CHAPTER 3

Coarse Particulate Organic Matter Measurements in the Jordan River and its Major Tributaries, 2010 – 2015

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Introduction

The most widely accepted paradigm for the cause of dissolved oxygen deficits in lakes and streams is the assumed linkage to elevated nutrients (i.e. eutrophication) and increased temperature. In certain situations, elevated nutrients can cause excessive algal blooms which in turn are known to consume oxygen during respiration or eventual decomposition. Early drafts of the Jordan River TMDL accepted this paradigm and claimed that the occasional violations of the dissolved oxygen (DO) standard were caused by excessive nutrients entering the river. This claim was questioned in 2009 by the Wasatch Front Water Quality Council (Council). In addition to initiating an extensive water quality monitoring program, Council field technicians performed the Stream Visual Assessment Protocol (SVAP) during the summer of 2009 to begin understanding the physical and chemical characteristics of the river and particularly downstream from 2100 (the reach that was designated as impaired for DO; see Chapter 1). Starting in 2009, the Council also started deploying data recording sondes fitted with DO, temperature, pH and conductivity probes and permanent installation of similar probes with real-time cellular connections to the internet took place in 2013.

Two important and related characteristics were initially identified from these efforts:

1) DO violations are limited to the lower reaches of the river (near and below 300 N). These locations are downstream from the diversion of 55% to >95% of the flow to the Surplus Canal (One of the primary purposes of the Surplus Canal is to divert Storm water and high spring flows to avoid flooding downstream neighborhoods);

2) This severe reduction in flow, velocity and turbulence, reduces reaeration potential, allows the settling of suspended and bedload organic debris, leaving the river bottom dominated by depositional zones with depths of 30 to 100 cm of organic debris among the clay and silt particles that exists in various stages of decomposition. In turn, measured sediment oxygen demand (SOD) values from decomposing organic matter are among the highest values measured across the nation (Goel 2010, Hogsett, 2015).

Initially these high values of SOD were thought to be the result of settled algae that had been dislodged from upstream substrates and from Utah Lake. However, our frequent monitoring of algal species, chlorophyll a (Chl a), algal biomass and VSS all contradicted this assumption. Indeed, similar concentrations of algal biomass, Chl a, TSS and VSS were measured at Utah Lake, the top of the segment (2100 S), and at the end of the segment (Burnham Dam), indicating that organic matter comprised of algal biomass or measured as VSS did not settle out of the water column, further indicating that it does not contribute to SOD.

Rather, these observations prompted us to measure the load of this coarse particulate organic matter (CPOM) delivered from tributaries and carried down the main channel in an effort to account for its potential contribution to SOD and the oxygen deficit. There are no published methods for directly measuring CPOM. The limited literature on this subject most often focuses on the ability of certain stream segments to retain “artificial”

CPOM in the form of small dowel segments or dumping measured quantities of non-native leaves so that the proportion of such leaves that are retained within a stream can be identified (e.g. see Quinn et al. 2007). This chapter focuses on initial methods development (2010) and a refinement (2011, 2012) used to estimate CPOM loading with major tributaries and along the main stem of the Jordan River.

Methods

CPOM sampling was performed monthly from April to November in 2010 and monthly throughout 2011 and 2012. In addition, during the high flow periods of the spring and during the heavy leaf fall periods of September to November of 2011, samples were collected biweekly to more accurately account for the higher CPOM delivery periods. Up to four sites were identified in each of the major tributaries, City, Emigration, Mill, Big Cottonwood and Little Cottonwood creeks. The sample sites in each tributary included one at the canyon mouth, and one as close to the confluence with the Jordan River as possible. Additional sites were included to evaluate the efficacy of constructed debris basins/ponds in removing CPOM. Additionally, sample sites were identified in the Lower Jordan to assess the quantity of organic matter delivered to the lower Jordan and its potential to settle out of the water column throughout the lower portions of the river.

During relatively low-flow (non-spring runoff) conditions (< approximately 300 CFS), samples were collected with a standard 10 x 18-inch sweep net. The only mesh available during 2010 to 2012 was 500 µm whereas the standard separation between FPOM (VSS) and CPOM is defined using a 1 mm mesh size. Therefore, samples were immediately rinsed in a 1 mm- mesh soil sieve for accurate separation of particle sizes. At each site, samples were collected at ¼, ½ and ¾ distance across a perpendicular transect. Where or when the stream depth was > approximately 30 cm, and floating debris was visible, samples were collected with the net at the surface and with the net resting on the bottom in order to collect floating debris as well as bed load and suspended material. The top and bottom samples were composited when collected. In addition, samples collected at ¼, ½ and ¾ distance across the stream were composited and this process was performed in triplicate. The duration of sample collection was timed in order to calculate the load and the duration of each "set" was adjusted in order to collect sufficient sample for accurate measurement as well as to limit sample volume to < approximately 200 g dry weight to facilitate sample handling, drying and combustion in the laboratory. Concentration or mass of the organic debris was determined by dividing the sample mass by the product of the stream velocity x net dimensions x sampling duration. During high flows or during the autumn leaf fall, typical duration of net placement was 10 to 30 seconds. During low flow conditions of winter and summer, net placement was extended to 60 seconds or more in order to collect sufficient sample volume. During high flow conditions (> approximately 300 CFS), we used a 3-inch trash pump. About ½ of the cross-linkages of the intake screen were removed to facilitate the uptake of the debris. The intake screen was weighted with approximately 40-pounds of steel plates to ensure that the screen remained on the stream bottom. Sample collections from the surface were not performed during these high flows because the turbulence caused sufficient mixing that the leaf material was rapidly saturated and was assumed to be distributed randomly throughout the water column. Also, because of this homogeneity, sample collection was only performed near the center of the channel. The discharge volume from the pump was measured using a 55-gallon barrel and each of triplicate samples included ten volumes (550 gallons) of water. Similarly, this material was sieved using the 1 mm soil sieve to collect the CPOM fraction.

Where samples were collected near stream gauges, these flow measurements were used to calculate loads. Where stream gauge data were not available, channel dimensions were measured and velocity measurements were performed using a Valeport mechanical flow meter.

Results and Discussion

There were three principle tasks in this effort to characterize CPOM: 1) Develop a representative and repeatable method for measuring CPOM concentrations and loads; 2) Determine loads delivered to the Jordan River from the major tributaries; and 3) Understand the persistence or attenuation of CPOM as it travels down the Jordan River and particularly downstream from 2100 S.

There is no standard protocol for CPOM sampling. Our CPOM program began in 2010 with designing and testing methods for sample collection. The only rule we adhered to was the basic definition of CPOM being that fraction of organic matter that is retained by 1 mm mesh size. Otherwise, it was a challenge to collect a representative and measurable sample without having to require the laboratory personnel to subdivide samples in order to use the drying and combustion chambers. Thirdly, it was important to collect samples during high flow events because these were the conditions of greatest CPOM transport. However, it was impossible to safely sample deep swift water, so we developed a sampling method using a 3-inch trash pump that could be operated from a bridge deck (Figure 1). We tested the comparability of sampling with a sweep net vs the trash pump (Figure 2). For most sampling events the results were comparable. The single outlier revealed in sample 7 of the sweep net was a larger piece of branch that weighed more than 100 g dry weight. Hence, it was small enough to be collected in the net but would have been too large to fit through the approximate 4 cm mesh size of the trash pump intake screen. Woody debris of this size and even much larger was common during high flow events. Therefore, it became apparent that collecting CPOM using these manageable techniques provides only a very conservative estimate of the total annual CPOM load.

Figure 40. Photographs illustrating the two techniques used for sampling coarse particulate organic matter. With either technique the water was initially filtered through the same net, followed by screening with a 1-mm soil sieve.

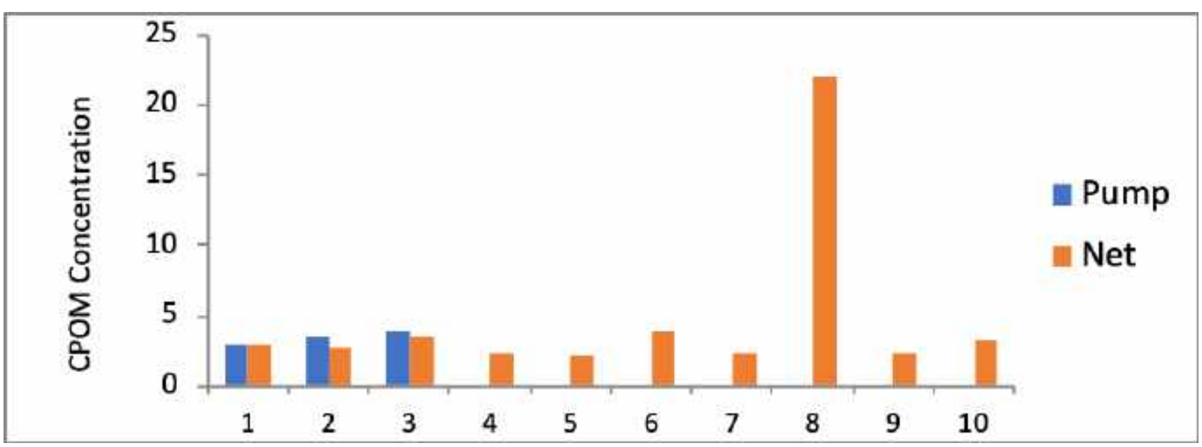


Figure 41. A comparison of samples collected by the trash pump and by the sweep net. Each pump sample consisted of filtering 550 gallons (filling a 55-gallon drum 10 times). The net sample number 8 collected a large stick, which was not uncommon throughout the entire sampling program. See text for details.

