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SUBJECT: **Spokane Stormwater**

Background: The first comprehensive sampling of the City of Spokane stormwater discharges (4 CSO basins and 10 stormwater basins) occurred in May and June 2007 by Ecology and Parsons (Parsons, 2007). This sampling event, coupled with the Spokane River PCB Source Assessment (Serdar et al, 2011) suggested that stormwater was a significant contributor of PCBs to the Spokane River. In 2009-2011, Ecology collected some samples from select basins (e.g. Union) in an effort to trace sources. From 2012 through 2014, the City of Spokane monitored 3 MS4 stormwater basins (Cochran, Union, Washington) and 2 CSO basins (CSO34 and CSO06) regularly (nearly monthly). The monitoring was part of City's Integrated Clean Water Plan (City of Spokane, 2015). The monitoring began in October 2012 for 2 of the MS4s (Cochran and Union) and in spring 2013 for the Washington MS4 basin and CSO 34, and late 2013 for CSO 6. The City of Spokane has completed a significant amount of work on the stormwater infrastructure since the 2007 sampling. Many of the basins have changed configuration and CSOs have been re-routed. Furthermore, sampling techniques are different between the 2007 (grab) and 2012-13 (composite) sampling periods. Comparison between the sample periods is therefore difficult. However, rough comparisons between available data suggests that there have been minimal changes in the PCB concentrations of stormwater. Loads were not compared because previous loads were annual, while the current loads are storm event-based. The City of Spokane has 129 stormwater basins and 24 CSOs that discharge to the river via 20 outfalls. The current area sampled by the City represents 43% of the total stormwater catchment area, leaving 57% un-sampled.

Goal: To provide an understanding of current stormwater quantity and quality in order to refine our understanding of stormwater loading to the Spokane River. This information will be useful to the Spokane River Regional Toxics Task Force (SRRTTF) in designing sampling to fill data gaps in our understanding of stormwater loading. This analysis involved three components:

1. Evaluation of hydrologic contributions of stormwater
2. Evaluation of PCB concentrations over time
3. Mass loading of PCBs to the river

Runoff Quantity **:** Runoff quantity was assessed by comparing 2 individual storm events (October 25-29, 2012 and May 21-23, 2013) that have measured flow volume and precipitation data with the USGS recorded flow of the Spokane River for the same period of time. The USGS station (12422500) at Spokane was used. The City of Spokane supplied the measured flow volumes and precipitation data from their ongoing monitoring program. The calculations therefore do not encompass all stormwater contributions to the Spokane River, only the monitored outfalls. Storms were selected in October 2012 and May 2013 based on the completeness of the data. The amount of precipitation varied across the City of Spokane. The October 2012 event ranged from 0.03 - 0.43 inches of precipitation, and 1.09 - 0.25 inches in May 2013. The flow of the Spokane River during the October 2012 event was near average, whereas the flow during the May 2013 event was at and below average (Figure 1).

