



URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

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SUMMARY REPORT

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SUBJECT: Water quality summary report of the Denver Botanic Gardens green roof

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The Urban Drainage and Flood Control District (UDFCD) partnered with Denver Botanic Gardens (DBG) in 2011 to monitor a new green roof constructed by DBG. The green roof is located on top of a parking structure and is almost half an acre. Adjacent grade on the north side of the parking structure rises up to the green roof to provide a total of three acres of garden space that is open to the public. The top deck of the south side of the structure provides additional parking for DBG.

Green roofs provide multiple benefits to an urban environment, such as air quality improvement, reduced energy requirements for heating and cooling, habitat provision, extended roof lifetime, stormwater runoff reduction, and water quality improvement (EPA, 2010). Since the spring of 2011, UDFCD has monitored the runoff from the DBG green roof to evaluate the benefits associated with stormwater reduction and treatment. UDFCD constructed a sampling manhole to receive stormwater from the underdrain of the green roof. A rain gage and anemometer measure rain and wind speed at the site. Wind speed is used to correct the measured rainfall. When both rain and flow in the underdrain is detected, the automatic sampler located in sampling manhole begins collecting samples of the stormwater. Composite samples from each storm event are analyzed for a number of constituents. Data is collected for storm events that occur during the months of April through October.

In order to evaluate the effectiveness of the green roof, water quality data over several years was monitored by UDFCD at a conventional aggregate rooftop in Denver (referred to as the “control roof”). Although the site is located approximately three miles from DGB, these data provide a comparison for both water quality and runoff volume between a green roof and an alternative conventional roof. Additionally, UDFCD has compared DBG green roof data to commercial runoff collected over several years in the Denver area. This provides a comparison between the DBG green roof runoff and the runoff anticipated if DBG had extended the top deck of this parking structure north (rather than construct the green roof). Note that this is a comparison of runoff from a green roof and that of a commercial site. Although this is relevant to the DBG site, this comparison is not representative of a typical green roof alternative.

Table 1 lists the statistics for constituent concentrations at the green roof and reference sites. The green roof experiences higher concentrations than the conventional roof for all constituents, except for TSS and DOC. While measuring concentration may be useful for meeting a specific water quality objective, it is not necessarily the only measure important to evaluate overall performance. Measuring the pollutant load, or the total amount of constituent mass that passes a point of measurement, may provide more useful information on performance than concentration (EPA, 2014). Because one of the major benefits from green roofs is volume reduction, pollutant loads from green roofs may often be lower than loads from conventional rooftops despite higher concentrations.

Load was calculated by using the event mean concentrations in **Table 1** and multiplying by total annual runoff volume. The total annual runoff volume was estimated by multiplying a site-specific runoff coefficient by the total annual rainfall volume. The total annual rainfall volume used in the calculation was 7450 cubic feet, based on the annual rainfall at the DBG green roof in 2012. The tabulated constituent loads, reported in units of grams per year, represent the expected total load during the sampling season of a typical year. The runoff coefficients for the green roof and the conventional aggregate rooftop were estimated from rainfall and runoff data at each site using only storm events with rainfall between 0.2 and 0.8 inches. Based on data collected during 20 storms from 2011 to 2014, the green roof is estimated to have a runoff coefficient of 0.27 (representing a 73% reduction in runoff volume). Based on data collected during 15 storms from 2011 to 2013 the control roof coefficient is 0.54 (representing a 46% reduction in runoff volume). Runoff coefficients at these sites were estimated by dividing measured outflow by calculated rainfall volume based on the roof area and the measured rainfall depth. The runoff coefficient for a commercial lot was assumed to be 0.8.

Table 2 shows pollutant loads and the load reduction provided by the DBG green roof when compared to a conventional aggregate rooftop. Loads were reduced for most constituents, with TSS and DOC showing the highest load reductions of 77 and 67 percent, respectively. The monitored constituents that did not see load reductions were dissolved phosphorus, orthophosphates, and copper. **Table 3** shows the load reductions provided by the DBG green roof when compared to a commercial lot. When compared to a commercial site, the green roof shows the highest load reduction in TSS and COD of 98 and 88 percent, respectively. The only constituents that did not see load reduction were nitrate plus nitrite and copper.