Tributary samples

Tributary sampling was conducted for two purposes. First, we wanted to estimate the monthly, seasonal and annual CPOM loads from the major tributaries. Second, we were interested in the effectiveness of debris basins or man-made ponds that were constructed in some of the tributaries.

City Creek

City Creek is a small tributary that flows out of City Creek Canyon. At the mouth of the canyon, approximately 0.5 mile upstream from Memory Grove, there are two small ponds, approximately 1/4 acre in size (Figure 3). Despite their small size, we chose to sample upstream and downstream in 2010 to evaluate the ability of these small basins to remove CPOM. Figure 4 illustrates the effectiveness of CPOM removal during this relative low flow year.

Figure 42. Image depicting the two small debris basins located near the mouth of City Creek Canyon.

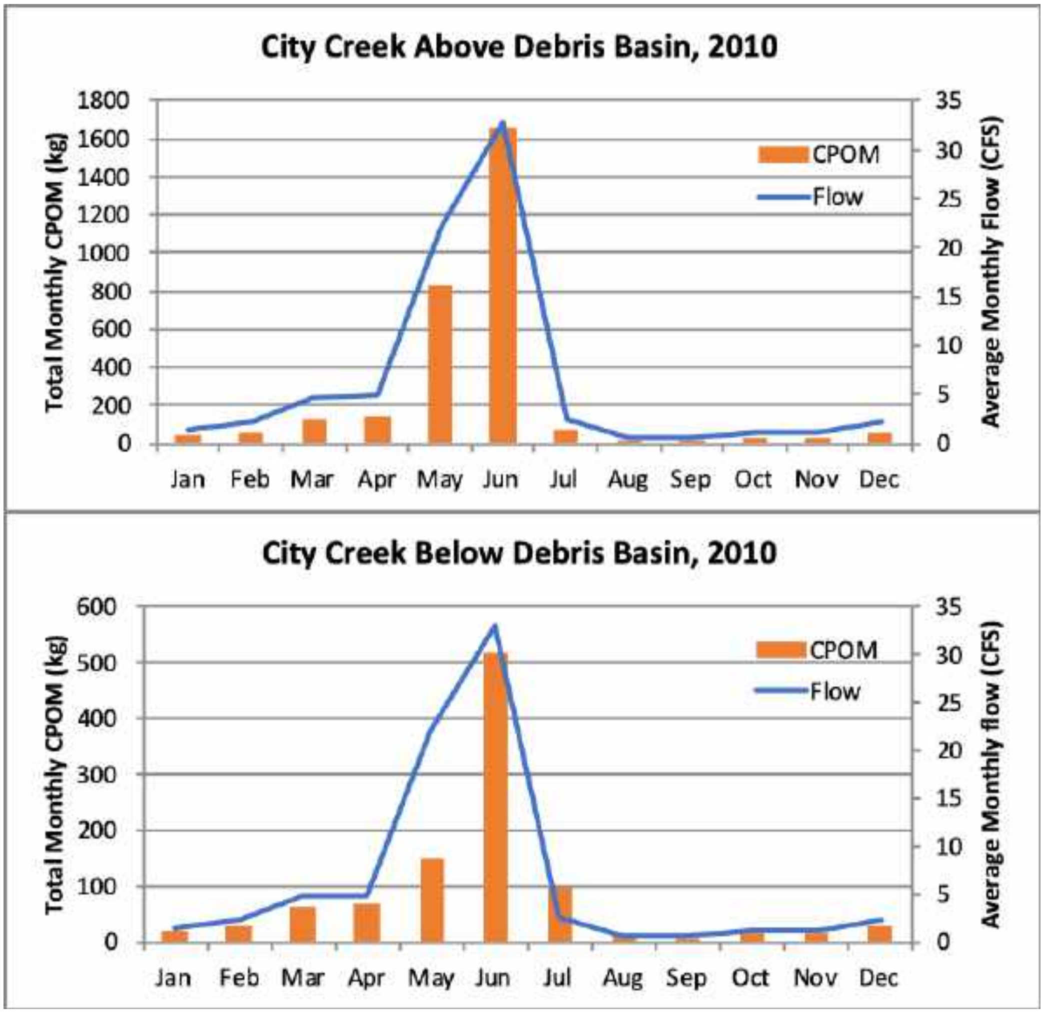


Figure 43. Monthly CPOM values in City Creek during 2010. Top: Samples collected approximately 100 m upstream from the debris basins; Bottom: Samples collected approximate 50 m downstream from the basins.

The two small debris basins reduced the CPOM load by about 2/3. This suggests that if these debris basins are maintained that substantial quantities of the CPOM can be removed and prevented from settling in and affecting downstream segments. Data collected during 2011 and 2012 are illustrated in Figure 5. During these years sampling was only performed at a point downstream from both debris basins. Because City Creek is directed to an underground culvert not far below Memory Grove, we feel that samples collected from this location provide an estimate of CPOM that is delivered to the Lower Jordan River near North Temple Street.

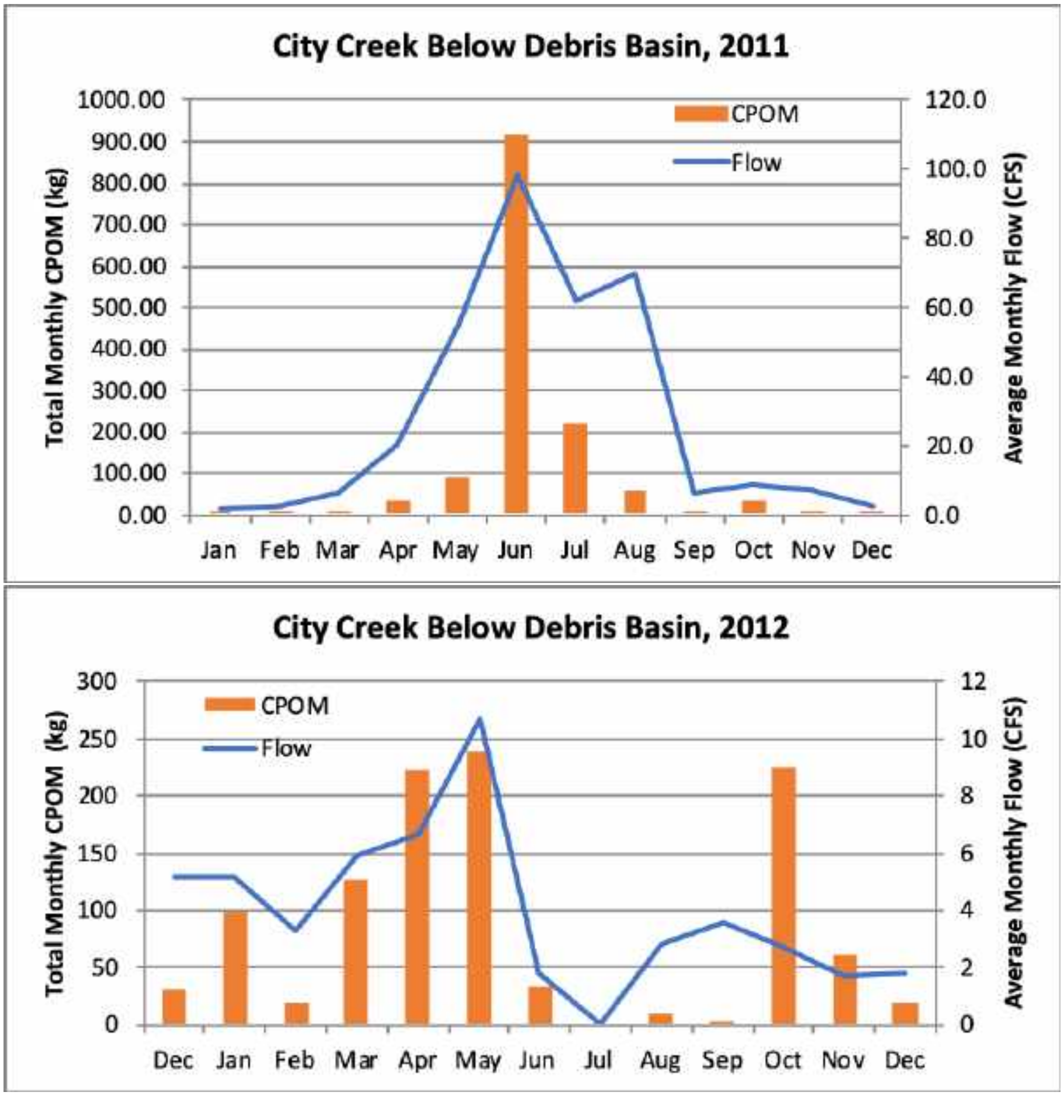


Figure 44. Monthly measurements of CPOM during 2011 and 2012 in City Creek. Samples were collected downstream from the small debris basins in Memory Grove.