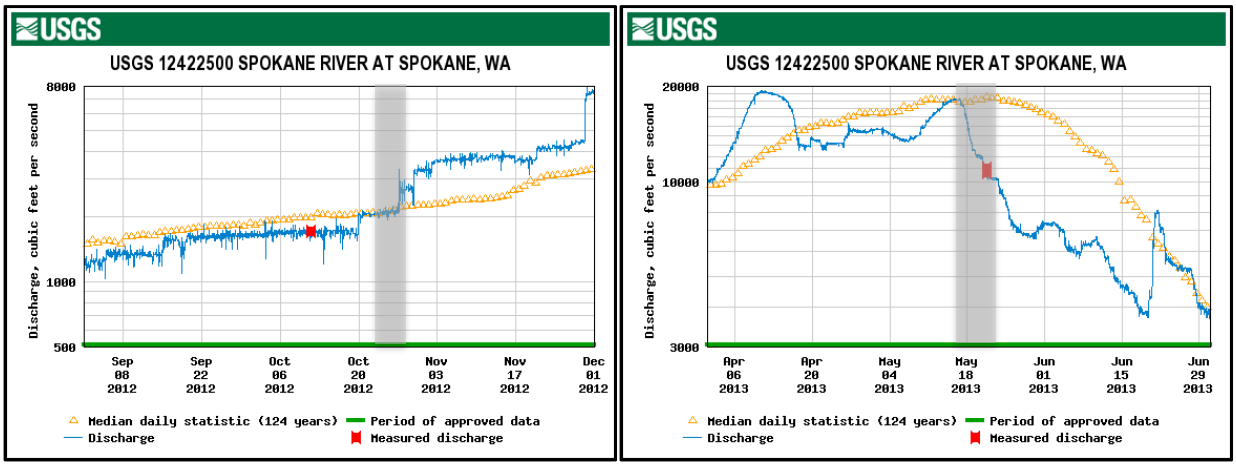


Figure 1: Hydrographs of Spokane River discharge for October 2012 (left panel) and May 2013 (right panel). Grey shading indicates the period of time used in comparison to stormwater flow.

The results show that during the October 2012 storm the stormwater contributed approximately 0.25% of the volume of water present in the Spokane River (Table 1). During May, the percent contribution was an even smaller fraction of the (0.03%) of the total volume of the Spokane (Table 1).

Table 1: % contribution of measured stormwater/CSOs during the October 2012 and May 2013 storm event by absolute volume.

	hydrology (liters)
October 2012	
Spokane River	6.65×10^{9}
stormwater/CSO	1.60×10^{7}
	0.240%
May 2013	
Spokane River	3.72×10^{10}
stormwater/CSO	1.20×10^{7}
	0.032%

The measured stormwater and CSO discharge volumes were also compared with volumes derived using standard approaches to estimating runoff. These standard methods are based on the "Simple Method" and were used in both the Parsons (Parsons, 2007) and Ecology (Serdar et al. 2011) previous studies. The Simple Method estimates stormwater runoff pollutant loads from urban areas (Shueler, 1987). The Simple Method estimates annual runoff as a product of annual runoff volume and the runoff coefficient (Rv); where Rv is unitless and can be estimated using the formula:

$$Rv = 0.05 + 0.9 * fraction\ of\ impervious\ cover\ (Ia)$$

In reality the runoff coefficient is simply the ratio of volume of precipitation falling onto a catchment basin : volume of runoff from the catchment basin. The measured runoff coefficients were calculated for each storm event for approximately 2 years of sampling using the City of Spokane data and compared to estimated values from the Simple Method. The measured values are an order of magnitude lower than those estimated using the Simple Method. Table 2 describes the measured and estimated percent of the rainfall that becomes runoff from the three main basins runoff. This would mean that actual runoff volumes are lower than those estimated using the Simple Method. Furthermore, the runoff coefficients vary from storm to storm and would likely vary with the season. The estimated runoff volumes were used in the previous assessment of PCB load from stormwater and therefore it was likely an over-estimate of actual runoff volumes. The over-estimate of runoff volumes would result in an over-estimate of PCB loads. It would be preferable that the runoff coefficient be as accurate as possible when used to estimate runoff volumes. It may be possible to calculate an adjustment factor between measured and estimated runoff coefficients for Spokane.

Table 2: Estimated and measured runoff coefficients as percentages for 3 main stormwater basins. The values are the percent of the rainfall that becomes runoff. The measured coefficients are described as median values with total number of values used (n) and the standard deviation of the data (sd).

