site Restoration	LS	$ 15,000	1	$ 15,000
				Capital Subtotal:	**$ 147,803**
				25% Contingency	$ 36,951
				8% Final Design Services	$ 11,824
				6% Construction Services	$ 8,868
				3% Administrative	$ 4,434
				Capital Total:	**$ 209,880**
				Annual Operations & Maintenance	$ 1,000
				Present Worth Operations & Maintenance	$ 18,665
				Total Improvement Costs	**$ 228,545**

Table 8: Cost Estimate Alternative 1-B Pipe to Swale to Water Quality Pond

Item No	Description	Unit	Unit Cost (USD)	Quantity	Cost
1	18" RCP	LF	$ 60	471	$ 28,260
2	Remove Asphalt Paving	SY	$ 8	109	$ 875
3	Asphalt Patch	SY	$ 40	109	$ 4,373
4	Swale Grading	CY	$ 12	370	$ 4,444
5	Trail Relocate	SY	$ 6	530	$ 3,180
6	Pond Grading	LS	$ 10,000	1	$ 10,000
7	Pond Outlet Structure	LS	$ 10,000	1	$ 10,000
8	18" FES + Outlet Protection	LS	$ 1,100	1	$ 1,100
9	Curb Inlet	LS	$ 4,500	1	$ 4,500
10	Area Inlet	LS	$ 4,500	2	$ 9,000
11	Manhole	LS	$ 2,000	2	$ 4,000
12	Outfall #2 Water Quality	LS	$ 3,375	1	$ 3,375
13	Cut/Cap/Fill Abandon CMP	LF	$ 26	150	$ 3,900
14	Pond Maintenance Access	LF	$ 14	50	$ 700
15	Erosion Control	LS	$ 12,000	1	$ 12,000
16	Mobilization/Demobilization	LS	$ 15,000	1	$ 15,000
17	Site Restoration	LS	$ 18,000	1	$ 18,000
				Capital Subtotal:	**$ 99,199**
				25% Contingency	$ 24,800
				8% Final Design Services	$ 7,936
				6% Construction Services	$ 5,952
				3% Administrative	$ 2,976
				Capital Total:	**$ 140,863**
				Annual Operations & Maintenance	$ 1,500
				Present Worth Operations & Maintenance	$ 27,997
				Total Improvement Costs	**$ 168,860**

Table 9: Cost Estimate Alternative 2-A Hydrodynamic Separator

Item No	Description	Unit	Unit Cost (USD)	Quantity	Cost
1	Materials	LS	$ 25,760	1	$ 25,760
2	Installation	LS	$ 15,000	1	$ 15,000
3	18" RCP	LF	$ 60	347	$ 20,820
4	Remove Asphalt Paving	SY	$ 8	74	$ 589
5	Asphalt Patch	SY	$ 40	74	$ 2,947
6	18" FES + Outlet Protection	LS	$ 1,100	1	$ 1,100
9	Curb Inlet	LS	$ 4,500	1	$ 4,500
10	Area Inlet	LS	$ 4,500	2	$ 9,000
11	Manhole	LS	$ 2,000	2	$ 4,000
7	Outfall #2 Water Quality	LS	$ 3,375	1	$ 3,375
8	Cut/Cap/Fill Abandon CMP	LF	$ 26	150	$ 3,900
9	Erosion Control	LS	$ 6,000	1	$ 6,000
10	Mobilization/Demobilization	LS	$ 14,000	1	$ 14,000
11	Site Restoration	LS	$ 16,000	1	$ 16,000
				Capital Subtotal:	**$ 126,991**
				25% Contingency	$ 31,748
				8% Final Design Services	$ 10,159
				6% Construction Services	$ 7,619
				3% Administrative	$ 3,810
				Capital Total:	**$ 180,327**
				Annual Operations & Maintenance	$ 22,000
				Present Worth Operations & Maintenance	$ 410,621
				Total Improvement Costs	**$ 590,949**

Table 10: Cost Estimate Alternative 2-B Stormwater Filtration System

Item No	Description	Unit	Unit Cost (USD)	Quantity	Cost
1	Materials	LS	$ 58,500	1	$ 58,500
2	Installation	LS	$ 35,000	1	$ 35,000
3	18" RCP	LF	$ 60	347	$ 20,820
4	Remove Asphalt Paving	SY	$ 8	74	$ 589
5	Asphalt Patch	SY	$ 40	74	$ 2,947
6	18" FES + Outlet Protection	LS	$ 1,100	1	$ 1,100
9	Curb Inlet	LS	$ 4,500	1	$ 4,500
10	Area Inlet	LS	$ 4,500	2	$ 9,000
11	Manhole	LS	$ 2,000	2	$ 4,000
7	Outfall #2 Water Quality	LS	$ 3,375	1	$ 3,375
8	Cut/Cap/Fill Abandon CMP	LF	$ 26	150	$ 3,900
9	Erosion Control	LS	$ 6,000	1	$ 6,000
10	Mobilization/Demobilization	LS	$ 20,000	1	$ 20,000
11	Site Restoration	LS	$ 20,000	1	$ 20,000
Capital Subtotal:					**$ 189,731**
25% Contingency					$ 47,433
8% Final Design Services					$ 15,178
6% Construction Services					$ 11,384
3% Administrative					$ 5,692
Capital Total:					**$ 269,418**
Annual Operations & Maintenance					$ 27,000
Present Worth Operations & Maintenance					$ 503,945
Total Improvement Costs					**$ 530,945**

Table 11: Cost Estimate Outfall #2

Item No	Description	Unit	Unit Cost (USD)	Quantity	Cost
1	Grouted 36" Boulders	CY	$ 200	10	$ 2,000
2	Bedding Material	CY	$ 50	4	$ 200
3	Willow Planting	LS	$ 500	1	$ 500
Subtotal:					**$ 2,700**
25% Contingency					**$ 675**
Total:					**$ 3,375**

5.0 Evaluation Procedure

The status quo or no-action alternative was also considered by the Authority prior to initiating the alternative analysis presented in this report. However, because of the direct water quality impacts from the discharge of polluted parking lot runoff into the reservoir, the Authority determined that corrective measures were necessary and incorporated the project into its 2011 capital improvement program.

In evaluating the alternatives, not only were the costs of the improvements evaluated, but qualitative aspects were also evaluated. The following evaluation criteria were considered in the alternatives analysis:

- Water Quality
- Impacts on Existing Site
- Aesthetics
- Public Safety

Each of these alternative plans were evaluated by the Authority for water quality benefits associated with reduction in total phosphorus (Tp), total suspended sediment (TSS), and oil/grease. The results of the analysis are documented in a memorandum from William P. Ruzzo, PE dated November 18, 2011 (Revised December 2, 2011). A copy of the memorandum in included in Appendix C. The results are summarized below in Table 12.

Table 12: Summary of Water Quality Benefits for each Alternative

Alt	Description	Cost			Phosphorus Treatment		Sediment Transport		Oil & Grease
		Capital	O&M	Annual					
					(lbs)	$/lb	(lbs)	$/lb	
	No-Action	-	-	$1,100	2.6	$2,854	1,796	---	
1-A	EDS w/ Pipe Diversion	$209,880	$1,000	$12,245	1.4	$9,050	1,308	$9	Poor to good w/baffle system at inlet
1-B	EDS w/Pipe & Swale Diversion	$140,863	$1,500	$9,048	1.4	$6,680	1,635	$6	Poor to good w/baffle system at inlet
2-A	Proprietary Hydrodynamic Separator	$180,327	$22,000	$21,663	0.3	$122,050	1,347	$24	Good
2-B	Proprietary Filter System	$269,418	$27,000	$28,448	1.2	$24,370	1469	$19	Good to Very Good

The evaluation criteria were comparatively scored against the other alternatives. The evaluation criteria were weighted based on relative importance to the project stakeholders which were determined at the September 23, 2011 project meeting. **Error! Reference source not found.**13 shows the evaluation matrix developed to select the recommended alternative.

Table 13: Alternatives Evaluation Matrix

Alternative	Evaluation Criteria / Factor					TOTAL SCORE
	Total Project Costs	Water Quality	Impact on Existing Site	Aesthetics	Public Safety	
	2.5	2.0	1.0	1.0	1.0	
Alt. 1a – WQ Pond (Pipe Only)	3	2	4	4	3	**22.5**
Alt. 1b – WQ Pond (Pipe & Swale)	4	3	4	4	2	**26**
Alt. 2a – Proprietary BMP (Hydrodynamic)	2	2	1	1	4	**15**
Alt. 2b – Proprietary BMP (Filter)	1	4	1	1	4	**16.5**

Scoring: 1 (Low) – 4 (High)
* Costs are based on preliminary comparison costs, not on estimated costs of construction
** Total Score equals the Sum of Evaluation Criteria X Factor

6.0 Conclusion and Recommendation

After conducting a preliminary analysis on four PRF alternatives to address the Cherry Creek Reservoir west boat ramp parking lot water quality concerns, AMEC recommends that the CCBWQA consider Alternative 1-B to be carried forward to the preliminary design phase. Figure 2 in Appendix C shows the recommended alternative. This alternative is the most cost effective and requires minor maintenance of periodic removal of trash, debris and excessive sediment buildup from the pond. The existing pond has sufficient size and location and with the addition of an outlet structure as well as minor grading to provide maintenance access, would serve as a water quality pond for the boat storage area as well as the west boat ramp parking lot that meets UDFCD guidelines.

The project was presented to the Technical Advisory Committee (TAC) on December 1, 2011. The TAC voted to accept AMEC's recommendation outlined above as the Selected Alternative and the following modifications should be considered during final design:

1. Investigate alternate trail and swale alignments to minimize disturbance area and trail-use impacts.

2. Consider the need for fencing the swale to protect and preserve the water quality function, while providing access for maintenance.

3. Consider using an inlet insert to trap trash or debris, and possibly oil and grease in storm runoff.

7.0 References

Urban Drainage and Flood Control District 2010. *Urban Storm Drainage Criteria Manual,* Volumes 2 and 3.