It should be noted that rainfall and snowpack during 2010 was near the long-term average for the Wasatch front. Rainfall and snowpack during 2011 was approximately 30% above average while that for 2012 was about 30% below average. Therefore, the CPOM load during 2011 above the debris basins was likely much larger than that delivered in 2010, further suggesting that the debris basins were quite effective in reducing organic matter loads to the Jordan River. The CPOM loads during 2012 was predictably low.

Emigration Creek

Emigration is also a small tributary to the Jordan River and it is also directed underground shortly after it enters Salt Lake Valley. It also has a small debris basin at the mouth of the canyon. Our upstream sampling station was located approximately 1 mile upstream from the canyon mouth near the kiosk where fees are collected. The downstream sampling location was immediately below the debris basin. Similar to the effectiveness of the basins in City Creek, CPOM was drastically reduced by the debris basin at the mouth of Emigration Canyon (Figure 6). Emigration, Red Butte and Parleys creeks are united into one culvert and flow under the city streets until they discharge to the Jordan River at 1300 S or through an overflow channel that discharges at 900 S.

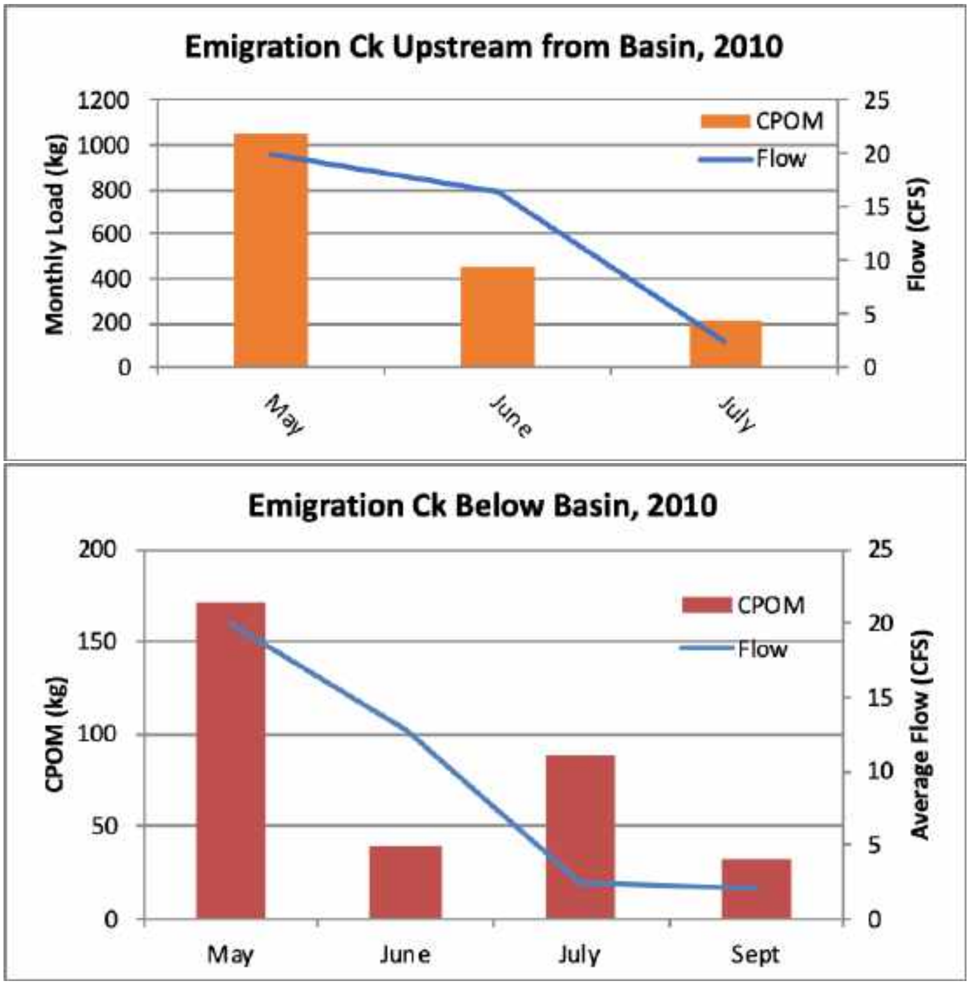


Figure 45. Monthly measurements of CPOM during 2011 and 2012 in Emigration Creek.

Mill Creek

Mill Creek is another small tributary to the Jordan River. It forms the next canyon south of Parleys Canyon. Again, it had similar flows and contains two smaller debris basins, although they are located about 3 and 4 miles out from the canyon mouth. The stream intermittently flows above ground and through underground culverts. Figure 7 illustrates the 2010 data collected upstream and downstream from the 1300 E basin.

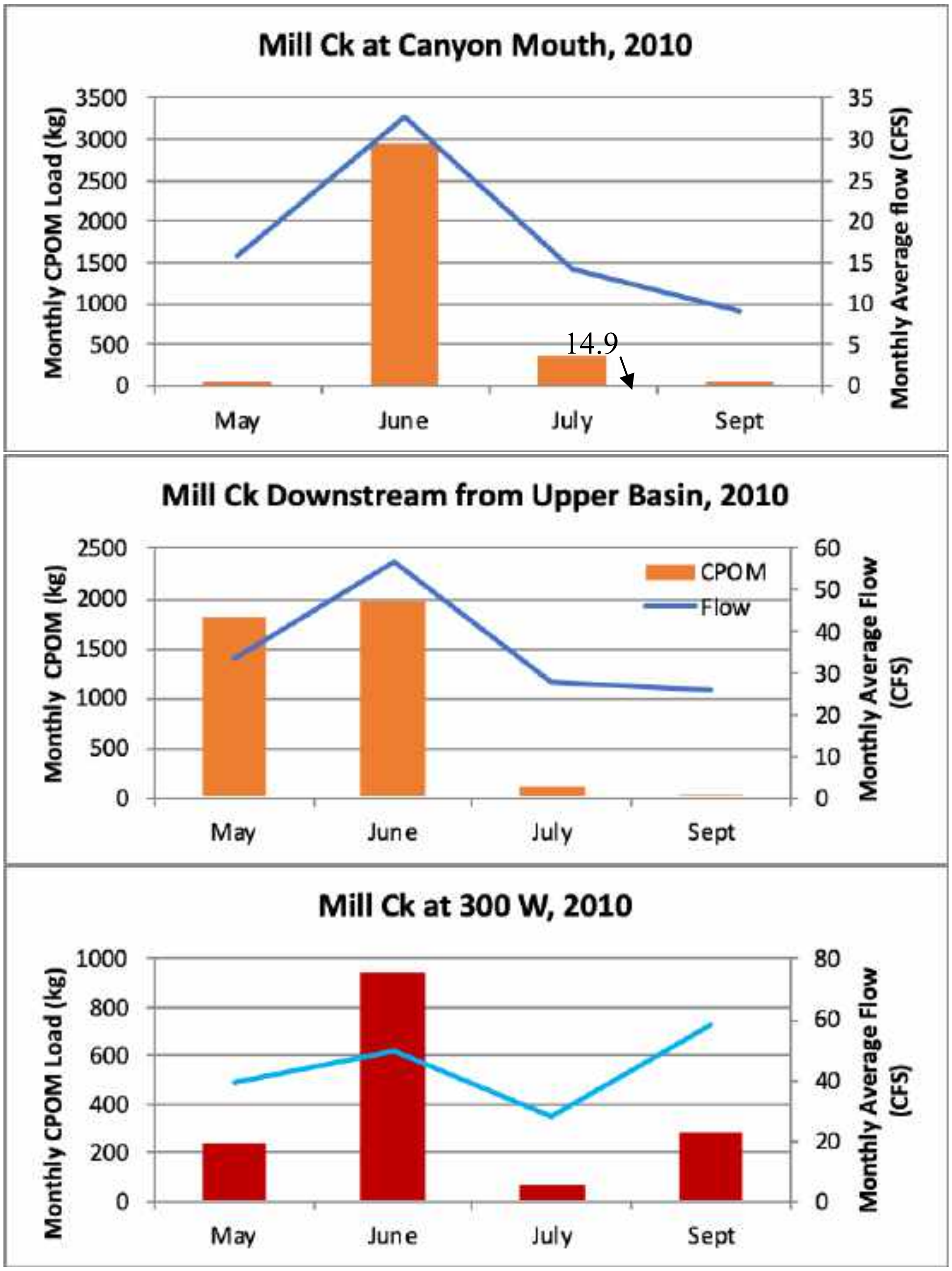


Figure 46. Monthly measurements of CPOM during 2011 and 2012 in Mill Creek.