	Measured runoff coefficient			**Estimated runoff coefficient (simple method)**
	Median	**n**	**sd**	
Trent & Erie (Union Basin)	8.72%	8	4.2%	31%
Cleveland & Nettleton (Cochran Basin)	7.17%	21	31.9%	23%
Washington St Bridge (Washington Basin)	6.70%	7	5%	29%

PCB Concentrations: The City of Spokane has 2 years of high resolution PCB data for the Union storm basin. Union basin has not changed considerably since the Parsons sampling in 2007. Alterations to the Cochran basin prevent comparisons between Ecology and City of Spokane sampling. The concentrations obtained during the Union sampling by Parsons and later by Ecology can be compared to gauge whether

PCB concentrations have changed. However, it should be acknowledged that sampling protocols were different between the sampling events; grab sampling in the Parsons and Ecology and composite sampling by the City of Spokane. Composite samples are more representative of event mean concentrations for a storm event. Sampling events were compared as three groups of data (Ecology/Parsons 2007, Ecology-2009-2011, and City of Spokane 2012-2013) (Table 3 and Figure 2). Data was also explored in groups of data separated by cleaning events in the Union lines (Table 3). Data was grouped by pre-cleaning, post-maintenance (2010), and post-maintenance (2012) (Figure 2). All data was tested for statistical significance using an analysis of variance on log transformed data to assure normality of the data.

Table 3: PCB data from City of Spokane (2014) report (Table 5) and Parsons (2007) report from Union basin.

SAMPLE/ ORGANIZATION	**DATE**	**Sample Type**	**Precipitation (inches)**	**PCBs (pg/l)**
Ecology/Parsons (UNION)	5/2/2007	Grab	unk	168,160
	5/21/2007	Grab	unk	16,100
Ecology (UNIONLPT Sample Location)	6/8/2009	Grab	0.29	73,000
	10/2/2009	Grab	0.11	58,200
	2/16/2010	Grab	0.12	460,000
	4/29/2010	Grab	0.48	60,600
	Union Basin Pipe Cleaning and Lee/Springfield Plug Installed June 2010; Remedial Maintenance July-Aug 2010			
	9/9/2010	Grab	0.06	256,000
	1/7/2011	Grab	0.19	55,300
City of Spokane (Trent & Erie Sample Location)	10/29/2012	Composite	0.43	37,346
	Union Basin Remedial Maintenance 10/29/12 to 11/5/12			
	11/1/2012	Composite	0.11	43,841
	11/3/2012	Composite	0.24	47,972
	11/8/2012	Composite	0.34	18,113
	11/12/2012	Composite	0.33	48,862
	3/20/2013	Composite	0.26	19,403
	4/10/2013	Composite	0.07	13,766
	5/13/2013	Composite	0.31	47,455

Union basin continues to have the highest measured concentrations of PCBs out of all basins monitored by the City. Sampling of the Union basin over time has shown a decrease in concentrations (Figure 2). Overall, there is a statistically significant difference over time (ANOVA p=0.045). This difference is because of the decrease between the Ecology 2009 and City of Spokane 2012-13 sampling (p=0.036); there is no difference between the Ecology 2007 and 2009 samples. It is possible that the observed difference in concentration is due to differences in sampling technique. The Ecology 2007 and 2009 samples were collected as grab samples, whereas the City samples in 2012/13 were composite samples.

Composite samples would better represent the storm event mean concentrations and therefore be more reliable.

In addition, the City has cleaned the stormwater pipes in the Union basin on two occasions (2010 and 2012), as detailed in Table 3. The analysis of data pre- and post-cleaning of the pipes includes both grab and composite samples. Cleaning of the Union line has not reduced the PCB concentrations to a level of statistical significance (ANOVA p=0.124) (Figure 2).

