

EFFECTS OF A BEAVER POND IN SOUTHWESTERN MONTANA ON METALS CONCENTRATIONS AND LOADS

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ABSTRACT

A 400-m² beaver pond on Cabbage Gulch (Deer Lodge County, MT) was investigated for its retention of total recoverable (TR) and dissolved arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), and total suspended solids (TSS) during three storm water runoff events in the summer of 2013. Water samples were collected and flow rates were measured at monitoring stations above and below the pond. Decreases in TR metals concentrations were -17 percent for As (that is, As concentrations increased), 10 percent for Cu, 7 percent for Pb, and 27 percent for Zn. Total recoverable metals retained in the pond, on a mass basis, were 24 percent for As, 47 percent for Cu, 45 percent for Pb, and 55 percent for Zn. The average retention was 49 percent (by mass) for TR Cu, Pb, and Zn. Twenty-four percent of the influent TR Cu and TR Zn loads were retained because the metals were suspended in the pond with stored storm water. An additional 27 percent of the influent TR Cu and TR Zn loads settled out of the water during the sampling periods. Arsenic retention was low because all of the As was in the dissolved phase and no As could settle out. Total suspended solids concentrations decreased by 2 percent and TSS mass retention was 41 percent.

Keywords: beaver pond, sedimentation, metals, arsenic, cadmium, copper, lead, zinc, suspended solids, Montana

INTRODUCTION

Historic smelting activity in Anaconda, Montana, released contaminants of concern (COCs) into the air with the flue gas from the smelter stack. The COCs were then deposited on the land downwind from the smelter. The COCs spread across the Mill Creek (Deer Lodge County, Montana) drainage. Storm water runoff contains these COCs and contaminates streams when the runoff enters the streams. Beaver ponds improve water quality because they retain storm water runoff (Naiman et al. 1988, Beedle 1991, Pollock et al. 2003) and increase particle removal by sedimentation of some of the solid particles and particulate phase COCs in the water (Maret et al. 1987, Naiman et al. 1988, Gurnell 1998,

Butler and Malanson 1995, 2005). Beaver ponds may reduce maximum daily loads by reducing stream flow rates because they store water during floods and release the stored water slowly, which may spread the release of loads over more than one day.

This study had four objectives: (1) to measure stream flow rates and COC concentrations above and below a beaver pond in the Mill Creek drainage during storm water runoff, (2) to compare the COC concentrations to Montana DEQ-7 surface water quality standards and determine if the pond reduced COC concentrations to below surface water quality standards, (3) to quantify COC retention by a beaver pond during the first-flush of storm water runoff, and (4) to quantify how much of the COC retention was due to particle sedimentation compared to dissolved and suspended COCs that were retained in stored pond water during the sampling periods.

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STUDY AREA

The beaver pond studied in this project was located at 46.074°N latitude and 112.924°W longitude, and was in Cabbage Gulch, a tributary to Mill Creek. Cabbage Gulch is ~ 4.5 km south of the decommissioned Anaconda Company smelter smokestack. The pond was 39 m wide and 11 m long; its dam lay on an approximate east-west line (Fig. 1). Global positioning system coordinates taken around the pond periphery were used to calculate a pond surface area of 400 m² (Lorenzo 2014). Cabbage Gulch entered the pond in its southeast corner and left through a hole in the dam near its eastern end. The water surface was about 0.5 m below the dam crest during this study, and the hole in the dam was below the pond surface at all times. The dam contained a significant hole because beavers did not inhabit the pond in 2013 and the dam was not being maintained. A dead tree lay along the west side of the inlet, with its trunk roughly parallel to the direction of inlet flow. The flow pattern relative to the inlet, outlet and dead tree divided the pond into a hydraulically active zone (40 m²) east

of the dead tree and a stagnant zone west of the dead tree.

METHODS AND MATERIALS

Two monitoring sites were established to collect stream samples above and below the beaver pond. Teledyne ISCO Model 3700 automated samplers activated by liquid level sampler actuators collected samples at each site. The sampler actuators started the samplers when the water stage reached a depth indicating that a storm runoff event had started. Both sites had Solinst Model 3001 Edge F15 series pressure transducers that recorded the stream stage at 15-min intervals. The lower station had a 23-cm H-flume while the upper station had a 7.6 cm Parshall flume. Stream stages were calculated from pressures measured by the two pressure transducers, and flow rates were calculated from these stream stages (Lorenzo 2014).