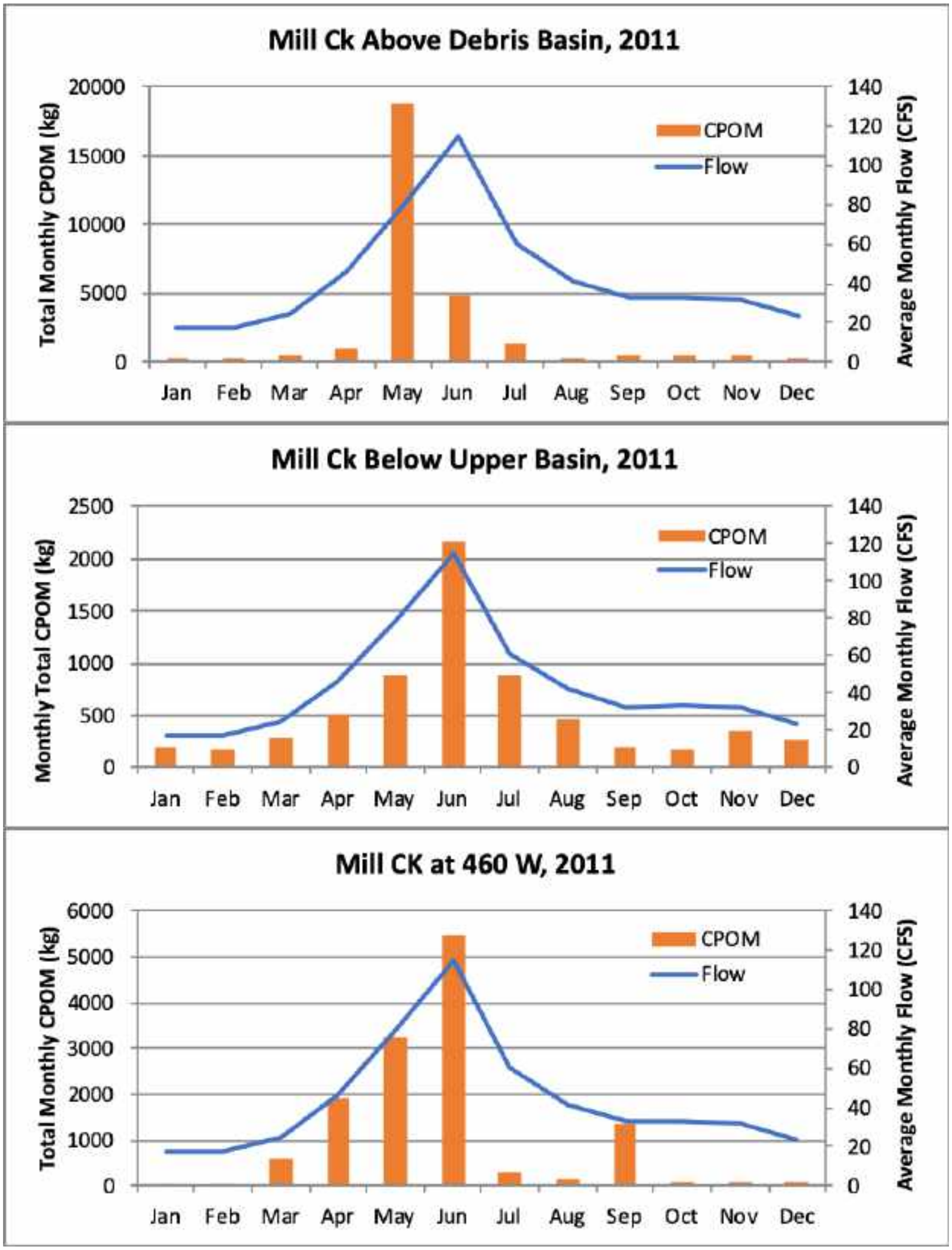


Figure 7. Continued. The unexpected high value in May above the debris basin was due to the collection of a large stick in the sweep net.

The debris basins again significantly reduced the amount of CPOM that is delivered to the Jordan River. Similar samples were collected during 2012 (Figure 8). It should be noted that rainfall and snowpack were much less than average, resulting in considerably less flows than during 2011. These low flows led to predictably low CPOM values at the canyon mouth. The channel gains consider flow as it travels toward the Jordan River. There are unusually high levels of CPOM above the 900 E debris basin even though flows are minimal. In addition, CPOM levels were elevated for the last three months. The fact that flows were diminished suggests that material was delivered anthropogenically at a location between the mouth of the canyon and 900 E.

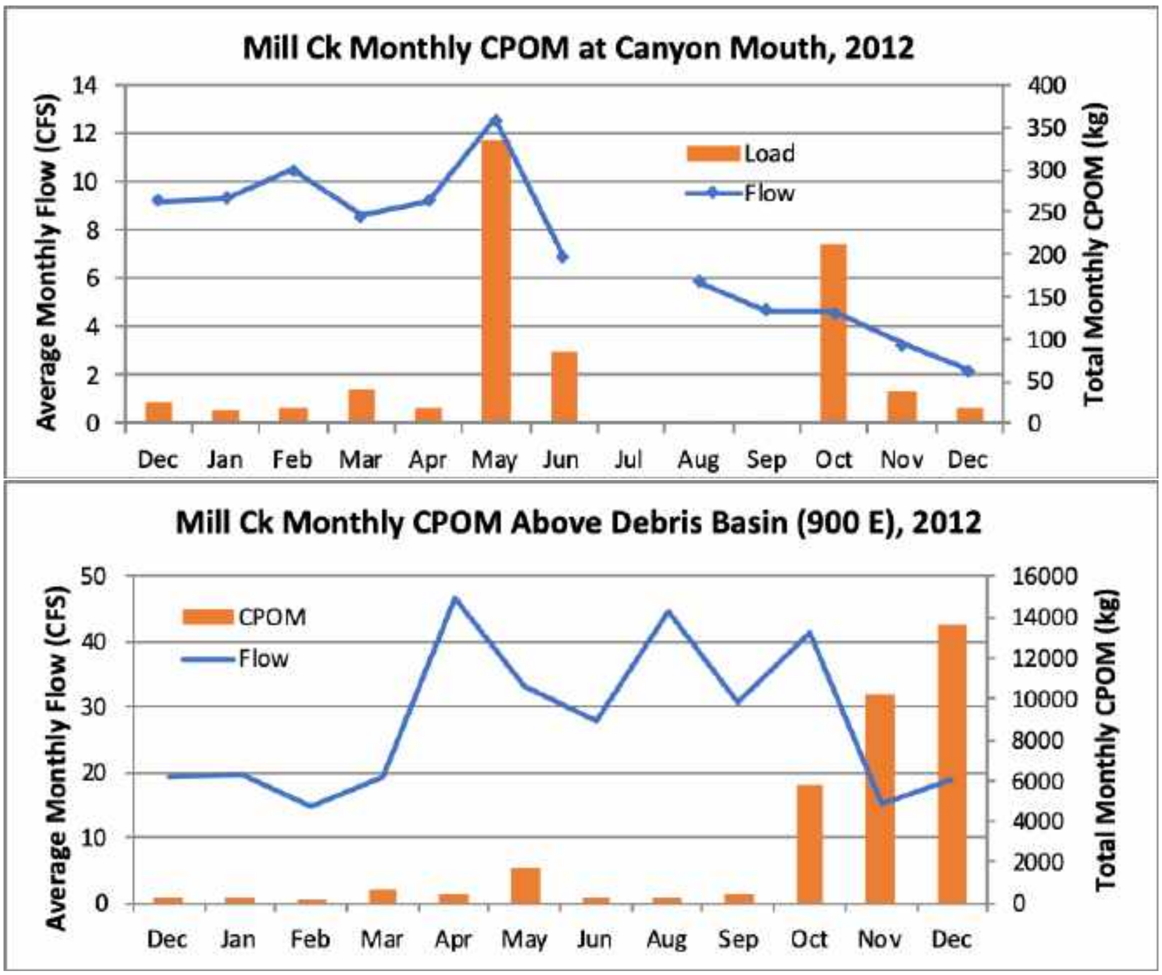


Figure 47. Monthly flow and CPOM values at four sites in Mill Creek during 2012. Mill Creek has two debris basins, immediately downstream from 900 E and immediately upstream from 500 E. Note the large increase in CPOM at 900 E and 500 E in October November and December, despite the low seasonal flow.

