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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

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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.

[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

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.

		Metals (micrograms/liter)													
BMP Category	Sample Type	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.