Appendix A: Calculations

1.0 Pipe Capacity Calculation

2.0 Inlet Capacity Calculations

3.0 Rational Method Runoff Calculations

4.0 Water Quality Capture Volume Calculations

1.0 Pipe Capacity Calculation

Worksheet for Pipe to Pond

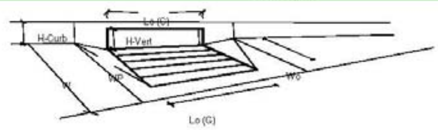
Project Description		
Friction Method	Manning Formula	
Solve For	Full Flow Capacity	
Input Data		
Roughness Coefficient	0.013	
Channel Slope	0.01000	ft/ft
Normal Depth	1.50	ft
Diameter	1.50	ft
Discharge	10.50	ft³/s
Results		
Discharge	10.50	ft³/s
Normal Depth	1.50	ft
Flow Area	1.77	ft²
Wetted Perimeter	4.71	ft
Hydraulic Radius	0.38	ft
Top Width	0.00	ft
Critical Depth	1.25	ft
Percent Full	100.0	%
Critical Slope	0.00977	ft/ft
Velocity	5.94	ft/s
Velocity Head	0.55	ft
Specific Energy	2.05	ft
Froude Number	0.00	
Maximum Discharge	11.30	ft³/s
Discharge Full	10.50	ft³/s
Slope Full	0.01000	ft/ft
Flow Type	SubCritical	
GVF Input Data		
Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	
GVF Output Data		
Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%

Bentley Systems, Inc. Haestad Methods Solution Center Bentley FlowMaster [08.11.00.03]
11/04/2011 1:12:50 PM 27 Siemons Company Drive Suite 200 W Watertown, CT 06795 USA +1-203-755-1666 Page 1 of 2

2.0 Inlet Capacity Calculations

INLET IN A SUMP OR SAG LOCATION

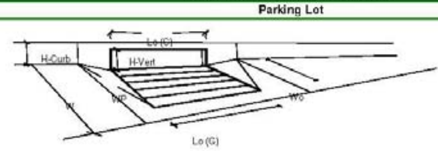
Project = Cherry Creek Boat Ramp Parking Lot
Inlet ID = Parking Lot



Design Information (Input)		MINOR	MAJOR	
Type of Inlet	Inlet Type =	CDOT/Denver 13 Combination		
Local Depression (additional to continuous gutter depression 'a' from 'Q-Allow')	a_{local} =	2.00	2.00	inches
Number of Unit Inlets (Grate or Curb Opening)	No =	1	1	
Flow Depth outside of Local Depression at Inlet	Flow Depth =	6.0	12.0	inches
Grate Information		MINOR	MAJOR	
Length of a Unit Grate	L_o (G) =	3.00	3.00	feet
Width of a Unit Grate	W_o =	1.73	1.73	feet
Area Opening Ratio for a Grate (typical values 0.15-0.90)	A_{ratio} =	0.43	0.43	
Clogging Factor for a Single Grate (typical value 0.50 - 0.70)	C_f (G) =	0.50	0.50	
Grate Weir Coefficient (typical value 2.15 - 3.60)	C_w (G) =	3.30	3.30	
Grate Orifice Coefficient (typical value 0.60 - 0.80)	C_o (G) =	0.60	0.60	
Curb Opening Information		MINOR	MAJOR	
Length of a Unit Curb Opening	L_o (C) =	3.00	3.00	feet
Height of Vertical Curb Opening in Inches	H_{vert} =	6.50	6.50	inches
Height of Curb Orifice Throat in Inches	H_{throat} =	5.25	5.25	inches
Angle of Throat (see USDCM Figure ST-5)	Theta =	0.00	0.00	degrees
Side Width for Depression Pan (typically the gutter width of 2 feet)	W_p =	2.00	2.00	feet
Clogging Factor for a Single Curb Opening (typical value 0.10)	C_f (C) =	0.10	0.10	
Curb Opening Weir Coefficient (typical value 2.3-3.6)	C_w (C) =	3.70	3.70	
Curb Opening Orifice Coefficient (typical value 0.60 - 0.70)	C_o (C) =	0.66	0.66	
		MINOR	MAJOR	
Total Inlet Interception Capacity (assumes clogged condition)	Q_a =	**3.6**	**9.2**	**cfs**
WARNING: Inlet Capacity less then Q Peak for Minor Storm	$Q_{PEAK\ REQUIRED}$ =	**4.8**	**8.8**	cfs

INLET IN A SUMP OR SAG LOCATION

Project = Cherry Creek Boat Ramp Parking Lot
Inlet ID = Parking Lot



Design Information (Input)		MINOR	MAJOR	
Type of Inlet	Inlet Type =	CDOT Type C Grate		
Local Depression (additional to continuous gutter depression 'a' from 'Q-Allow')	a_{local} =	0.00	0.00	inches
Number of Unit Inlets (Grate or Curb Opening)	No =	2	2	
Flow Depth outside of Local Depression at Inlet	Flow Depth =	6.0	12.0	inches
Grate Information		MINOR	MAJOR	
Length of a Unit Grate	L_o (G) =	2.92	2.92	feet
Width of a Unit Grate	W_o =	2.92	2.92	feet
Area Opening Ratio for a Grate (typical values 0.15-0.90)	A_{ratio} =	0.70	0.70	
Clogging Factor for a Single Grate (typical value 0.50 - 0.70)	C_f (G) =	0.50	0.50	
Grate Weir Coefficient (typical value 2.15 - 3.60)	C_w (G) =	2.41	2.41	
Grate Orifice Coefficient (typical value 0.60 - 0.80)	C_o (G) =	0.67	0.67	
Curb Opening Information		MINOR	MAJOR	
Length of a Unit Curb Opening	L_o (C) =	N/A	N/A	feet
Height of Vertical Curb Opening in Inches	H_{vert} =	N/A	N/A	inches
Height of Curb Orifice Throat in Inches	H_{throat} =	N/A	N/A	inches
Angle of Throat (see USDCM Figure ST-5)	Theta =	N/A	N/A	degrees
Side Width for Depression Pan (typically the gutter width of 2 feet)	W_p =	N/A	2.00	feet
Clogging Factor for a Single Curb Opening (typical value 0.10)	C_f (C) =	N/A	N/A	
Curb Opening Weir Coefficient (typical value 2.3-3.6)	C_w (C) =	N/A	N/A	
Curb Opening Orifice Coefficient (typical value 0.60 - 0.70)	C_o (C) =	N/A	N/A	
		MINOR	MAJOR	
Total Inlet Interception Capacity (assumes clogged condition)	Q_a =	**2.5**	**12.2**	**cfs**
WARNING: Inlet Capacity less then Q Peak for Minor Storm	$Q_{PEAK\ REQUIRED}$ =	**4.8**	**8.8**	cfs

3.0 Rational Method Runoff Calculations

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Ramp

I. Catchment Hydrologic Data

Clear Worksheet

Catchment ID = Boat Ramp
Area = 0.65 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information   I (inch/hr) = C1 * P1 /(C2 + Td)^C3

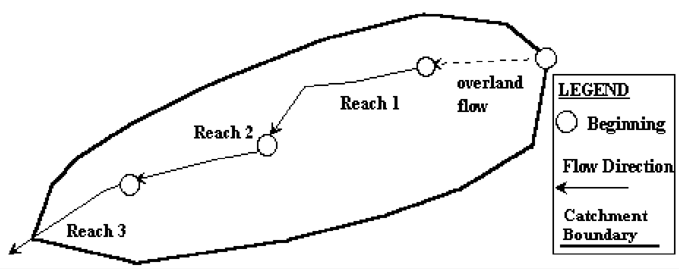
Design Storm Return Period, Tr =	2	years	(input return period for design storm)
C1 =	28.50		(input the value of C1)
C2=	10.00		(input the value of C2)
C3=	0.786		(input the value of C3)
P1=	0.95	inches	(input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.89
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.90	N/A	1.13	4.44
1	0.1000	213		20.00	6.32	0.56
2						
3						
4						
5						
	Sum	513			Computed Tc =	5.00
					Regional Tc =	12.85
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 3.22 inch/hr   Peak Flowrate, Qp = 1.86 cfs

amec

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Ramp

I. Catchment Hydrologic Data

Catchment ID = Boat Ramp
Area = 0.65 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

Clear Worksheet

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

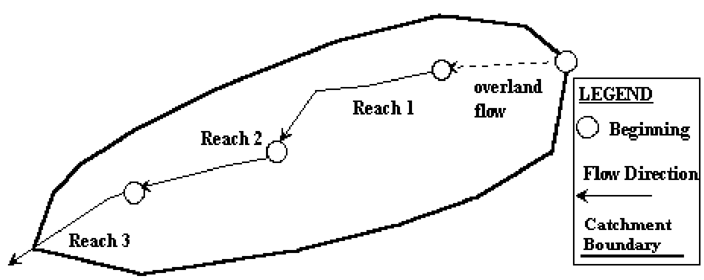
Design Storm Return Period, Tr = 5 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 1.35 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.90
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.90	N/A	1.13	4.44
1	0.1000	213		20.00	6.32	0.56
2						
3						
4						
5						
	Sum	513			Computed Tc =	5.00
					Regional Tc =	12.85
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 4.58 inch/hr

Peak Flowrate, Qp = 2.67 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Ramp

I. Catchment Hydrologic Data

Catchment ID = Boat Ramp
Area = 0.65 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