Samples were collected at both sites during each storm runoff event. Six individual samples were taken 1 hr apart during a sampling period. The number of samples was determined from the

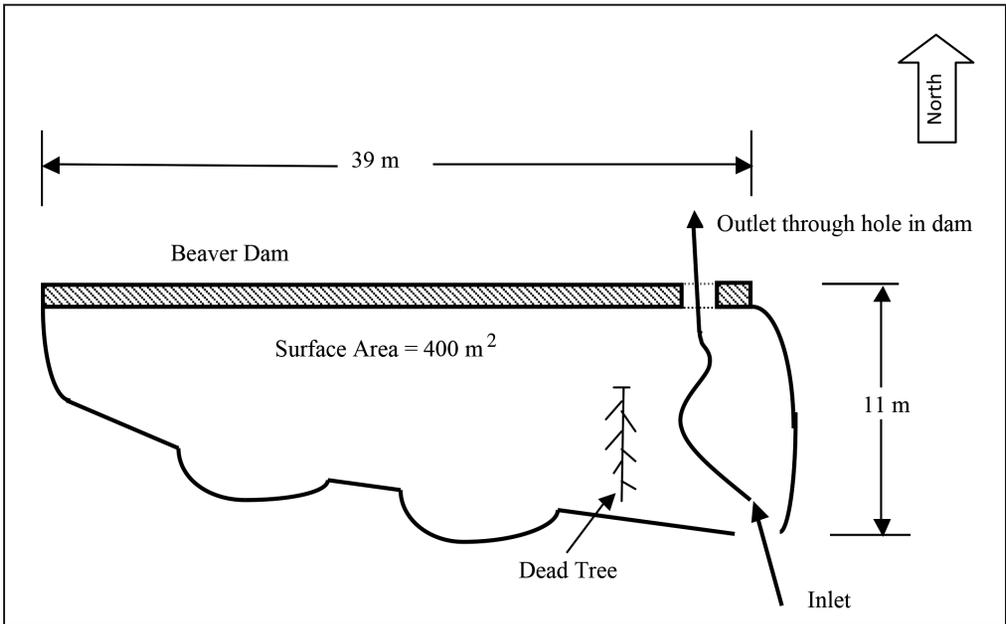


Figure 1. Plan view and dimensions of a beaver pond on Cabbage Gulch in southwestern Montana. Measurements taken in June 2013.

capacity of the ISCO samplers and the sample volume required for all specified analyses on individual samples. Samples were collected during the rising limbs of the storm hydrographs because the water quality below the pond was to be assessed for compliance with Montana DEQ-7 acute toxicity water quality standards (Tucci 2014). Water quality standards are most likely to be exceeded when a storm hydrograph is rising (the “first flush”) because that is when water quality is the worst (Stenstrom and Kayhanian 2005). Thus, samples were taken only during a portion of the rising limb of a storm hydrograph.

Arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) were analyzed for both total recoverable (TR) and dissolved concentrations in all samples. Total suspended solids (TSS) were measured in one sample taken at each monitoring site per storm event. All analyses were performed by the Montana Bureau of Mines and Geology (MBMG) Analytical Laboratory. Metals analyses followed EPA Methods 200.2, 200.7 and 200.8. Total suspended solids (TSS) analyses followed Standard Methods Method 2540D (APHA 2005).

Mass loads were calculated by multiplying concentrations times flow rates. Flow rate data was obtained every 15 min, but COC concentrations were sampled hourly. Flow rates were averaged from 30 min before to 30 min after sampling, resulting in a 6-hr sampling period. The average flow rate for each of the 6 hrs was multiplied by the COC concentrations in the sample from that hour. The 1 August 2013 event was an exception, where the flow rate associated with the first of the six samples was averaged from 15 min before the sample was taken to 30 min after the sample was taken because the 1 August storm hydrograph did not start until 15 min before the first sample was taken.

RESULTS

Storm runoff events were sampled on 1 August 2013, 17 September 2013, and 24 September 2013. The samplers were

activated manually on 1 August and 24 September to assure that samples were taken during those storm events.