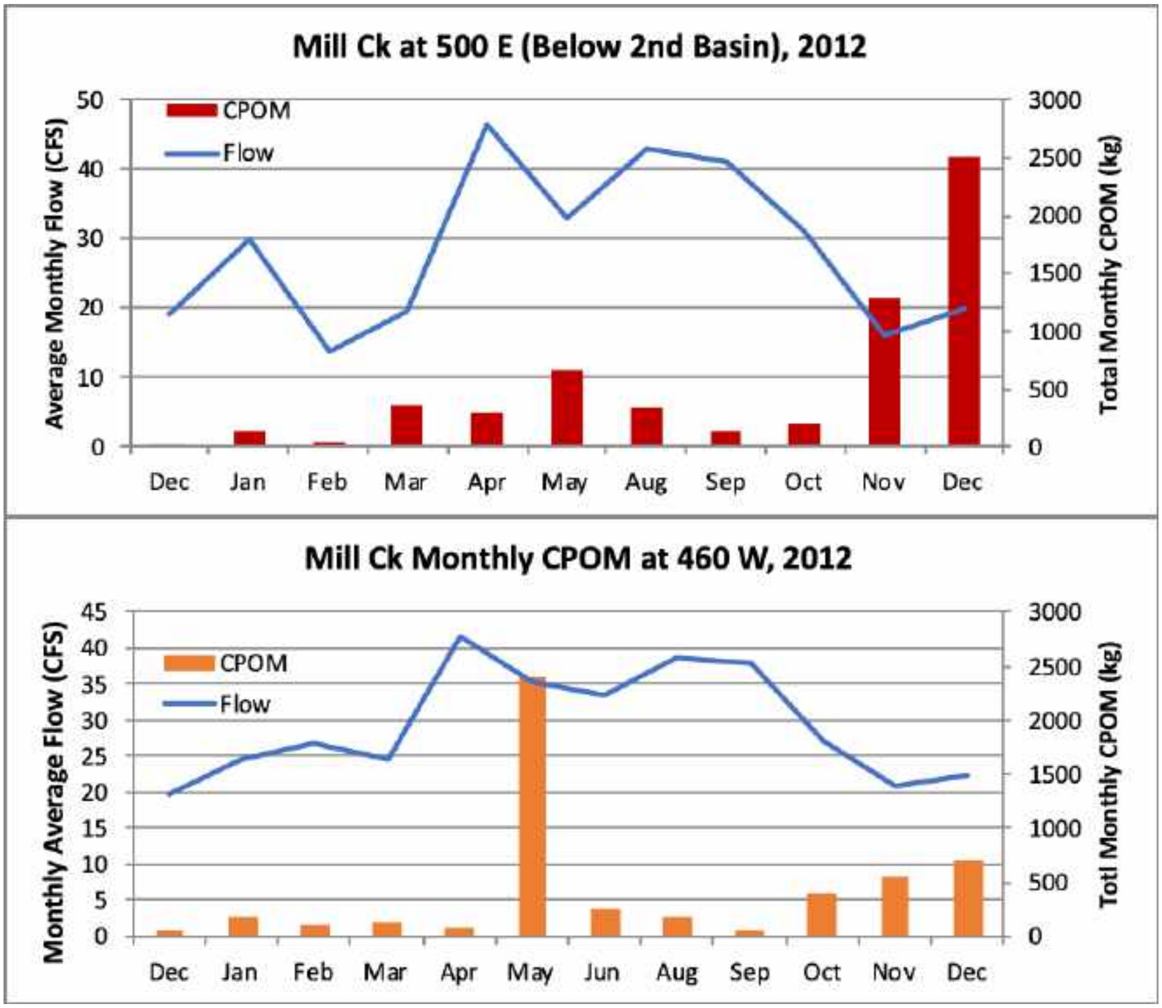
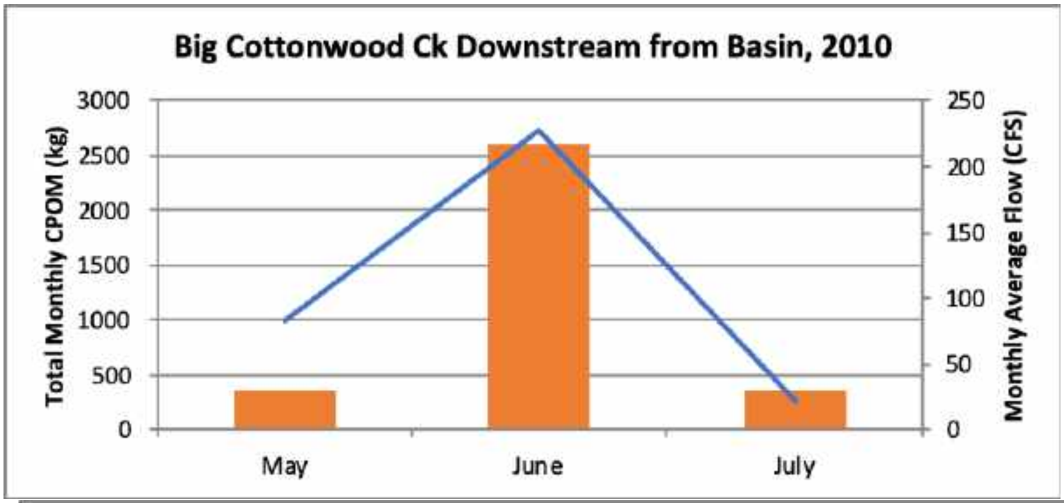


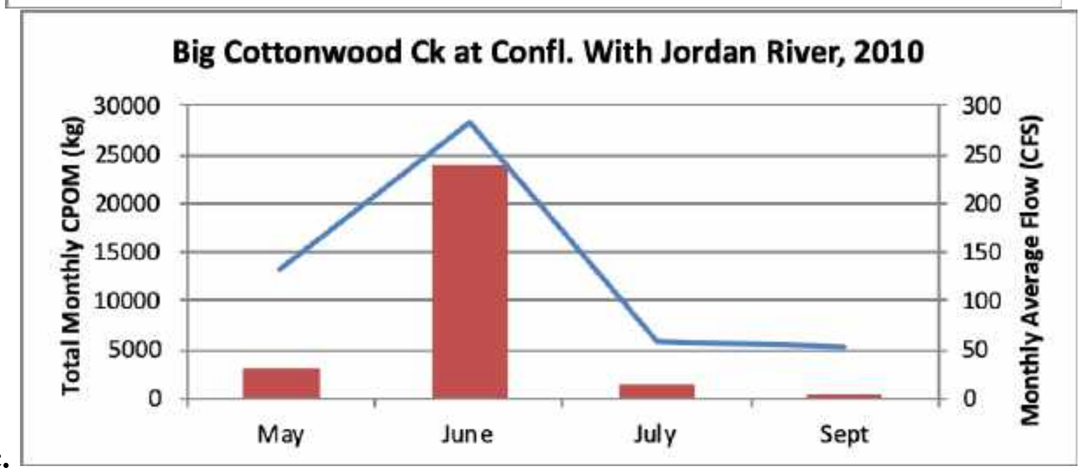
Figure 8. Continued. Monthly flow and CPOM values for Mill Creek during 2012.

Big Cottonwood Creek

Big Cottonwood Creek is one of the two major tributaries to the Jordan River. It was also subject to both extremely high and low flows. Again, it should be noted that 2010 represented a low runoff year, 2011 represented an above-average runoff year and 2012 represented another low runoff year. Both the highest flow and highest CPOM loads occurred in June for all three years. Even with the low flow years of 2010 and 2012, substantial CPOM loads are carried out of Big Cottonwood Canyon. During 2010, approximately 40,000 kg of CPOM was transported to the debris basin at the canyon mouth (Figure 9.a). Notably, however, the debris basin had sufficient residence time to provide for considerable removal of CPOM (Figure 9.b).

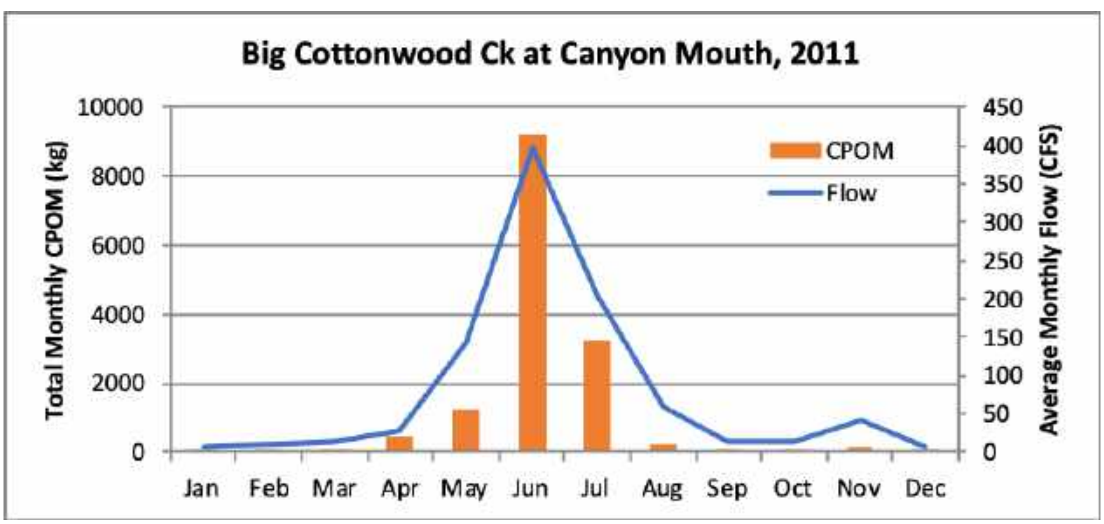
a. **b.**



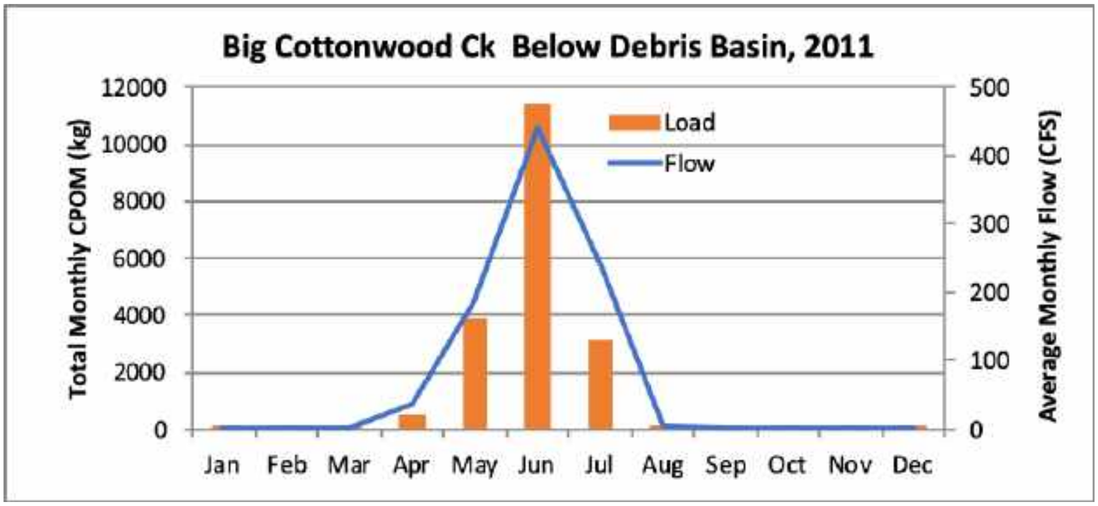


c.