Clear Worksheet

II. Rainfall Information   I (inch/hr) = C1 * P1 /(C2 + Td)^C3

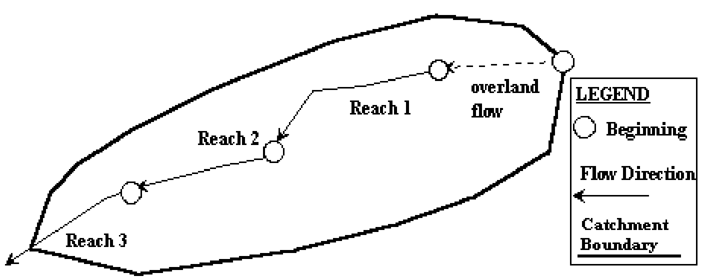
Design Storm Return Period, Tr = 10 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 1.55 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.92
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.90	N/A	1.13	4.44
1	0.1000	213		20.00	6.32	0.56
2						
3						
4						
5						
	Sum	513			Computed Tc =	5.00
					Regional Tc =	12.85
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 5.26 inch/hr   Peak Flowrate, Qp = 3.13 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Storage

I. Catchment Hydrologic Data

Catchment ID = Boat Ramp
Area = 0.65 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

Clear Worksheet

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

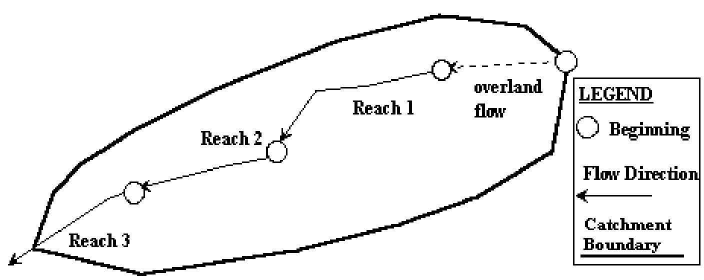
Design Storm Return Period, Tr = 100 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 2.60 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.96
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.90	N/A	1.13	4.44
1	0.1000	213		20.00	6.32	0.56
2						
3						
4						
5						
	Sum	513			Computed Tc =	5.00
					Regional Tc =	12.85
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 8.82 inch/hr

Peak Flowrate, Qp = 5.48 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Storage

I. Catchment Hydrologic Data

Catchment ID = Boat Storage

Clear Worksheet

Area = 0.46 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

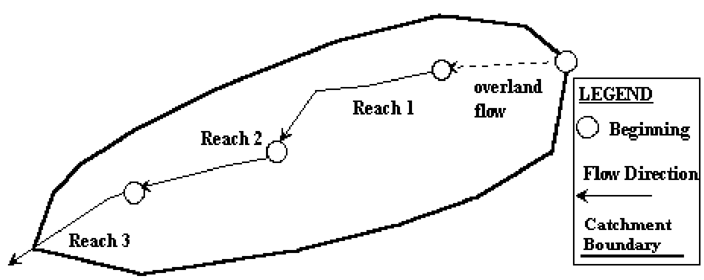
Design Storm Return Period, Tr = 2 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 0.95 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.89
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	254	0.90	N/A	1.04	4.09
1						
2						
3						
4						
5						
Sum		254			Computed Tc =	4.09
					Regional Tc =	11.41
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 3.38 inch/hr   Peak Flowrate, Qp = 1.38 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Storage

I. Catchment Hydrologic Data

Clear Worksheet

Catchment ID = Boat Storage
Area = 0.46 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

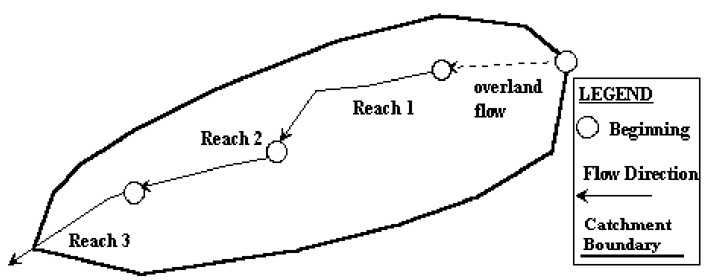
Design Storm Return Period, Tr = 5 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 1.35 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.90
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	254	0.90	N/A	1.04	4.09
1						
2						
3						
4						
5						
Sum		254			Computed Tc =	4.09
					Regional Tc =	11.41
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 4.81 inch/hr

Peak Flowrate, Qp = 1.98 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Storage

I. Catchment Hydrologic Data

Clear Worksheet

Catchment ID = Boat Storage
Area = 0.46 Acres
Percent Imperviousness = 100.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

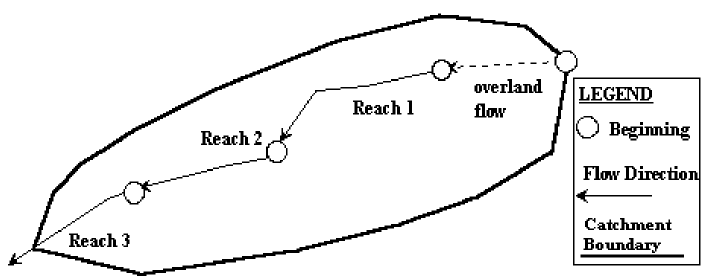
Design Storm Return Period, Tr = 10 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 1.55 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.92
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.90
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	254	0.90	N/A	1.04	4.09
1						
2						
3						
4						
5						
Sum		254				

Computed Tc = 4.09
Regional Tc = 11.41
User-Entered Tc = 5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 5.52 inch/hr
Peak Flowrate, Qp = 2.33 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Boat Storage

I. Catchment Hydrologic Data

Catchment ID = Boat Storage

Area = 0.46 Acres

Percent Imperviousness = 100.00 %

NRCS Soil Type = D A, B, C, or D

Clear Worksheet

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

Design Storm Return Period, Tr = 100 years (input return period for design storm)

C1 = 28.50 (input the value of C1)

C2= 10.00 (input the value of C2)

C3= 0.786 (input the value of C3)

P1= 2.60 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

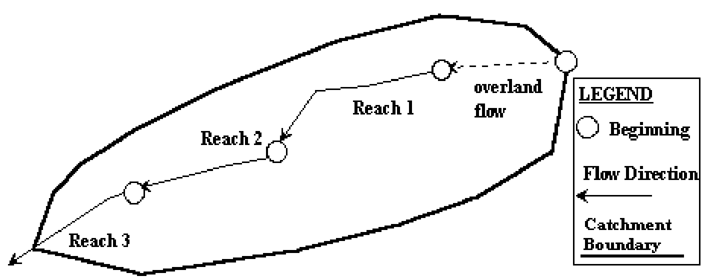
Runoff Coefficient, C = 0.96

Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)

5-yr. Runoff Coefficient, C-5 = 0.90

Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	254	0.90	N/A	1.04	4.09
1						
2						
3						
4						
5						
	Sum	254			Computed Tc =	4.09
					Regional Tc =	11.41
					User-Entered Tc =	5.00

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 9.26 inch/hr

Peak Flowrate, Qp = 4.07 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Parking Lot

I. Catchment Hydrologic Data

Clear Worksheet

Catchment ID = Parking Lot
Area = 3.80 Acres
Percent Imperviousness = 76.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

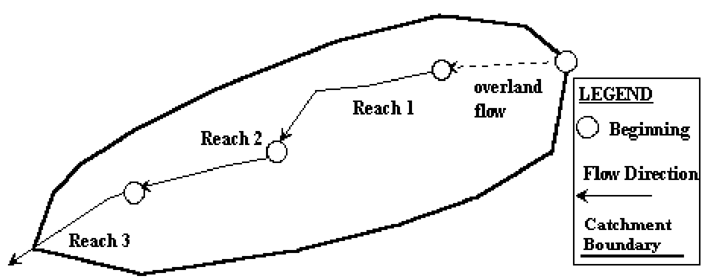
Design Storm Return Period, Tr = 2 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 0.95 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.55
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.58
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.58	N/A	0.45	11.21
1	0.0150	326		20.00	2.45	2.22
2						
3						
4						
5						
	Sum	626			Computed Tc =	13.43
					Regional Tc =	13.48
					User-Entered Tc =	13.43

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 2.27 inch/hr

Peak Flowrate, Qp = 4.75 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Parking Lot

I. Catchment Hydrologic Data

Clear Worksheet

Catchment ID = Parking Lot
Area = 3.80 Acres
Percent Imperviousness = 76.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

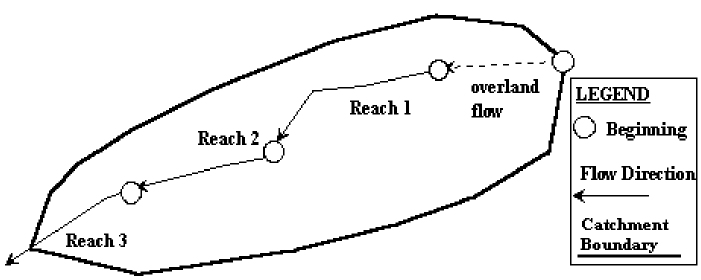
Design Storm Return Period, Tr = 5 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 1.35 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.58
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.58
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.58	N/A	0.45	11.21
1	0.0150	326		20.00	2.45	2.22
2						
3						
4						
5						
	Sum	626			Computed Tc =	13.43
					Regional Tc =	13.48
					User-Entered Tc =	13.43

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 3.23 inch/hr

Peak Flowrate, Qp = 7.17 cfs

amec

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Parking Lot

I. Catchment Hydrologic Data

Catchment ID = Parking Lot
Area = 3.80 Acres
Percent Imperviousness = 76.00 %
NRCS Soil Type = D A, B, C, or D

Clear Worksheet

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

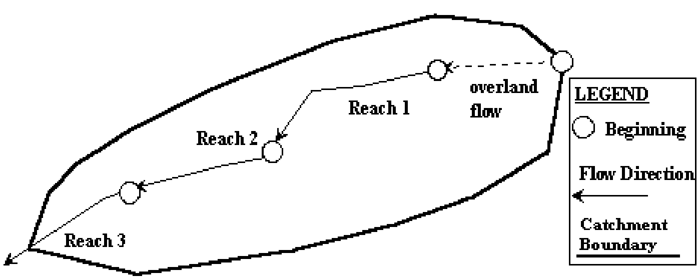
Design Storm Return Period, Tr =	10 years	(input return period for design storm)
C1 =	28.50	(input the value of C1)
C2=	10.00	(input the value of C2)
C3=	0.786	(input the value of C3)
P1=	1.55 inches	(input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.62
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.58
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.58	N/A	0.45	11.21
1	0.0150	326		20.00	2.45	2.22
2						
3						
4						
5						
Sum		626			Computed Tc =	13.43
					Regional Tc =	13.48
					User-Entered Tc =	13.43