Storm Hydrographs

Hydrographs show that the rising limbs of the upper site hydrograph preceded the rising limbs of the lower site hydrograph (Figs. 2 and 3). The hydrographs for the 1 August storm and the 17 September storm were similar (Fig. 2) with the upper site having a rising limb and a falling limb that preceded these limbs at the lower site. The storm hydrographs for 24 September (Fig. 3) were different in that the falling limb at the upper site occurred after the falling limb at the lower site.

Water Quality

Copper, Pb, and Zn had TR metals concentrations were greater than dissolved metal concentrations for all but one analysis (Fig. 4). Dissolved As metal concentrations equaled TR As metal concentrations. Nearly all Cd TR and dissolved metals concentrations were below the minimum reportable limit, so no analysis of Cd concentrations was possible.

Most COC concentrations were less than the Montana DEQ-7 acute toxicity surface water quality standards (Table 1). Copper was the only COC that exceeded the DEQ-7 standard, and this occurred at both monitoring sites. All As, Pb, and Zn concentrations were below surface water quality standards.

The effect of the beaver pond on concentrations and mass loads varied with each COC (Table 2). Zinc had the greatest decreases in both TR and dissolved metal concentrations, followed by Cu and Pb. Decreases in TSS concentrations were negligible. Total recoverable and dissolved As concentrations increased as water flowed through the pond. Total recoverable metals masses retained in the pond (as a percent of upper site loads) were greater than were decreases in TR metal concentrations, and averaged 49 percent for Cu, Pb, and Zn (Table 2). Zinc had the greatest mass retained in the pond, and As had the lowest mass retained in the pond. Concentration

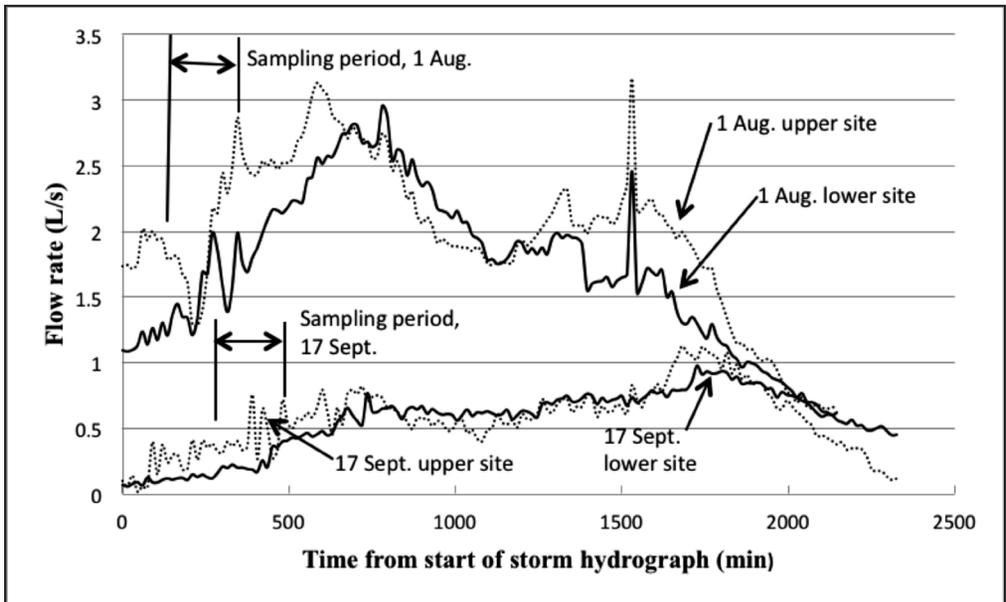


Figure 2. Hydrographs above and below a beaver pond in southwestern Montana for the 1 August 2013 and 17 September 2013 storm events.