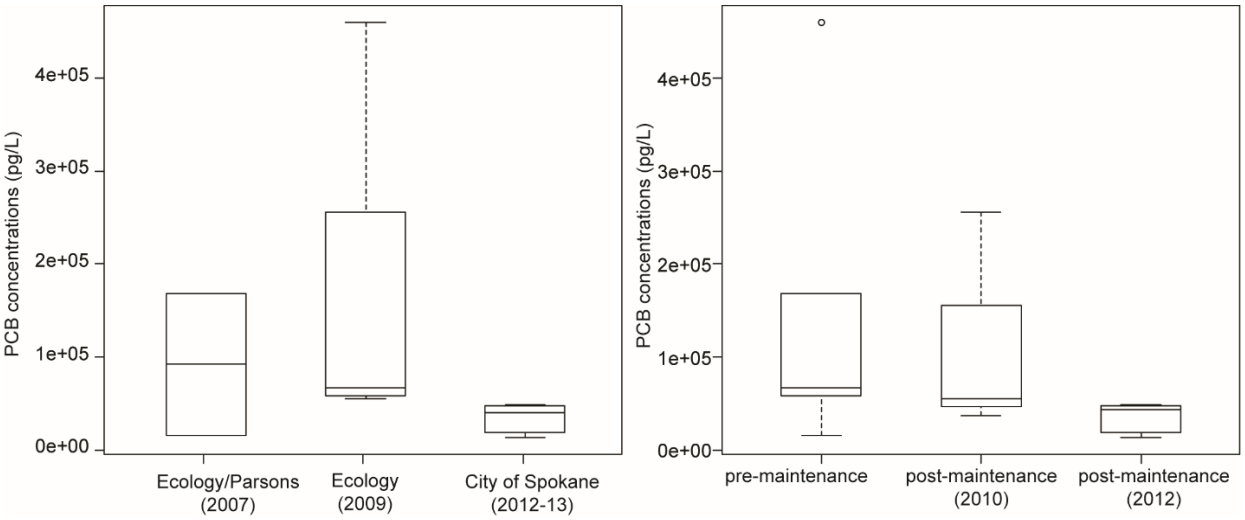
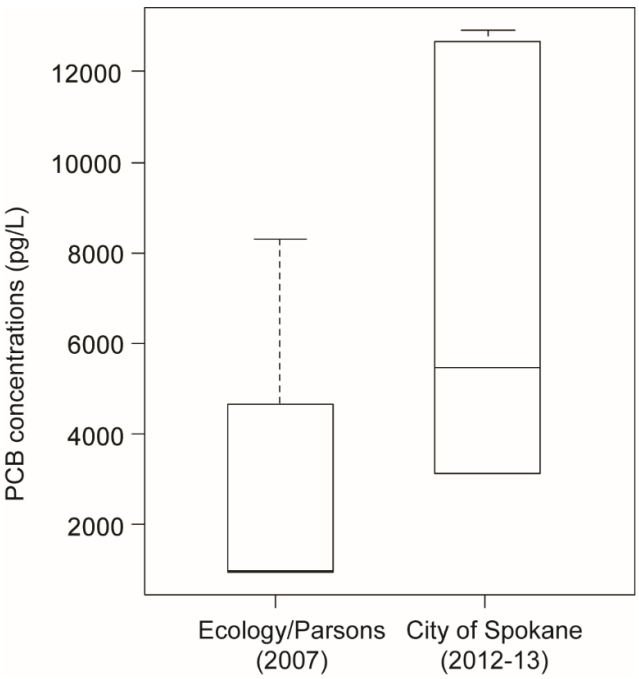


Figure 2: Boxplot of PCB concentrations from the Union basin over time (left panel) and pre- and post-maintenance of the lines (right panel). Horizontal lines within the boxes are median concentrations and the limits of the boxes are 25th and 75th percentiles of the data.



The Washington storm basin was sampled by Ecology in 2007 and by the City of Spokane in 2012. It appears there are higher PCB concentrations during the more recent City sampling (Figure 3), however there is no statistical difference between the two sample periods (t-test p=0.052).

Figure 3: Boxplot of PCB concentrations from Washington basin, comparing the 2007 and 2012 sampling periods. There is no significant difference.

PCB Loading: In a similar approach to assessing water quantity, the PCB concentrations were used to compare the measured PCB mass (load) contributed during the October 2012 and May 2013 storm events with the total PCB mass in the Spokane River over the same period of time. PCB mass was summed from the monitored stormwater / CSO basins. The PCB mass in the Spokane River during each storm event was calculated using the USGS flow data over the period of sampling and the concentration data from Era-Miller (2013). The Era-Miller (2013) data were accessed through Ecology's EIM system using the project code "BERA0009" (https://fortress.wa.gov/ecy/eimreporting/). Comparisons were made for 2 locations in the Spokane River (Table 4). The measurements of flow and PCB mass from the Spokane River are not co-located, but the timing of river and stormwater sampling do overlap.