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 3.70 inch/hr

Peak Flowrate, Qp = 8.78 cfs

CALCULATION OF A PEAK RUNOFF USING RATIONAL METHOD

Project Title: Cherry Creek West Boat Ramp Parking Lot
Catchment ID: Parking Lot

I. Catchment Hydrologic Data

Clear Worksheet

Catchment ID = Parking Lot
Area = 3.80 Acres
Percent Imperviousness = 76.00 %
NRCS Soil Type = D A, B, C, or D

II. Rainfall Information I (inch/hr) = C1 * P1 /(C2 + Td)^C3

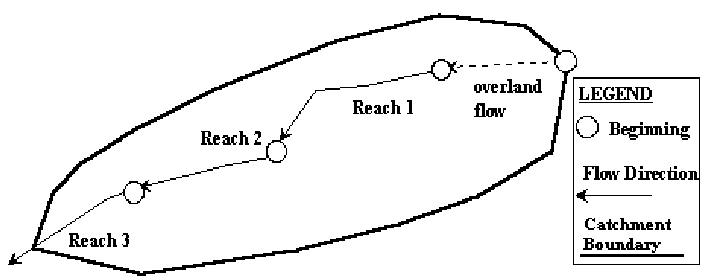
Design Storm Return Period, Tr = 100 years (input return period for design storm)
C1 = 28.50 (input the value of C1)
C2= 10.00 (input the value of C2)
C3= 0.786 (input the value of C3)
P1= 2.60 inches (input one-hr precipitation--see Sheet "Design Info")

Click here to accept Denver area default values for C1, C2, & C3

III. Analysis of Flow Time (Time of Concentration) for a Catchment

Runoff Coefficient, C = 0.71
Overide Runoff Coefficient, C = (enter an overide C value if desired, or leave blank to accept calculated C.)
5-yr. Runoff Coefficient, C-5 = 0.58
Overide 5-yr. Runoff Coefficient, C = (enter an overide C-5 value if desired, or leave blank to accept calculated C-5.)

Illustration



NRCS Land Type	Heavy Meadow	Tillage/ Field	Short Pasture/ Lawns	Nearly Bare Ground	Grassed Swales/ Waterways	Paved Areas & Shallow Paved Swales (Sheet Flow)
Conveyance	2.5	5	7	10	15	20

Calculations:

Clear Table

Reach ID	Slope S ft/ft input	Length L ft input	5-yr Runoff Coeff C-5 output	NRCS Convey-ance input	Flow Velocity V fps output	Flow Time Tf minutes output
Overland	0.0300	300	0.58	N/A	0.45	11.21
1	0.0150	326		20.00	2.45	2.22
2						
3						
4						
5						
	Sum	626			Computed Tc =	13.43
					Regional Tc =	13.48
					User-Entered Tc =	13.43

IV. Peak Runoff Prediction

Rainfall Intensity at Computed Tc, I = 6.21 inch/hr

Peak Flowrate, Qp = 16.86 cfs

4.0 Water Quality Capture Volume Calculations

$$WQCV = a * (0.91I3 \quad - 1.19I2 \quad + 0.78I)$$

Parking Lot		
a =	0.8	
I =	0.75	
WQCV =	0.24	in
Area =	167094	ft^2
WQCV =	**3,337**	**ft^3**
Boat Ramp		
a =	0.8	
I =	1	
WQCV =	0.4	in
Area =	28342	ft^2
WQCV =	**945**	**ft^3**
Boat Storage		
a =	0.8	
I =	1	
WQCV =	0.40	in
Area =	20200	ft^2
WQCV =	**673**	**ft^3**

Appendix B: Water Quality Analysis Memorandum

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bill.ruzzo@comcast.net

Memorandum

To: Rick Goncalves, P.E., TAC Chairman

CC: Dorothy Eisenbraun, P.E., AMEC

From: William P. Ruzzo, P.E.

Date: November 18, 2011, Revised December 2, 2011

Re: West Boat Ramp Parking Lot Improvements – Water Quality Analysis

---

Presented in this memorandum is an evaluation of water quality benefits associated with alternative plans to reduce water quality impacts from the West Boat Ramp Parking lot located in Cherry Creek State Park.

AMEC was retained by the Authority to prepare a PRF water quality management plan for the West Boat Ramp Parking Lot (Project). The management plan includes, among other tasks, identification and investigation of alternatives to reduce water quality impacts to Cherry Creek reservoir from storm runoff. AMEC has identified four alternative plans[1] to address water quality impacts from the Project area and prepared conceptual level plans and a cost estimate for each alternative plan. Each of these alternative plans were then evaluated by the Authority for water quality benefits associated with reduction in total phosphorus (Tp), total suspended sediment (TSS), and oil/grease. The results of the analysis are presented herein.

AMEC presented the recommended plan to the Technical Advisory Committee (TAC) at the December 1, 2011 meeting. The TAC requested that the water quality analysis include the status quo or no-action alternative; therefore this memorandum was revised to include a discussion of this alternative.

APPROACH

Water quality benefits for the Project were calculated based on reduction in annual pollutant loads that are discharged to the Reservoir, namely Tp, TSS, and oil/grease. The hydrologic basis for all alternatives is to capture runoff up to the storm inlet capacity (approximately the 5-year) and either divert runoff to a detention pond or

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[1] AMEC November 2011. *Alternative Analysis Cherry Creek Reservoir West Boat Ramp Parking Lot Water Quality Improvements.* (draft report).

treat the runoff using a proprietary BMP prior to discharging into the Reservoir. To evaluate water quality benefits, calculations were made to determine:

1. Annual Tp and TSS loads from the Project area.
2. Estimate of the long-term performance in Tp and TSS for each alternative described below:
   - 2.1. Alternative 1-A: Water quality detention with pipe conveyance
   - 2.2. Alternative 1-B: Water quality detention with pipe and swale conveyance
   - 2.3. Alternative 2-A: Proprietary BMP – Hydrodynamic Separator
   - 2.4. Alternative 2-B: Proprietary BMP – Filtration System
3. Calculation of annual Tp and TSS reduction load reduction for each alternative.
4. Comparison of the capital and annual costs per pound of Tp and TSS for each alternative.

Because quantification of oil/grease is not available, the ability of each alternative to control oil/grease was qualitatively evaluated relative to other alternatives investigated.

Calculations and data used to perform the analysis are attached to this memorandum.

Annual Tp and TSS Loads.

Determination of annual loads was made using event mean concentrations (EMC) and estimate of mean annual storm runoff from the Project area. EMCs for Tp were obtained from the Authority's watershed model[2], which were derived specifically for the Cherry Creek watershed. EMC's for TSS were obtained from Table 1-1 in Urban Drainage & Flood Control District (UDFCD[3]) Volume 3 Manual. Calculation of mean storm runoff volume procedures are also documented in the Authority's watershed model report. Annual Tp and TSS load calculations are provided on Sheet 1/2 in the appendix.

Performance Estimate.

The alternatives represent four different treatment technologies including extended detention basin (EDB), grassed swale, proprietary filter system, and proprietary hydrodynamic system. The primary source for performance of these BMPs can be found in the UDFCD Volume 3 Manual in Table 2-2.

As presented in Table 2-2, BMP performance (i.e.: effluent concentration) is dependent on influent concentration. Therefore, adjustments to the BMP performance (i.e.: effluent concentration) were necessary, since EMC used in this analysis differ from the data set provided in Table 2-2. The adjustment in performance was calculated as the ratio of Table 2-2 effluent to influent

[2] CCBWQA February 2009. *Cherry Creek Basin Watershed Phosphorus Model Documentation.*
[3] UDFCD 2010. *Urban Storm Drainage Criteria Manual Volume 3, Best Management Practices.*

concentration times the EMC used in the Authority's analysis. Calculations of these adjustments are provided in sheet 2/3 of the appendix.

In addition to the performance adjustments, it was also necessary to make assumptions for the ability of the hydrodynamic separator to remove Tp and TSS, due to lack of available data. For the Authority's analysis, the hydrodynamic separator was assumed to remove 10% of the Tp and 75% of TSS, due to its ability to trap fine sediment.

For the proprietary filter system, the performance values listed in Table 2-2 for "media filters" were used to calculate BMP effluent concentrations.

Calculations of annual Tp and TSS load reductions for alternatives 1-A and 1-B are provided on Sheet 3/4 and calculations for alternatives 2-A and 2-B are provided on Sheet 4/-.

No-Action Alternative. The no-action alternative assumes that no improvements will be made to reduce the discharge of pollutants to Cherry Creek Reservoir. This means that phosphorus, sediment, and oil and grease would continue to drain into the reservoir during storm events.

Pollutants have a negative impact on reservoir water quality, therefore, beneficial uses (i.e.: swimming, boating, fishing, etc.) can be impaired which in turn has a negative impact on the economic value of the reservoir. Economic analysis of Cherry Creek Reservoir has estimated the present value may be over $1 billion[4]. However, no attempt has been made to quantify or otherwise estimate the economic impact of the no-action alternative associated with park uses for recreation.

The financial impact of a no-action alternative is related, at least in part, to the cost to prevent or minimize the discharge of pollutants. The Authority evaluated 27 individual projects on its long term capital improvement program (CIP) list to determine cost per pound of phosphorus that is prevented from being discharged to the reservoir by construction of the project. The cost per pound ranges from $100 to over $2,500 per pound with an annual average around $1,100. Data regarding cost of preventing sediment from being discharge to the reservoir is not available and no estimate was made for this water quality analysis.