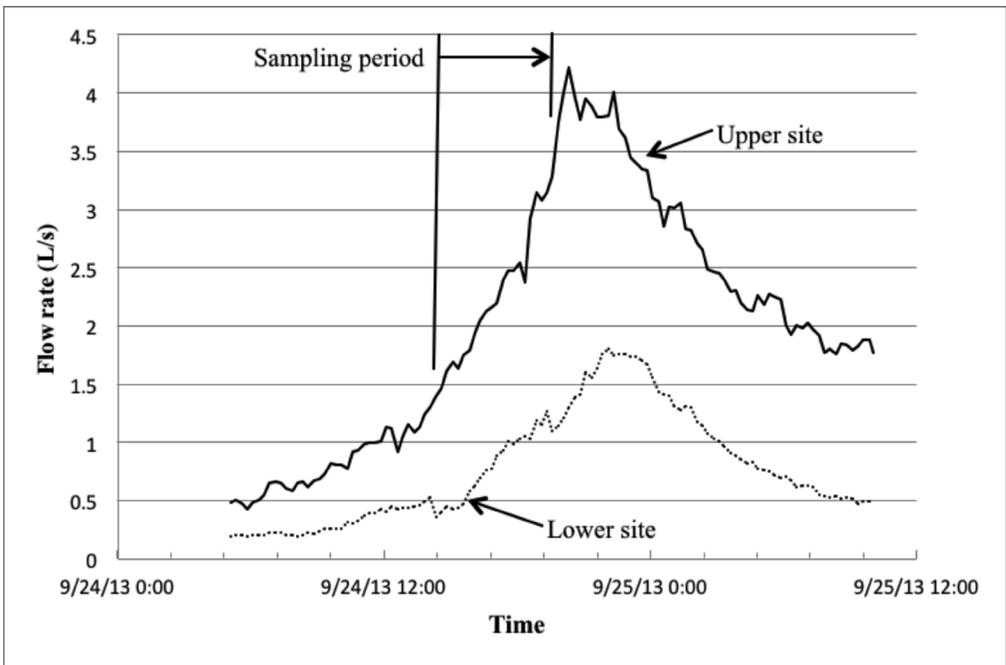


Figure 3. Hydrographs above and below a beaver pond in southwestern Montana for the 24 September 2013 storm event.

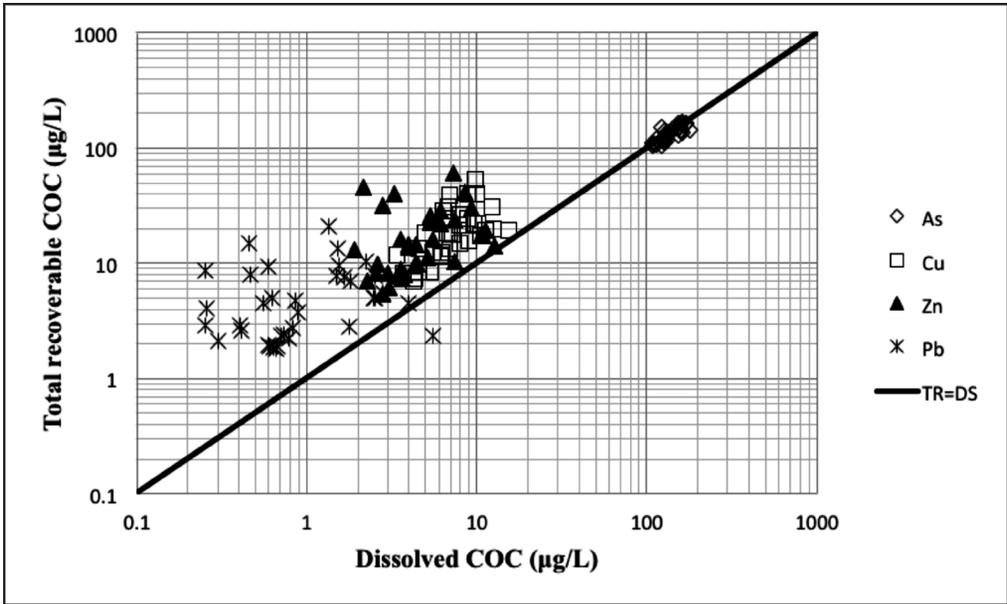


Figure 4. Total recoverable COC concentrations vs. dissolved COC concentrations.

Table 1. Total recoverable COC concentrations (µg/L) above and below a beaver pond in southwestern Montana during storm events in August and September 2013. The concentrations are the averages of the six samples per event. The acute toxicity standards for Cu, Pb, and Zn were calculated with the average hardness values from both sites.

Date	Upper site	Lower site	Acute toxicity standard
Arsenic			
1 Aug	142	162	340
17 Sept	119	142	340
24 Sept	110	128	340
Copper			
1 Aug	33.6	29.3	6.7
17 Sept	13.9	8.6	6.7
24 Sept	19.2	16.0	6.7
Lead			
1 Aug	11.7	8.8	30.3
17 Sept	2.2	2.4	30.3
24 Sept	4.9	3.9	30.3
Zinc			
1 Aug	37.8	27.0	61.9
17 Sept	10.4	7.9	61.9
24 Sept	17.7	11.7	61.9

Table 2. Effect on concentrations and mass loads from a beaver pond in southwestern Montana during storm runoff events in August and September 2013. The reported values are averages from the three storm events.