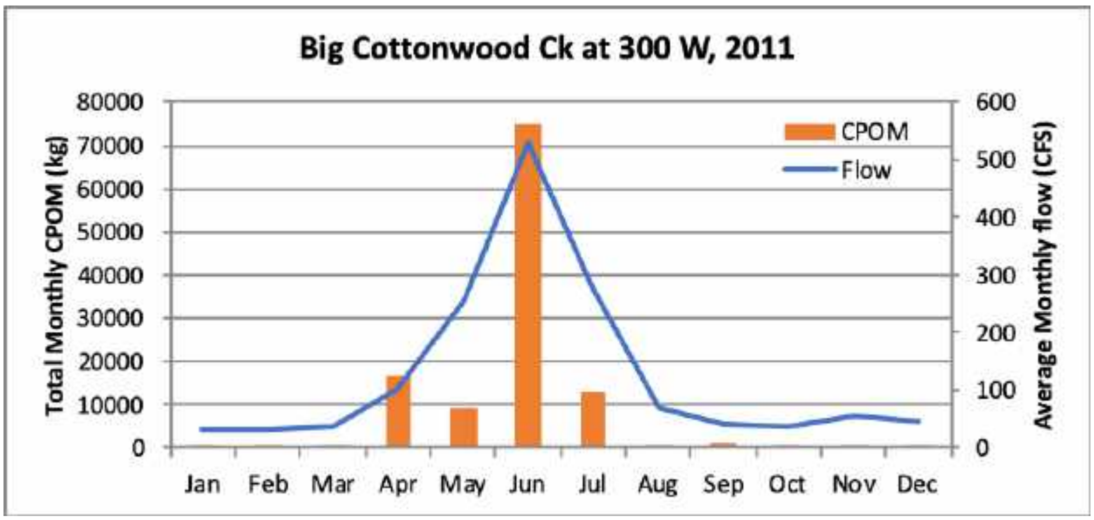
Figure 48. Flow and CPOM at selected sites along Big Cottonwood Creek during 2010, 2011, and 2012. The debris basin was located approximately 800 m (1/2 mile) below the canyon mouth.



d.

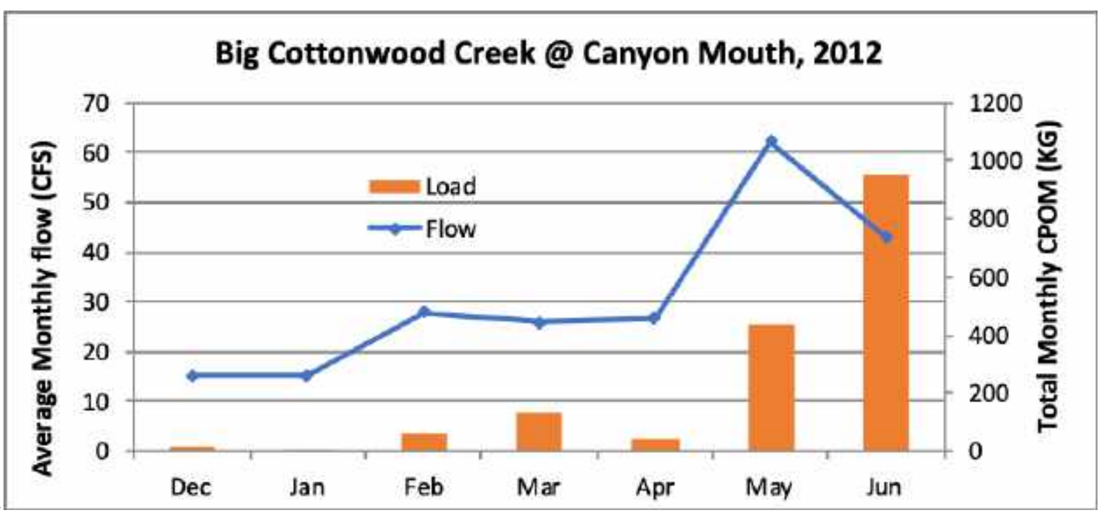


e.

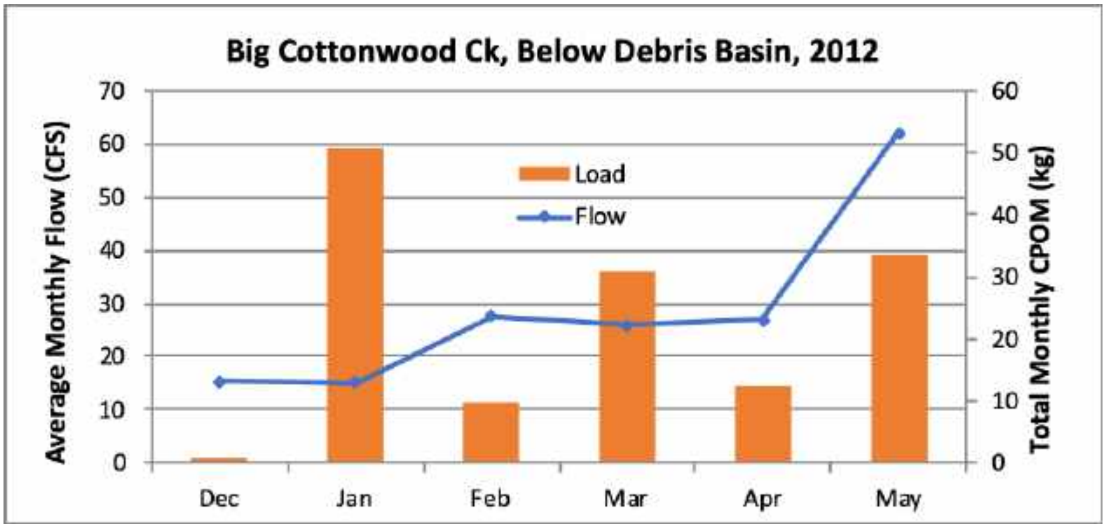


f.

Figure 9. Continued. Note in Figure 9 f. CPOM values for Oct. Nov. and Dec. were very low (13, 5 and 2.2 kg respectively).



g.

h.