RESULTS

Presented in the following table is a summary of alternative costs, reduction in annual Tp and TSS loads, and a qualitative assessment of their ability to reduce oil and grease from being discharged to the Reservoir.

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[4] Stratus Consulting August 2, 2000. *Preliminary Evaluation of Recreational Value Provided by Cherry Creek State Park.*

Summary of Water Quality Benefits for each Alternative

Altern.	Description	Cost			Phosphorus Treatment		Sediment Treatment		Oil and Grease
		Capital	O&M	Annual					
		(usd)	(usd)	(usd)	(lbs)	$/lb	(lbs)	$/lb	
	No-Action	$ -	$ -	$ 1,100	2.6	$ 2,854	1,796	---	
1-A	EDB w/Pipe Diversion	$ 209,880	$ 1,000	$ 12,245	1.4	$ 9,050	1,308	$ 9	Poor to good w/baffle system at inlet
1-B	EDB w/Pipe & Swale Diversion	$ 140,863	$ 1,500	$ 9,048	1.4	$ 6,680	1,635	$ 6	Poor to good w/baffle system at inlet
2-A	Proprietary Hydrodynamic Separator	$ 180,327	$ 22,000	$ 31,663	0.3	$ 122,050	1,347	$ 24	Good
2-B	Proprietary Filter System	$ 269,418	$ 27,000	$ 28,448	1.2	$ 24,370	1,469	$ 19	Good to Very Good

Note that for the “no-action” alternative, the average annual cost of phosphorus that is prevented from being discharged to the reservoir (i.e.: $1,100) is believed to be a conservatively low value since it does not include economic impacts to recreational uses of the reservoir.

Based on this comparison, Alternate 1-B is the highest ranked alternative because:

1. It has the lowest annual cost
2. It has the lowest annual cost per pound of phosphorus and sediment removed.

CALCULATION APPENDIX

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
WEST BOAT RAMP PARKING LOT
ESTIMATE OF ANNUAL POLLUTANT LOADS

Sheet 1/2

REFERENCE

1 EMC's for Total P from CCBWQA Feb 2009. *Cherry Creek Basin Watershed Phosphorus Model Documentation*

2 EMC's for TSS and BMP effluent EMC's from: UDFCD 2010. *Urban Storm Drainage Crieria Manual Volume 3,* Table 1-2 & 2-2

EVENT MEAN CONCENTRATIONS:

Land Use	Total P, (mg/l)	TSS, (mg/l)
	EMC	**EMC**
Industrial	0.33	399
Commercial	0.33	225
Residential	0.49	240
Undeveloped.	0.28	400

MEAN PRECIPITATION

Mean storm =	0.43	inches
Avg # of Runoff producting events per year =	32	storms
Mean annual =	13.8	inches

MEAN ANNUAL POLLUTANT LOAD POTENTIAL

Parking Lot Imp Area =	2.85	Ac	(paved area only)
% I =	100%		
2-yr Runoff Coeff =	0.90		
Annual Runoff Vol =	2.93	AF	
EMC (phos) =	0.33	mg/l	
EMC (TSS) =	225	mg/l	
Total Load (phos) =	**2.6**	**lbs**	
Total Load (TSS) =	**1796**	**lbs**	

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
WEST BOAT RAMP PARKING LOT
ESTIMATE OF BMP PERFORMANCE

Sheet 2/3

REFERENCE

1 EMC's for Total P from CCBWQA Feb 2009. *Cherry Creek Basin Watershed Phosphorus Model Documentation*

2 EMC's for TSS and BMP effluent EMC's from: UDFCD 2010. *Urban Storm Drainage Crieria Manual Volume 3,* Table 1-2 & 2-2

EXTENDED DETENTION BASIN/WET POND

1. The existing boat storage pond will retain some runoff and infiltrate into the ground or evaporate. Therefore, use "retention pond" EMC in Table 2-2 for influent and effluent
2. Use UDFCD Table 2-2 to estimate effluent (discharge) EMC, but adjust effluent EMC based on ratio of effluent/influent concentrations, similar to % reduction

Table 2-2 EMC Values

Total Phosphorus			Total Suspended Solids		
Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)	Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)
0.23	0.11	0.48	44.5	12.1	0.27

GRASSED SWALE

1. Use UDFCD Table 2-2 to estimate effluent (discharge) EMC, but adjust effluent EMC based on ratio of effluent/influent concentrations, similar to % reduction

Table 2-2 EMC Values

Total Phosphorus			Total Suspended Solids		
Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)*	Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)
0.22	0.23	1.0	54.5	18	0.33

"*" Assume no Total P reduction through grass swale

PROPRIETARY FILTER SYSTEM

1. Use UDFCD Table 2-2 to estimate effluent (discharge) EMC, but adjust effluent EMC based on ratio of effluent/influent concentrations, similar to % reduction
2. Assume the "media filters" performance is similar to proprietary filter system

Table 2-2 EMC Values

Total Phosphorus			Total Suspended Solids		
Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)	Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)
0.2	0.11	0.55	44	8	0.18

PROPRIETARY HYDRODYNAMIC SEPARATOR

1. Use UDFCD Table 2-2 to estimate effluent (discharge) EMC, but adjust effluent EMC based on ratio of effluent/influent concentrations, similar to % reduction
2. Assume that separator will reduce TP by 10% and TSS by 75%

Table 2-2 EMC Values

Total Phosphorus			Total Suspended Solids		
Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)	Influent (mg/l)	Effluent (mg/l)	Ratio (E/I)
n/a	n/a	0.90	n/a	n/a	0.25

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
WEST BOAT RAMP PARKING LOT
ESTIMATE OF ANNUAL POLLUTANT LOAD REDUCTIONS

Sheet 3/4

REFERENCE

1 EMC's for Total P from CCBWQA Feb 2009. *Cherry Creek Basin Watershed Phosphorus Model Documentation*

2 EMC's for TSS and BMP effluent EMC's from: UDFCD 2010. *Urban Storm Drainage Crieria Manual Volume 3,* Table 1-2 & 2-2

LOAD REDUCTION FROM ALTERNATIVE 1-A WATER QUALITY POND W/PIPE

Trib. Area treated EDB =	2.85	Ac	Paved area only
% I =	100%		
2-yr Runoff Coeff =	0.90		
Annual Runoff Vol =	2.93	AF	
Pond Treatment			
Influent EMC (phos) =	0.33	mg/l	
Effluent EMC (phos) =	**0.16**	mg/l	Sheet 2 for adjustment
Effluent Load (phos) =	**1.2**	lbs	
Load Reduction =	**1.4**	lbs	
Influent EMC (TSS) =	225.0	mg/l	
Effluent EMC (TSS) =	**61**	mg/l	Sheet 2 for adjustment
Effluent Load (TSS) =	**488**	lbs	
Load Reduction =	**1308**		
Annual Load (phos) =	2.6	lbs	
Load Reduction (phos) =	**1.4**	**lbs**	
Annual Load (TSS) =	1796	lbs	
Load Reduction (TSS) =	**1308**	**lbs**	

LOAD REDUCTION FROM ALTERNATIVE 1-B WATER QUALITY POND W/SWALE

Trib. Area treated EDB =	2.85	Ac	Paved area only
% I =	100%		
2-yr Runoff Coeff =	0.90		
Annual Runoff Vol =	2.93	AF	
Swale Treatment			
Influent EMC (phos) =	0.33	mg/l	
Effluent EMC (phos) =	**0.33**	mg/l	Sheet 2 for adjustment
Effluent Load (phos) =	**2.6**	lbs	
Load Reduction =	**0.0**	lbs	
Influent EMC (TSS) =	225.0	mg/l	
Effluent EMC (TSS) =	**74**	mg/l	Sheet 2 for adjustment
Effluent Load (TSS) =	**593**	lbs	
Load Reduction =	**1203**	lbs	
Pond Treatment			
Influent EMC (phos) =	0.33	mg/l	from swale
Effluent EMC (phos) =	**0.16**	mg/l	Sheet 2 for adjustment
Effluent Load (phos) =	**1.2**	lbs	
Load Reduction =	**1.4**	lbs	
Influent EMC (TSS) =	74	mg/l	from swale
Effluent EMC (TSS) =	**20**	mg/l	Sheet 2 for adjustment
Effluent Load (TSS) =	161	lbs	
Load Reduction =	**432**	lbs	
Total Treatment			
Load Reduction (phos) =	**1.4**	**lbs**	
Load Reduction (TSS) =	**1635**	**lbs**	

CHERRY CREEK BASIN WATER QUALITY AUTHORITY
WEST BOAT RAMP PARKING LOT
ESTIMATE OF ANNUAL POLLUTANT LOAD REDUCTIONS

Sheet 4/-

REFERENCE

1 EMC's for Total P from CCBWQA Feb 2009. *Cherry Creek Basin Watershed Phosphorus Model Documentation*

2 EMC's for TSS and BMP effluent EMC's from: UDFCD 2010. *Urban Storm Drainage Crieria Manual Volume 3,* Table 1-2 & 2-2

LOAD REDUCTION FROM ALTERNATIVE 2-A HYDRODYNAMIC SEPARATOR

Trib. Area treated EDB =	2.85	Ac	Paved area only
% I =	100%		
2-yr Runoff Coeff =	0.90		
Annual Runoff Vol =	2.93	AF	
Pond Treatment			
Influent EMC (phos) =	0.33	mg/l	
Effluent EMC (phos) =	**0.29**	mg/l	Sheet 2 for adjustment
Effluent Load (phos) =	**2.3**	lbs	
Load Reduction =	**0.3**	lbs	
Influent EMC (TSS) =	225.0	mg/l	
Effluent EMC (TSS) =	**56**	mg/l	Sheet 2 for adjustment
Effluent Load (TSS) =	**449**	lbs	
Load Reduction =	**1347**		
Annual Load (phos) =	2.6	lbs	
Load Reduction (phos) =	**0.3**	**lbs**	
Annual Load (TSS) =	1796	lbs	
Load Reduction (TSS) =	**1347**	**lbs**	