Contaminant of Concern	Average TR concentration decreases (%)	Average TR mass retained (%)	Average dissolved concentration decreases (%)
As	-17	+24	-20
Cu	+10	+47	+12
Pb	+7	+45	+6
Zn	+27	+55	+20
TSS	+2	+41	--

differences of TR COCs (percent of upper site concentrations) were < 50 percent of the mass retention of TR COCs.

DISCUSSION

This beaver pond did not reduce TR Cu concentrations leaving the pond to below the Montana DEQ-7 acute toxicity surface water quality standard. Other beaver ponds in neighboring drainages studied by the MBMG had identical results (Tucci 2013, Tucci 2014). In the drainages studied, beaver ponds alone improve water quality but do not provide sufficient treatment to meet Montana DEQ-7 standards.

The fraction of storm water stored in the pond was determined as part of the calculation of COC retention. The storm water volume stored in each 15 min time increment was calculated with Equation 1:

$$Volume = \left(\frac{Q_{u1} + Q_{u2}}{2} - \frac{Q_{l1} + Q_{l2}}{2} \right) \times 15 \text{ min} \times 60 \text{ s/min} \quad (1)$$

where Q represents flow rate (L/s), the subscripts u and l represent the upper and lower monitoring sites, respectively, and the subscripts 1 and 2 represent the beginning and end of a time increment, respectively. The incremental storage volumes were then summed over a sampling period. The fraction of storm water stored equaled the storm water volume stored divided by the water volume that passed through the upper monitoring site. The fraction of water stored was 19 percent for the 1 August storm, 23 percent for the 17 September storm, and 26

percent for the 24 September storm, with an average storage of 23 percent. The fractions of the COC mass loads that were retained were positively correlated with the water volumes stored (Fig. 5). Lead is not shown in Figure 5 because its concentrations were scattered such that an analysis was not meaningful.

Contaminant of concern masses stored in the pond were the suspended and dissolved (not settled) COCs that entered but did not leave the pond during a sampling period. Mass stored was calculated by multiplying the water stored in each 15 minute time increment by the COC concentrations at the lower site. The incremental values were then averaged. We assumed the hydraulically active zone in the pond was completely mixed, which is reasonable considering its small volume. Thus, pond water COC concentrations equaled COC effluent concentrations.

Mass balances around the beaver pond were used to estimate the COC masses that settled out of the water in each 15 minute time increment (Equation 2):

$$mass \text{ settled} = mass \text{ in} - mass \text{ out} - mass \text{ stored} \quad (2)$$

Settled mass incremental values were then averaged for all three storm events. Twenty-four percent of the influent TR Cu and TR Zn mass loads were stored in the pond water while another 27 percent settled out of the water (Table 3). The fraction of influent TR Cu and TR Zn mass stored was