During the October 2012 storm event the measured outfalls contributed 51% of the PCB mass (Table 4). No samples exist during October 2012 from the Spokane River upriver of the storm outfalls. During the May 2013 storm event the measured outfalls contributed about 18% of the PCB mass (mg) (Table 4).

Table 4: % contribution of measured stormwater/CSOs during the October 2012 and May 2013 storm event by absolute PCB mass.

	Upriver Dam - PCB mass (mg)	**Above Latah - PCB mass (mg)**
October 2012		
Spokane River	ns	112
stormwater/CSO	ns	57.3
	ns	**50.97%**
May 2013		
Spokane River	1438	906
stormwater/CSO	166	166
	11.52%	**18.29%**

Un-sampled Load: The City of Spokane has 129 stormwater basins and 24 CSOs (Table 5). The basins currently sampled are all above the 80th percentile by area (Figure 4) and represent 43% of the total drainage area of Spokane. Delineation of the all the catchments exists, but no flow or PCB data for the basins outside those targeted in the Integrated Clean Water Plan (5 basins, 6 sample sites) is available.

The original Parsons report (2007) estimated contributions from un-sampled CSOs using the Simple Method for a "high CSO load scenario". The flow from a CSO is not described by the Simple Method and the runoff coefficients therein because it does not flow continuously, which is what the Simple Method assumes. Therefore only the "low CSO load scenario" (as estimated by Parsons, 2007) that relies on measured flow should be used. Un-sampled CSO basins do have continuous flow monitoring; therefore we can take a median CSO concentration and apply to the individual flows to get an estimate of un-sampled CSO PCB contributions.

Table 5: Statistical summary of Spokane storm basin areas in acres.

number of basins	minimum	maximum	mean	25%	median (50%)	75%	90%	95%
153	0.07	5245.00	115.5	0.85	4.15	54.35	188.94	458.37