LOAD REDUCTION FROM ALTERNATIVE 2-B FILTER SYSTEM

Trib. Area treated EDB =	2.85	Ac	Paved area only
% I =	1.00		
2-yr Runoff Coeff =	0.90		
Annual Runoff Vol =	2.93	AF	
Filter System			
Influent EMC (phos) =	0.33	mg/l	
Effluent EMC (phos) =	**0.18**	mg/l	Sheet 2 for adjustment
Effluent Load (phos) =	**1.4**	lbs	
Load Reduction =	**1.2**	lbs	
Influent EMC (TSS) =	225.0	mg/l	
Effluent EMC (TSS) =	**41**	mg/l	Sheet 2 for adjustment
Effluent Load (TSS) =	**327**	lbs	
Load Reduction =	**1469**		
Annual Load (phos) =	2.6	lbs	
Load Reduction (phos) =	**1.2**	**lbs**	
Annual Load (TSS) =	1796	lbs	
Load Reduction (TSS) =	**1469**	**lbs**	

Table 1-2. Event Mean Concentrations (mg/L) of Constituents in Denver Metropolitan Area Runoff
(per DRURP and Phase I Stormwater CDPS Permit Application for Denver, Lakewood and Aurora)
(Source: Aurora et al. 1992. *Stormwater NPDES Part 2 Permit Application Joint Appendix* and DRCOG 1983. *Urban Runoff Quality in the Denver Region.*

Constituent	Natural Grassland	Commercial	Residential	Industrial
Total Phosphorus (TP)	0.40	0.42	0.65	0.43
Dissolved or Orthophosphorus (PO_4)	0.10	0.15	0.22	0.2
Total Nitrogen (TN)	3.4	3.3	3.4	2.7
Total Kjeldahl Nitrogen (TKN)	2.9	2.3	2.7	1.8
Ammonia Nitrogen (NH_3)	0.1	1.5	0.7	1.2
Nitrate + Nitrite Nitrogen (NO_3/NO_2)	0.50	0.96	0.65	0.91
Lead (Total Recoverable) (Pb)	0.100	0.059	0.053	0.130
Zinc (Total Recoverable) (Zn)	0.10	0.24	0.18	0.52
Copper (Total Recoverable) (Cu)	0.040	0.043	0.029	0.084
Cadmium (Total Recoverable) (Cd)	Not Detected	0.001	Not Detected	0.003
Chemical Oxygen Demand (COD)	72	173	95	232
Total Organic Carbon (TOC)	26	40	72	22-26
Total Suspended Solids (TSS)	400	225	240	399
Total Dissolved Solids (TDS)	678	129	119	58
Biochemical Oxygen Demand (BOD)	4	33	17	29

Table 2-2. BMP Effluent EMCs (Source: International Stormwater BMP Database, August

Solids and Nutrients (milligrams/liter)										
BMP Category	Sample Type	Total Suspended Solids	Total Dissolved Solids	Nitrogen, Total	Total Kjeldahl Nitrogen (TKN)	Nitrogen, Ammonia as N	Nitrogen, Nitrate (NO3) as N*	Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N*	Phosphorus as P, Total	Phosphorus, Orthophosphate as P
Bioretention (w/Underdrain)	Inflow	44.6 (41.8-53.3, n= 6)	NC	1.46 (1.24-1.63, n= 7)	1.22 (1.00-1.33, n= 8)	0.19 (0.16-0.23, n= 8)	NC	0.30 (0.25-0.38, n= 10)	0.13 (0.12-0.17, n= 12)	0.04 (0.01-0.10, n= 7)
	Outflow	12.9 (6.8-17.3, n= 6)	NC	1.15 (0.92-2.98, n= 7)	0.94 (0.60-2.09, n= 8)	0.06 (0.05-0.38, n= 8)	NC	0.21 (0.14-0.29, n= 10)	0.13 (0.08-0.19, n= 12)	0.06 (0.03-0.33, n= 7)
Grass Buffer	Inflow	52.3 (50.0-63.3, n= 14)	57.5 (32.0-89.3, n= 12)	NC	1.40 (1.15-2.10, n= 13)	0.38 (0.23-0.64, n= 10)	0.44 (0.42-0.92, n= 13)	NC	0.18 (0.09-0.25, n= 14)	0.04 (0.03-0.06, n= 10)
	Outflow	22.3 (15.0-28.3, n= 14)	88.0 (73.3-110.0, n= 12)	NC	1.20 (0.95-1.50, n= 13)	0.25 (0.13-0.36, n= 9)	0.33 (0.23-0.78, n= 13)	NC	0.30 (0.11-0.56, n= 14)	0.10 (0.05-0.29, n= 10)
Grass Swale	Inflow	54.5 (30.5-76.5, n= 15)	79.5 (64.2-100.1, n= 12)	NC	1.83 (1.40-2.11, n= 12)	0.06 (0.02-0.09, n= 4)	0.41 (0.23-0.78, n= 12)	0.25 (0.19-0.37, n= 4)	0.22 (0.13-0.29, n= 15)	0.04 (0.03-0.04, n= 3)
	Outflow	18.0 (8.9-39.5, n= 19)	71.0 (34.9-85.0, n= 10)	0.60 (0.55-1.34, n= 6)	1.23 (0.41-1.48, n= 16)	0.05 (0.03-0.06, n= 8)	0.29 (0.21-0.66, n= 15)	0.22 (0.18-0.31, n= 8)	0.23 (0.19-0.31, n= 19)	0.10 (0.08-0.12, n= 7)
Detention Basin (aboveground extended det.)	Inflow	59.5 (17.8-83.8, n= 18)	88.5 (85.0-98.8, n= 6)	1.05 (1.04-1.25, n= 3)	1.32 (0.77-1.70, n= 10)	0.08 (0.04-0.10, n= 5)	0.45 (0.30-0.90, n= 8)	0.23 (0.17-0.50, n= 5)	0.20 (0.18-0.30, n= 17)	NC
	Outflow	22.0 (11.6-28.5, n= 20)	85.0 (54.3-113.5, n= 6)	2.54 (1.7-2.69, n= 3)	1.66 (0.86-1.95, n= 10)	0.09 (0.07-0.10, n= 5)	0.40 (0.27-0.85, n= 8)	0.17 (0.08-0.43, n= 6)	0.20 (0.13-0.26, n= 18)	NC
Media Filters (various types)	Inflow	44.0 (32.0-75.0, n= 21)	42.0 (28.4-59.0, n= 13)	1.51 (0.73-1.80, n= 5)	1.53 (0.87-2.00, n= 17)	0.34 (0.08-1.12, n= 11)	0.38 (0.23-0.57, n= 16)	0.33 (0.23-0.51, n= 6)	0.20 (0.13-0.33, n= 21)	0.02 (0.02-0.06, n= 7)
	Outflow	8.0 (5.0-17.0, n= 21)	55.0 (46.0-62.0, n= 13)	0.63 (0.43-1.41, n= 4)	0.80 (0.50-1.22, n= 17)	0.11 (0.04-0.15, n= 10)	0.66 (0.39-0.73, n= 16)	0.43 (0.05-1.00, n= 5)	0.11 (0.06-0.15, n= 21)	0.02 (0.02-0.06, n= 7)
Retention Pond (aboveground wet pond)	Inflow	44.5 (24.0-88.3, n= 40)	89.0 (59.3-127.5, n= 9)	1.71 (1.07-2.36, n= 19)	1.18 (0.77-1.42, n= 28)	0.09 (0.04-0.15, n= 23)	0.43 (0.32-0.69, n= 15)	0.27 (0.11-0.55, n= 24)	0.23 (0.14-0.39, n= 38)	0.09 (0.07-0.21, n= 26)
	Outflow	12.1 (7.9-19.7, n= 40)	151.3 (70.8-182.0, n= 9)	1.31 (1.01-1.54, n= 19)	0.99 (0.76-1.29, n= 30)	0.07 (0.04-0.17, n= 24)	0.19 (0.13-0.26, n= 15)	0.05 (0.02-0.20, n= 24)	0.11 (0.07-0.19, n= 40)	0.05 (0.02-0.08, n= 27)
Wetland Basin	Inflow	39.6 (24.0-56.8, n= 14)	NA	1.54 (1.07-2.16, n= 6)	1.10 (0.77-1.30, n= 4)	0.10 (0.04-0.13, n= 8)	0.32 (0.32-0.44, n= 5)	0.46 (0.11-0.63, n= 7)	0.12 (0.14-0.27, n= 11)	0.04 (0.07-0.13, n= 5)
	Outflow	12.0 (8.5-17.5, n= 16)	NC	1.16 (0.98-1.39, n= 6)	1.00 (0.90-1.14, n= 8)	0.06 (0.04-0.10, n= 8)	0.12 (0.10-0.16, n= 7)	0.17 (0.05-0.34, n= 7)	0.08 (0.05-0.14, n= 13)	0.06 (0.02-0.25, n= 7)
Permeable Pavement**	Inflow	23.5 (16.0-45.3, n = 5)	NA	NC	2.40 (1.80-3.30, n = 3)	NC	NC	0.59 (0.27-0.80, n = 5)	0.12 (0.10-0.13, n = 5)	NC
	Outflow	29.1 (16.3-34.0, n = 7)	NA	NC	1.05 (0.90-1.33, n = 7)	NC	NC	1.24 (1.21-1.39, n = 4)	0.13 (0.10-0.19, n = 5)	NC

*Some BMP studies include analyses for both NO2/NO3 and NO3; therefore, these analytes are reported separately, even though results are expected to be comparable in stormwater runoff.

Table Notes provided below part 2 of this table.