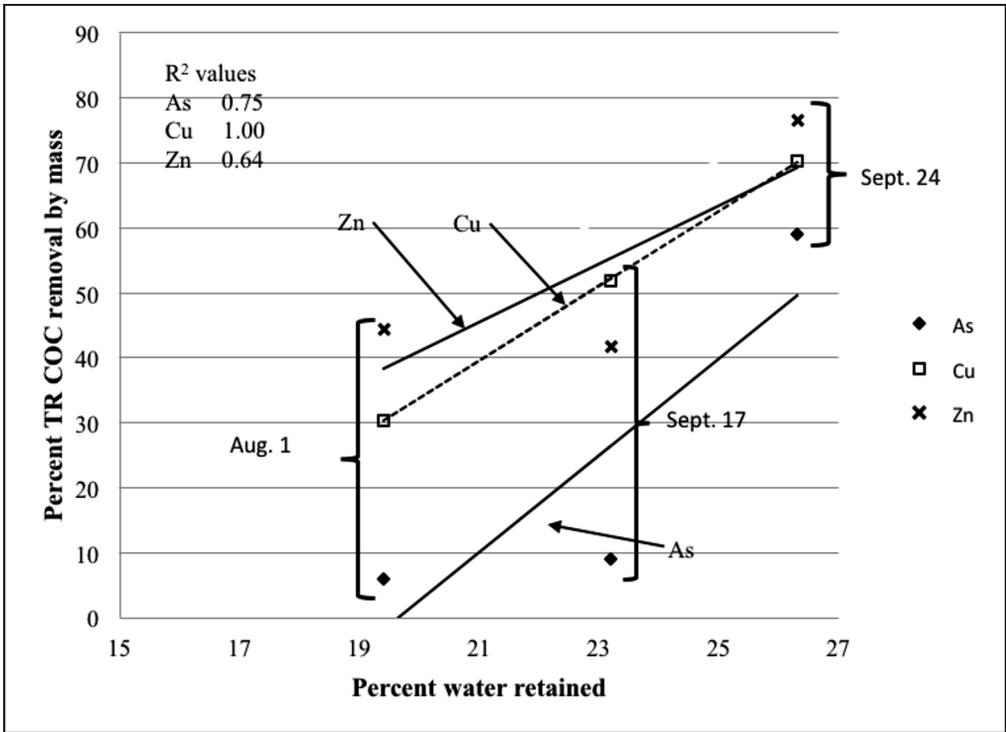


Figure 5. Percent TR COC retained vs. percent water retained. The lines are linear regression lines.

Table 3. Average TR Cu and TR Zn masses calculated to have settled out of the water during the three storm events.

	TR Cu				TR Zn			
	Mass in	Mass out	Mass stored	Mass settled	Mass in	Mass out	Mass stored	Mass settled
Average mass (mg)	937	500	260	176	972	434	201	336
Percent of mass in	--	53	28	19	--	45	21	35
		Mass in	Mass out		Mass stored	Mass settled		
Average of Cu + Zn (mg)		955	467		231	256		
Percent of Cu + Zn mass in		--	49		24	27		

consistent with the fraction of storm water retained in the pond (23 percent) and the reduction in As mass loads (24 percent). The decrease in the TR As mass loads must be attributed solely to storage, because all of the As was in the dissolved phase and dissolved solids do not settle.

Contaminant of concern masses that settled out or were stored in the pond were most likely different for the entire storm

hydrograph periods than those measured during the sampling periods. The sampling periods were short compared to the hydrograph lengths (Figs. 2 and 3). Some particulate-phase COCs suspended in the pond water should have settled out after the sampling periods ended, so the COC masses removed by sedimentation were most likely larger than the values shown in these data. Some of the particulate and dissolved COCs

stored in the pond water would have left in the pond outflow after the sampling periods ended as the pond volume returned to its base flow volume. Therefore, storages of suspended and dissolved COC masses for entire hydrographs were likely less than storages reported in the Results.

Arsenic retention on a mass basis was positive only because the flow rates at the upper site were higher than the flow rates at the lower site during the sampling periods. Arsenic was dissolved (Fig. 4) so there was no particulate As to settle out. Arsenic concentrations at the lower site were greater than those at the upper site (Table 1), which may have occurred because of the mobility of As in the sediment column, flux diffusion, and sediment re-suspension into the pond water (Cornett et al. 1992).

Total suspended solids concentrations varied significantly from runoff event to runoff event. Total suspended solids masses retained were sometimes high (24 Sep; 84% on a mass basis) and sometimes low (1 Aug; 17% on a mass basis). A reason why TSS retention was highly variable was that few TSS analyses were performed.

CONCLUSIONS

- The masses of TR COCs retained (either by sedimentation or by being suspended or dissolved in stored pond water) by a beaver pond on Cabbage Gulch in southwestern Montana during three storm water runoff events were 24 percent for As, 47 percent for Cu, 45 percent for Pb, 55 percent for Zn, and 41 percent for TSS.
- Concentrations of TR COCs decreased by -17 percent for As (that is, As concentrations increased), 10 percent for Cu, 7 percent for Pb, 27 percent for Zn and 2 percent for TSS.
- Cadmium concentrations were almost all below the minimum reportable limit.
- Arsenic was entirely in the dissolved phase.

- Upper monitoring site flow rates were higher than lower monitoring site flow rates during all storm events.
- Contaminant of concern retention on a mass basis was greater than decreases in COC concentrations.
- Total recoverable Cu and Zn retention in the stored storm water (24% of the inflow mass quantity) was approximately the same as mass retention due to sedimentation (27%).

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