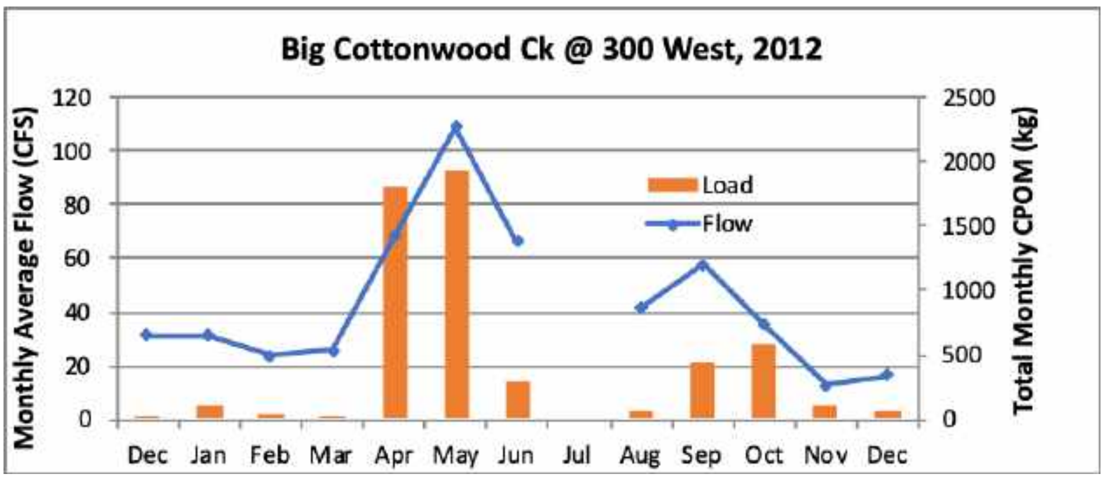
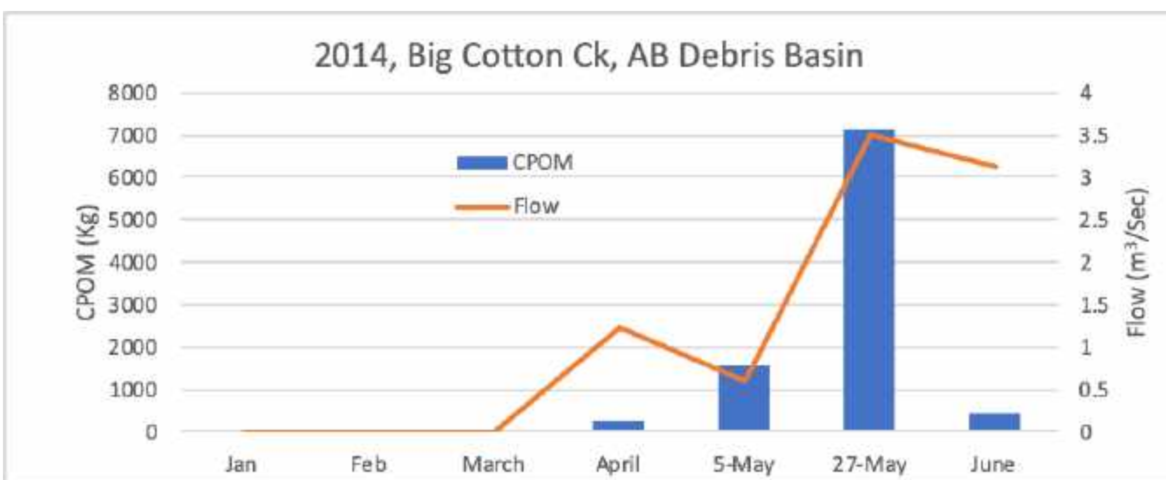
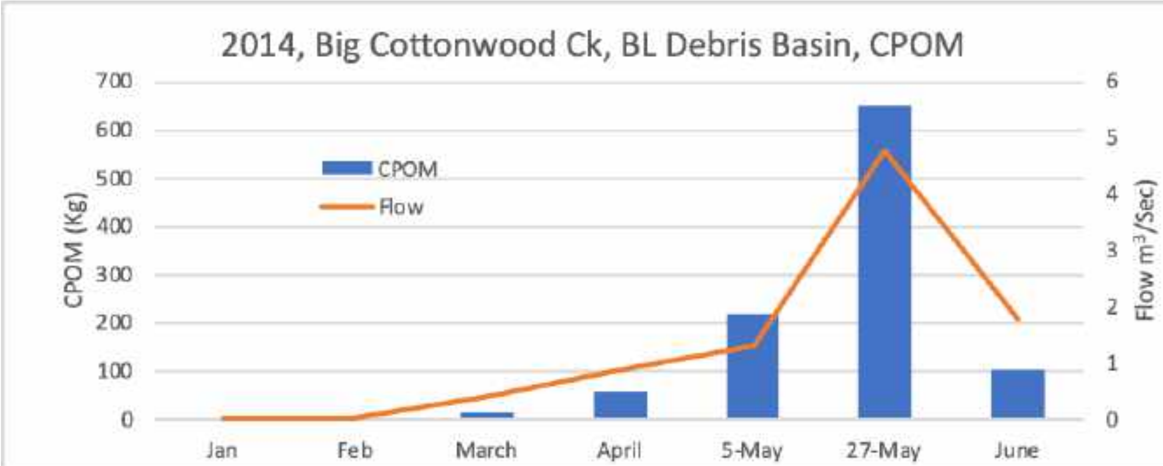
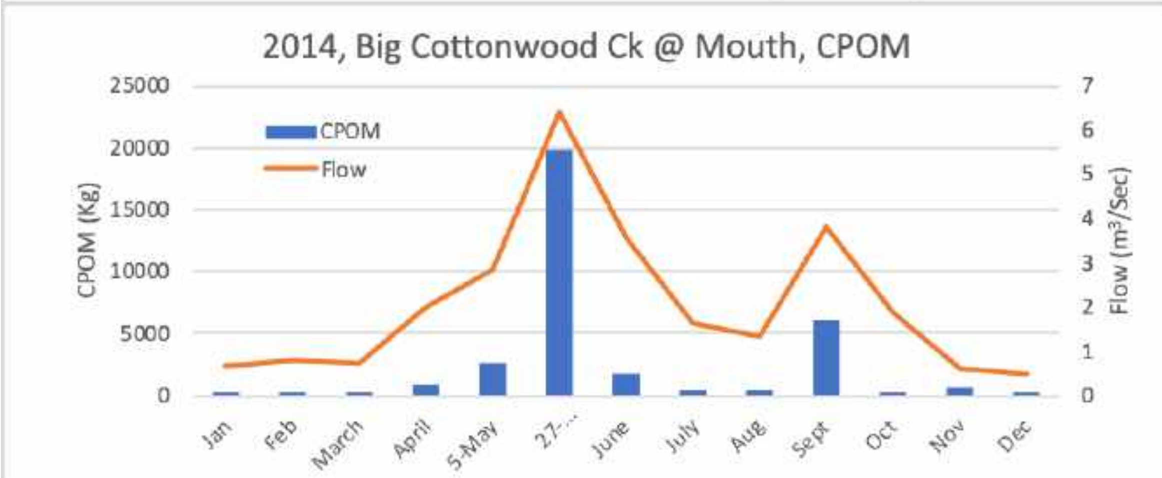
i.


Figure 9, Continued. Note, the creek was totally dewatered immediately below the debris basin after May, but then some return flows occurred by fall and continued carrying CPOM.







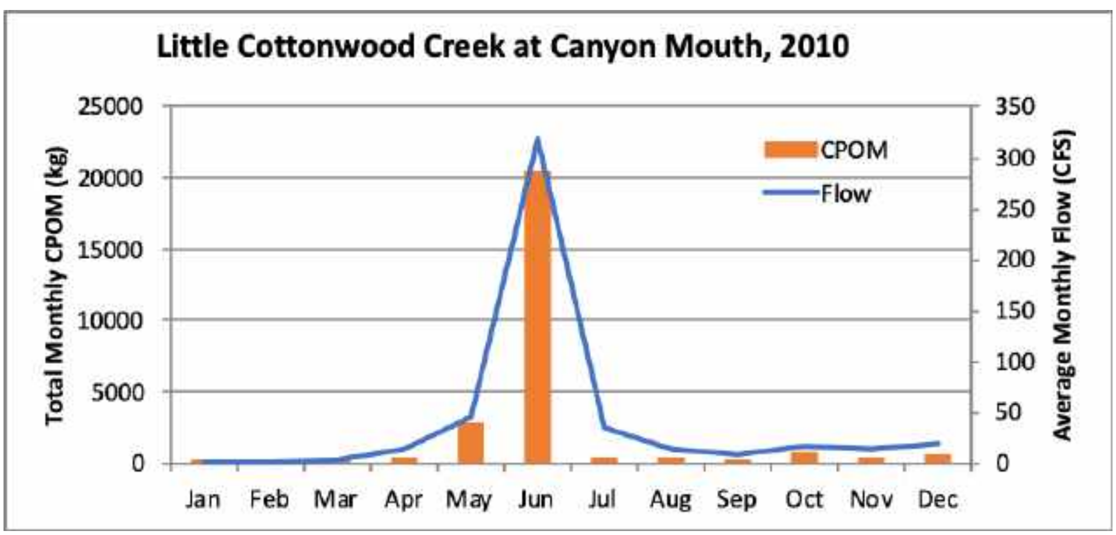
While the inflow delivered an estimated 40,000 kg during June, the outflow from the basin only carried 2,500 kg during June, a reduction of 94% (Figure 9b.). This reveals the effectiveness of debris basins if they provide sufficient residence time and are maintained. Despite the observed effectiveness of the debris basin during spring of 2010, Big Cottonwood Creek acquired considerable CPOM downstream of the debris basin (up to 25,000 kg during June) as it flowed through the urbanized section of the creek. This sampling site was located immediately upstream from the confluence of Big Cottonwood Ck and the Jordan River, indicating that this large load entered the Jordan River.
Flows were substantially greater during the greater snowpack year of 2011 (Figure 9, d., e. and f.). Yet, there was an unexpected lower load of CPOM. The CPOM samples for June were collected on June 8, which was relatively early on the ascending limb of the hydrograph during this specific year. This would have been before the creek reached or exceeded bankfull, whereby much more leaf and grass material that would have been deposited during the previous fall would be mobilized and transported by the creek. Also notable, the debris basin was ineffective in removing CPOM during this period. It is likely that either the increased flow did not provide adequate retention time, and/or the debris basin was relatively full of sediment and had not been dredged prior to the 2011 runoff season. Most notable, as with 2010, there was significant accrual of CPOM