BMP Category	Sample Type	Metals (micrograms/liter) Arsenic, Diss.	Arsenic, Total	Cadmium, Diss.	Cadmium, Total	Chromium, Diss.	Chromium, Total	Copper, Diss.	Copper, Total	Lead, Diss.	Lead, Total	Nickel, Diss.	Nickel, Total	Zinc, Diss.	Zinc, Total
Bioretention (w/Underdrain)	Inflow	NA	NC	NC	NC	NC	NC	NC	19.5 (15.3-35.8, n= 3)	NC	NC	NC	NC	NC	68.0 (51-68.5, n= 5)
	Outflow	NA	NC	NC	NC	NC	NC	NC	10.0 (7.3-16.8, n= 3)	NC	NC	NC	NC	NC	8.5 (5.0-35.0, n= 5)
Grass Buffer	Inflow	0.8 (0.5-1.2, n= 12)	1.1 (0.9-2.3, n= 12)	0.2 (0.1-0.2, n= 12)	0.4 (0.3-0.8, n= 12)	2.4 (1.1-4.5, n= 12)	4.9 (2.9-7.4, n= 13)	12.9 (6.8-17.3, n= 12)	21.2 (15.0-41.0, n= 13)	0.9 (0.5-2.0, n= 12)	11.0 (6-35, n= 13)	2.9 (1.1-3.2, n= 12)	4.8 (3.4-8.4, n= 12)	37.8 (12.8-70, n= 12)	100.5 (53.0-245.0, n= 13)
	Outflow	1.2 (0.5-2.4, n= 12)	2.0 (0.7-3.0, n= 12)	0.1 (0.1-0.2, n= 12)	0.2 (0.1-0.2, n= 12)	2.3 (1.0-3.8, n= 12)	2.9 (2.0-5.5, n= 13)	7.1 (4.8-11.6, n= 12)	8.3 (6.4-12.5, n= 13)	0.5 (0.5-1.3, n= 12)	3.2 (1.8-6.0, n= 13)	2.1 (2.0-2.3, n= 12)	2.6 (2.2-3.2, n= 12)	19.8 (10.7-24.3, n= 12)	25.5 (15.0-57.9, n= 13)
Grass Swale	Inflow	0.6 (0.5-2.2, n= 9)	1.7 (1.6-2.7, n= 9)	0.3 (0.1-0.4, n= 13)	0.5 (0.4-0.9, n= 14)	2.2 (1.1-3.3, n= 7)	6.1 (3.6-8.3, n= 7)	10.6 (8.1-15.0, n= 13)	33.0 (26-34, n= 13)	1.4 (0.6-6.7, n= 13)	21.6 (12.5-46.4, n= 14)	5.1 (4.5-6.6, n= 6)	8.7 (7-12.5, n= 6)	40.3 (35.3-109.0, n= 13)	149.5 (43.8-244.3, n= 15)
	Outflow	0.6 (0.6-1.2, n= 8)	1.2 (0.9-1.7, n= 8)	0.2 (0.1-0.2, n= 12)	0.3 (0.2-0.4, n= 13)	1.1 (1.0-3.0, n= 6)	3.5 (1.7-5.0, n= 6)	8.6 (5.5-9.7, n= 13)	14.0 (6.7-18.5, n= 17)	1.0 (0.5-4.1, n= 13)	10.5 (1.7-12.0, n= 18)	2.0 (2.0-2.3, n= 5)	4.0 (3.1-4.5, n= 5)	22.6 (20.1-33.2, n= 13)	55.0 (20.6-65.4, n= 19)
Detention Basin (aboveground extended det.)	Inflow	1.1 (0.9-1.2, n= 5)	2.1 (1.3-2.6, n= 6)	0.3 (0.2-0.4, n= 8)	0.6 (0.3-1.2, n= 11)	2.6 (2.0-3.2, n= 3)	5.6 (5.0-6.5, n= 6)	5.8 (2.6-11.8, n= 8)	10.0 (4.8-33.5, n= 11)	1.0 (0.5-1.4, n= 8)	10.0 (1.5-41.0, n= 11)	2.9 (1.9-3.9, n= 4)	6.3 (5-9.4, n= 5)	16.4 (6.1-53.5, n= 8)	125.0 (21.5-225.3, n= 11)
	Outflow	1.2 (0.9-1.2, n= 5)	1.7 (1.1-1.9, n= 6)	0.3 (0.2-0.4, n= 9)	0.4 (0.2-0.6, n= 12)	1.9 (1.7-3.0, n= 4)	2.9 (1.9-3.8, n= 6)	9.0 (3.0-13.0, n= 9)	11.0 (6.2-20.1, n= 12)	1.0 (0.5-1.3, n= 9)	9.5 (1.3-18.6, n= 12)	3.1 (2.0-3.2, n= 5)	4.3 (3.2-5.4, n= 6)	19.0 (7.8-54.0, n= 9)	48.5 (19.1-94.0, n= 13)
Media Filters (various types)	Inflow	0.7 (0.5-1.1, n= 12)	1.1 (0.6-1.6, n= 12)	0.2 (0.2-0.2, n= 14)	0.4 (0.2-1.0, n= 17)	1.0 (1.0-1.0, n= 13)	2.1 (1.4-4.0, n= 13)	6.2 (5.4-7.4, n= 13)	13.5 (8.8-16.4, n= 18)	1.1 (1.0-2.0, n= 14)	9.0 (5.3-22.0, n= 17)	2.0 (2.0-2.7, n= 13)	3.9 (3.3-4.8, n= 13)	42.7 (28.5-79.2, n= 14)	86.0 (51.8-106.0, n= 19)
	Outflow	0.7 (0.6-1.1, n= 12)	1.1 (0.7-1.6, n= 12)	0.2 (0.2-0.2, n= 13)	0.2 (0.1-0.7, n= 17)	1.0 (1.0-1.0, n= 13)	1.0 (1.0-1.9, n= 13)	5.8 (3.1-8.3, n= 13)	7.3 (4.3-9.6, n= 18)	1.0 (1.0-1.0, n= 13)	1.6 (1.0-4.4, n= 17)	2.0 (2.0-2.6, n= 13)	2.9 (2.0-3.9, n= 13)	12.5 (6.7-49.0, n= 13)	20.0 (8.6-35.0, n= 19)
Retention Pond (aboveground wet pond)	Inflow	NC	1.0 (1.0-1.4, n= 3)	0.2 (0.2-0.4, n= 3)	1.0 (0.3-2.6, n= 20)	5.9 (1.6-10.0, n= 4)	5.0 (3.0-7.4, n= 12)	7.0 (6.0-9.5, n= 7)	6.3 (4.3-10.6, n= 26)	2.0 (1.0-5.1.0, n= 11)	9.7 (4-28, n= 33)	10.0 (6.2-10.0, n= 3)	6.5 (3.6-9, n= 8)	30.0 (15.5-42.6, n= 8)	51.8 (43.9-78.1, n= 32)
	Outflow	NC	1.0 (0.8-1.0, n= 3)	0.2 (0.2-0.4, n= 3)	0.4 (0.2-2.5, n= 20)	5.5 (1.0-10.0, n= 4)	2.2 (1.4-5.3, n= 12)	5.0 (4.7-5.8, n= 7)	5.4 (3.0-6.2, n= 26)	1.2 (1.0-4.9, n= 12)	4.7 (1.6-10.0, n= 33)	10.0 (7.2-10.0, n= 3)	2.5 (2.0-5.5, n= 9)	12.5 (9.4-28.6, n= 8)	26.0 (12.0-37.0, n= 33)
Wetland Basin	Inflow	NA	NA	NC	0.3 (0.3-0.4, n= 3)	NA	NA	NC	10.5 (4.3-15.9, n= 4)	NC	16.0 (4.0-23.8, n= 4)	NA	NA	NC	51.0 (43.9-120.8, n= 7)
	Outflow	NA	NA	0.5 (0.3-0.5, n= 3)	0.3 (0.1-0.5, n= 5)	NA	NA	5.0 (5.0-5.7, n= 3)	4.5 (3.3-5.0, n= 6)	1.0 (0.8-1.0, n= 3)	1.0 (1.0-2.5, n= 6)	NA	NA	11.0 (11.0-13.1, n= 3)	15.0 (5.0-28.9, n= 9)
Permeable Pavement**	Inflow	NA	NC	NC	NA	NC	NC	5.0 (2.5-6.4, n =3)	7.0 (4.5-19.4, n = 3)	0.1 (0.03-0.3, n = 3)	2.5 (1.3-15.1, n = 3)	NC	NC	25.0 (19.0-27.5, n = 3)	50.0 (45.0-51.0, n = 5)
	Outflow	NA	NC	NC	0.3 (0.3-0.4, n =3)	NC	NC	6.2 (4.5-6.4, n =4)	9.0 (3.0-14.7, n = 5)	0.3 (0.04-0.5, n = 4)	2.5 (1.3-9.5, n = 7)	NC	NC	14.6 (13.5-16.0, n = 4)	22.0 (20.0-31.6, n = 7)

Table Key

Sample Type	Analyte	Description
Inflow	52.3	= Median inflow value
	(50-63.3, n= 14)	= Interquartile range, sample size
Outflow	22.3	= Median outflow value
	(15-28.3, n= 14)	= Interquartile range, sample size

NA = Not available; studies containing 3 or more storms not available.
NC = Not calculated because fewer than 3 BMP studies for this category.
Interquartile Range = 25th percentile to 75th percentile values, calculated in Excel, which uses linear interpolation to calculate percentiles. For small sample sizes (particularly n<5), interquartile values may vary depending on statistical package used.

Table Notes:

**Permeable pavement data should be used with caution due to limited numbers of BMP studies and small numbers of storm events typically monitored at these sites. "Inflow" values are typically outflows monitored at a reference conventional paving site.

Descriptive statistics calculated by weighting each BMP study equally. Each BMP study is represented by the median analyte value reported for all storms monitored at each BMP (i.e., "n" = number of BMP studies, as opposed to number of storm events). Depending on the analysis objectives, researchers may also choose to use a storm-weighted analysis approach, a unit treatment process-based grouping of studies, or other screening based on design parameters and site-specific characteristics.