List of acronyms

COD	Chemical Oxygen Demand
DBG	Denver Botanic Gardens
DOC	Dissolved Organic Carbon
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UDFCD	Urban Drainage and Flood Control District

Table 1. Constituent concentrations

Analyte	DBG Green Roof			Control Roof ¹			Commercial ²		
	n	Mean (95% CIs)	Median (95% CIs)	n	Mean (95% CIs)	Median (95% CIs)	n	Mean (95% CIs)	Median (95% CIs)
Total Kjeldahl Nitrogen (mg/L)	40	2.080 (1.78-2.38)	1.70 (1.50-2.40)	27	1.93 (1.59-2.27)	1.8 (1.6-2.1)	250	2.80 (2.50-3.09)	2.20 (2.03-2.40)
Nitrate Plus Nitrite (mg/L)	41	3.95 (2.58-5.32)	2.83 (1.69-3.70)	27	2.79 (2.24-3.33)	2.55 (1.91-3.44)	253	0.89 (0.79-0.99)	0.72 (0.63-0.78)
Nitrogen, ammonia as N (mg/L)	21	NP	NP	14	0.75 (0.55-0.95)	0.83 (0.5-1)	60	3.14 (2.29-3.98)	2.01 (1.60-2.70)
Phosphorus as P, Total (mg/L)	40	0.40 (0.37-0.44)	0.37 (0.33-0.42)	27	0.21 (0.17-0.25)	0.19 (0.15-0.24)	273	0.35 (0.29-0.42)	0.19 (0.17-0.24)
Phosphorus as P, Dissolved (mg/L)	32	0.37 (0.34-0.40)	0.34 (0.31-0.38)	18	0.14 (0.12-0.16)	0.15 (0.11-0.16)	192	0.13 (0.10-0.15)	0.07 (0.05-0.08)
Phosphorus, Ortho-P (mg/L)	25	0.42 (0.20-0.65)	0.31 (0.29-0.33)	16	0.17 (0.12-0.23)	0.16 (0.09-0.22)	136	0.15 (0.10-0.20)	0.06 (0.06-0.08)
TSS (mg/L)	36	15 (7.5-22)	8.5 (6-10)	26	33 (15-50)	11 (8-23)	280	219 (173-265)	85 (63-125)
COD (mg/L)	31	67 (57-77)	64 (51-70)	18	46 (32-60)	48 (30-61)	156	187 (159-215)	139 (114-162)
DOC (mg/L)	19	19 (17-21)	20 (16-22)	9	29 (4-54)	16 (8-47)	51	35 (24-45)	22 (17-34)
TOC (mg/L)	27	22 (17-26)	18 (16-24)	18	14 (11-17)	14 (9-16)	156	36 (28-44)	21 (18-27)
Cadmium, Total (ug/L)	39	NP	NP	27	0.34 (0.12-0.55)	0 (0-0.4)	147	NP	NP
Copper, Total (ug/L)	39	146 (120-172)	113 (102-148)	27	25 (16-34)	18 (15-22)	249	27 (20-34)	13 (12-16)
Lead, Total (ug/L)	39	NP	NP	27	11 (5-17)	6 (0-11)	209	13 (10-16)	5 (5-6)
Zinc, Total (ug/L)	39	NP	NP	27	321 (231-411)	247 (207-299)	251	156 (120-192)	64 (55-80)

CI = 95% confidence interval provided for mean and median values. n = number of samples. NP = Not provided due to large percentage of non-detects.

¹ Conventional aggregate rooftop in downtown Denver (Alliance Building)

² Monitoring locations limited to Denver Metro area. 1980's lead data excluded from summary due to the phase-out of leaded gasoline.

Table 2. Estimated green roof load reduction from conventional aggregate rooftop

Analyte	DBG Green Roof		Control Roof		Load Reduction
	Concentration (mg/L)	Load (g/yr)	Concentration (mg/L)	Load (g/yr)	
Total Kjeldahl Nitrogen	2.08	118	1.93	220	46%
Nitrate Plus Nitrite	3.95	225	2.79	318	29%
Phosphorus, Total	0.4	23	0.21	24	5%
Phosphorus, Dissolved	0.37	21	0.14	16	-32%
Phosphorus, Ortho-P	0.42	24	0.17	19	-24%
TSS	15	854	33	3,758	77%
COD	67	3,815	46	5,238	27%
DOC	19	1,082	29	3,302	67%
TOC	22	1,253	14	1,594	21%
Copper, Total	0.146	8	0.025	3	-192%

Table 3. Estimated green roof load reduction from commercial lot

Analyte	DBG Green Roof		Commercial		Load Reduction
	Concentration (mg/L)	Load (g/yr)	Concentration (mg/L)	Load (g/yr)	
Total Kjeldahl Nitrogen	2.08	118	2.8	472	75%
Nitrate Plus Nitrite	3.95	225	0.89	150	-50%
Phosphorus, Total	0.4	23	0.35	59	61%
Phosphorus, Dissolved	0.37	21	0.13	22	4%
Phosphorus, Ortho-P	0.42	24	0.15	25	5%
TSS	15	854	219	36,947	98%
COD	67	3,815	187	31,548	88%
DOC	19	1,082	35	5,905	82%
TOC	22	1,253	36	6,073	79%
Copper, Total	0.146	8	0.027	5	-83%

References

EPA. (2010). Green Infrastructure in Arid and Semi-Arid Climates. 8 pages. Retrieved from <http://www.epa.gov/ow/eparecovery>
 EPA. (2014). Three Keys to BMP Performance: Concentration, Volume and Total Load. Retrieved from <http://www.epa.gov/polwaste/npdes/stormwater/>