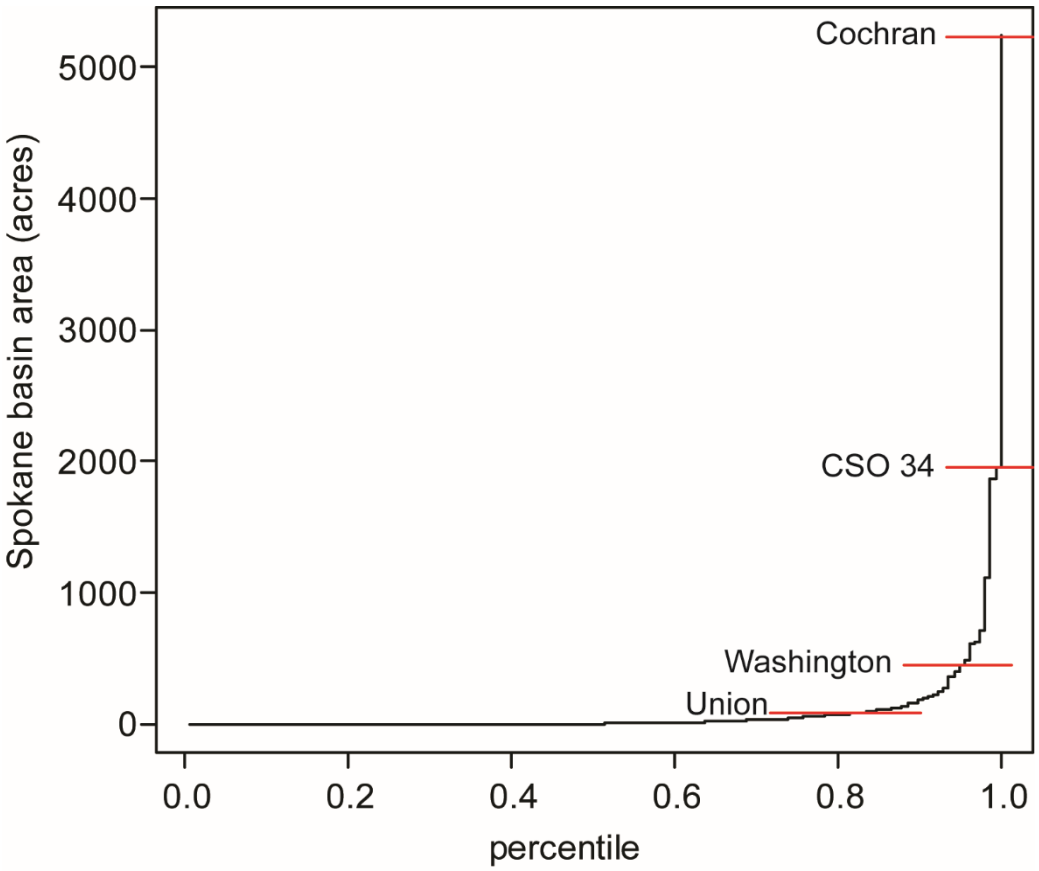


Figure 4: Empirical density function (EDF) of stormwater and CSO basin area (acres). Shows the distribution of all the basins by size. The basins currently monitored by the City of Spokane are highlighted by red lines. Percentile represents the percentage of basins smaller; for example the Washington basin is at percentile 0.94, meaning 94% of the basins are smaller than the Washington basin.

The flow from the Cochran basin is currently being modeled by the City of Spokane to understand the measured flow. Once this is complete it will provide a means to estimate flow from un-sampled basins more accurately. Unfortunately, this will not be completed in time for any potential sampling events in the Fall of 2015. In the interim estimating the un-sampled flow from all MS4 stormwater basins may be possible using established precipitation-runoff relationships from the sampled catchments and a corrected Simple Model for the un-sampled basins. The PCB load could then be estimated using the median PCB concentrations from the 2 years of sampling by the City.

An attempt was made here to use the precipitation – runoff relationships to estimate annual runoff volume and annual PCB load. However, verifying the results with the model established for the Cochran

basin showed that simple estimates based on the precipitation – runoff model overestimated annual runoff by 200%. Further work with the City of Spokane is required to be able to use precipitation-runoff relationships and existing stormwater models.

In addition, the previous estimates were based on one annual rainfall total. There is spatial variability among the Spokane rain gauges and each basin rainfall total should be triangulated to the nearest stations.

Summary of findings

- Based on recent sampling (2012-2013), the mass of PCBs discharged in the MS4 and CSO systems of Spokane, seem to represent a significant fraction of what's in the river during storm events. The 2 storm events analyzed suggest a range of 18-50% based on 2012-13 data.
- It does not appear that PCB concentrations have significantly changed between the 2007 (Parsons, 2007) and the 2013 (City of Spokane, 2014) sampling periods.
- The biggest gap in estimating PCB loads for all stormwater discharges is understanding the actual runoff volume.

Recommendations

- The simple method for estimating flow should not be applied to Spokane basins, unless a suitable correction factor or revision of coefficients is possible.
- CSO flow should rely on measured values from the City of Spokane system.
- Continue to develop the model for the Cochran basin; consider what would be necessary to measure during future sampling events to allow this model to be applicable to other smaller basins to get a decent estimate of flow.
- Consider sampling a subsection of the small basins which have not been monitored to give some estimate of concentrations and flow.
- Alternatively, consider sampling more of the larger basins to increase the total percent of Spokane drainage area sampled:
    - ► Sampling all the basins larger than Union, which is 30 basins, would capture 92% of the drainage area of Spokane
    - ► Sampling the top 10 basins by area, which are mainly CSOs, plus Union basin would capture 75% of the Spokane drainage area.
- All planning for future stormwater sampling should be done in consultation with the City of Spokane.

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