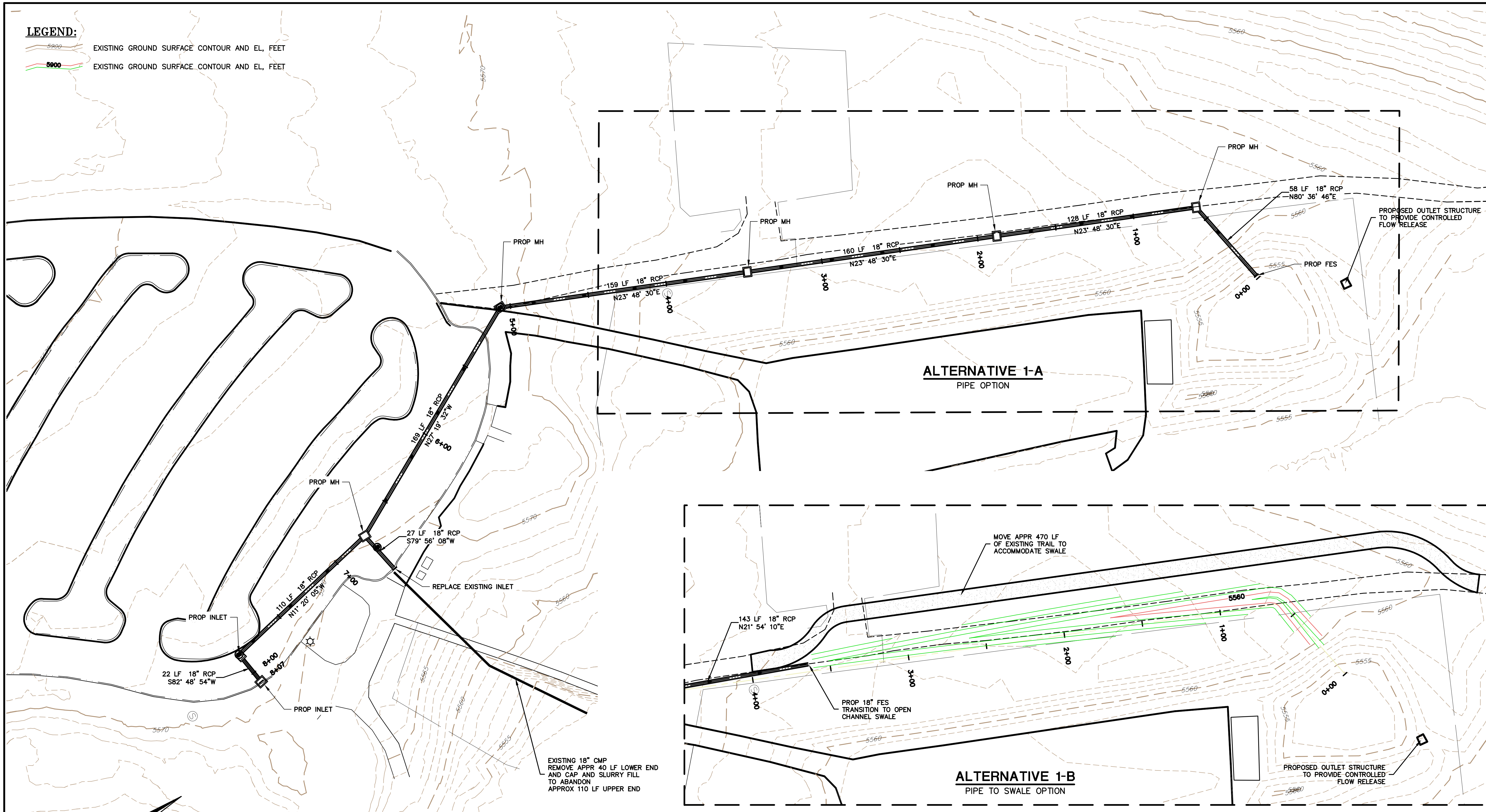
Analysis based on August 2010 BMP Database, which contains substantial changes relative to the 2008 BMP Database. Multiple BMPs have been recategorized into new BMP categories; therefore, the 2008 and 2010 data analysis are not directly comparable for several BMP types.

This table contains descriptive statistics only. Values presented in this table should not be used to draw conclusions related to statistically significant differences in performance for BMP categories. (Hypothesis testing for BMP Categories is provided separately in other BMP Database summaries available at www.bmpdatabase.org.)

These descriptive statistics are based on different statistical measures than those used in the 2008 BMP Database tabular summary. Be aware that results will vary depending on whether a "BMP Weighted" (one median or average value represents each BMP) or "Storm Weighted" (all storms for all BMPs included in statistical calculations) approach is used, as well as whether the median or another measure of central tendency is used. Several BMP Database publications in 2010 have focused on the storm-weighted approach, which may result in some differences between this table and other published summaries.

Values below detection limits replaced with 1/2 of detection limit.

Appendix C: Conceptual Drawings



CLIENT
CHERRY CREEK BASIN WATER QUALITY AUTHORITY

PROJECT
W BOAT RAMP PARKING LOT IMPROVEMENTS ALTERNATIVES ANALYSIS

TITLE
ALTERNATIVE 1
WATER QUALITY POND

0	12/1/11	ISSUED FOR REVIEW	CWM / CWM

DISCLAIMER
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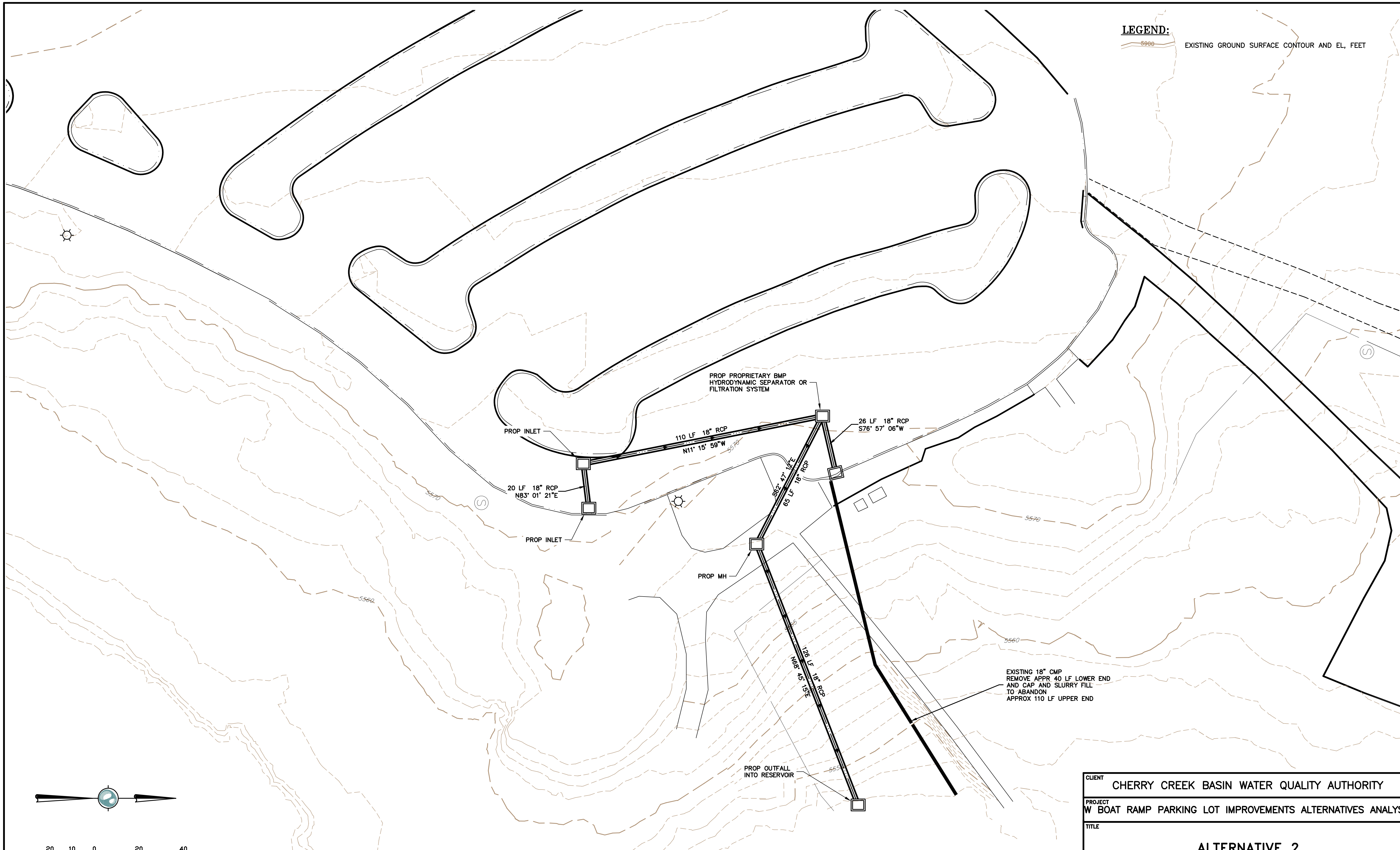
DESIGNED BY	CWM	CHECKED BY	DE
DRAWN BY	CWM	APPROVED BY	DE
FILENAME	ALT 1	DRAWING No. FIG 2	REV 0



REV	DATE	DESCRIPTION	BY
0	12/1/11	ISSUED FOR REVIEW	CWM / CWM

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CLIENT
CHERRY CREEK BASIN WATER QUALITY AUTHORITY

PROJECT
W BOAT RAMP PARKING LOT IMPROVEMENTS ALTERNATIVES ANALYSIS

TITLE
ALTERNATIVE 2
PROPRIETARY BMP

amec EARTH AND ENVIRONMENTAL

DESIGNED BY	CWM	CHECKED BY	DE
DRAWN BY	CWM	APPROVED BY	DE

FILENAME	DRAWING No.	REV
ALT 2	FIG 3	0