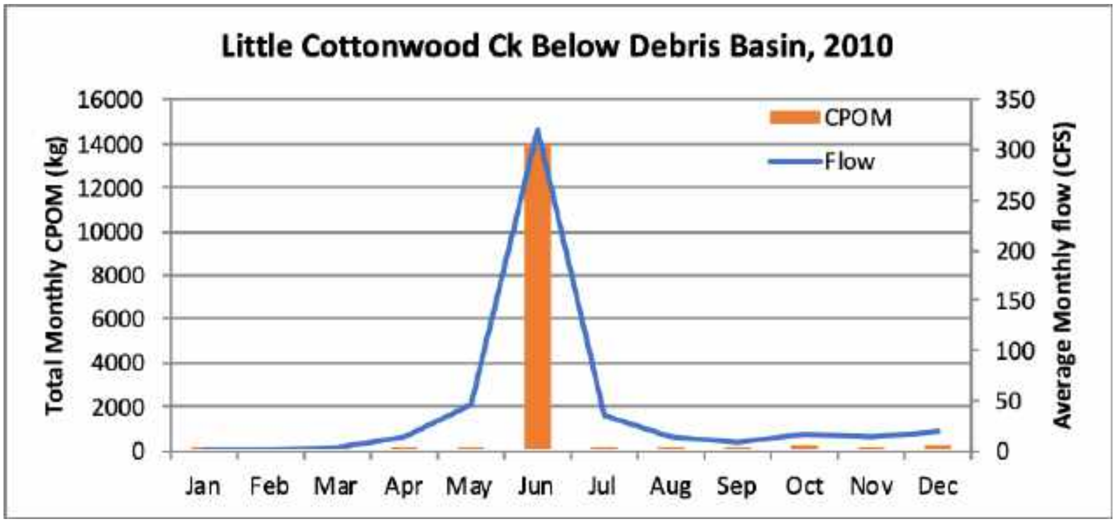
between the debris basin, and 300 W. The estimated CPOM load for the month at 300 W (and was undoubtedly delivered to the Jordan River) was near 75,000 kg (Figure 9 f.). This sample was collected about two weeks after sampling was performed at the canyon mouth, which was very close to the timing of peak flows in Big Cottonwood Creek. Flows during 2012 were substantially below average. The channel was completely dewatered by June at the canyon mouth and by May at the site below the debris basin. There were measurable flows at 300 W, which included a moderate amount of CPOM during May and June. The flow further diminished throughout the remainder of the year and this low flow undoubtedly contributed to the very low CPOM measurements, even though the months of leaf litter falling during September, October and November-suggesting that much of the leaf litter fell on the banks.

The flows during 2014 were about 40% higher than those of 2012 but still only about 30% of that during 2011. Predictably CPOM loads were proportional between these flows. About 20,000 kg flowed by the mouth during the spring of 2014, while 2000 kg flowed by the mouth the spring of 2012 and 70,000 kg flowed by the mouth during the spring of 2011 (Figures 8, 9 and 10)

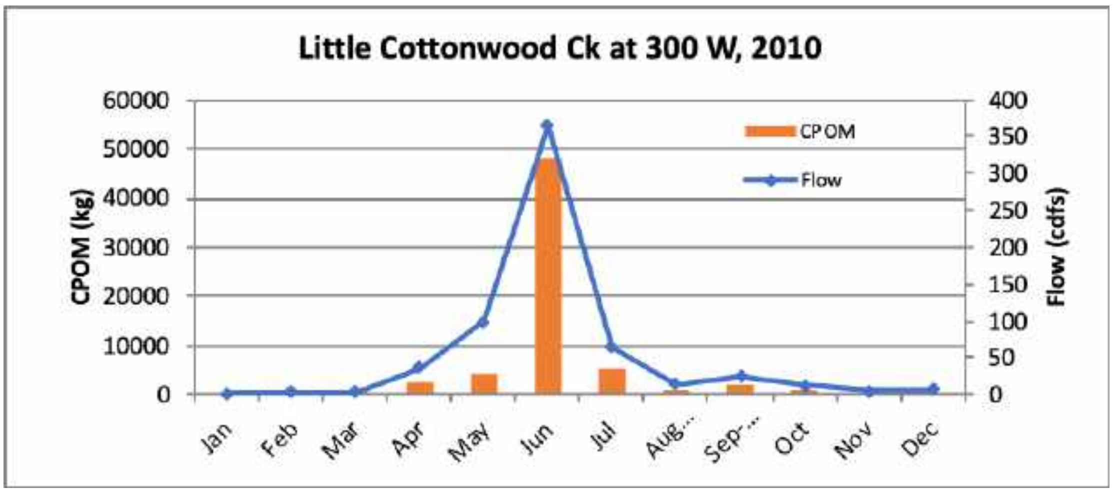
Little Cottonwood Creek

Little Cottonwood Creek behaved very similar to Big Cottonwood Creek. There is a small debris basin located just upstream from the diversion at the canyon mouth. This debris basin removed approximately ½ of the CPOM coming out of the canyon during 2010 (Figure 10). The snowpack was slightly below average during the 2010 spring with peak flows occurring during June. During 2011, runoff included much higher peak flow and this flow was sustained through both June and July.

a. 

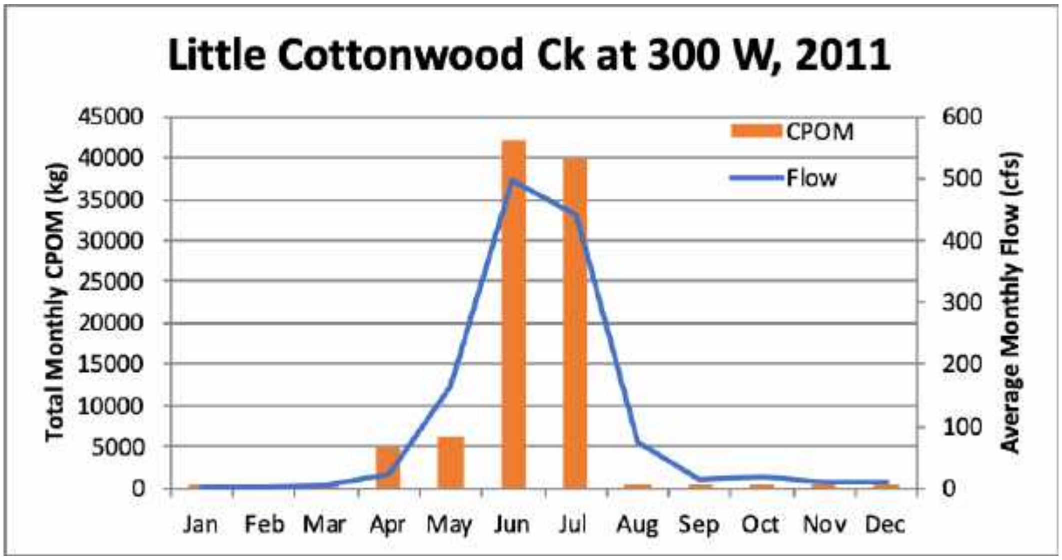


b.



c.

Figure 49. Flow and CPOM at selected sites along Little Cottonwood Creek. The debris basin was relatively small (approximately 0.5 hectare; 1 acre) located approximately 800 m (1/2 mile below the canyon mouth.

d. 

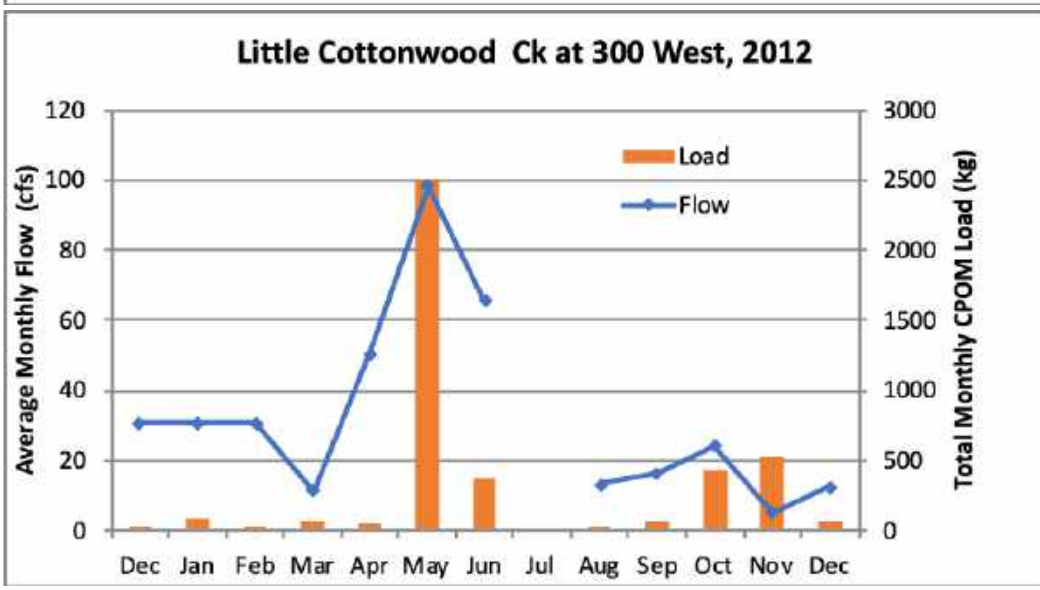
e. 

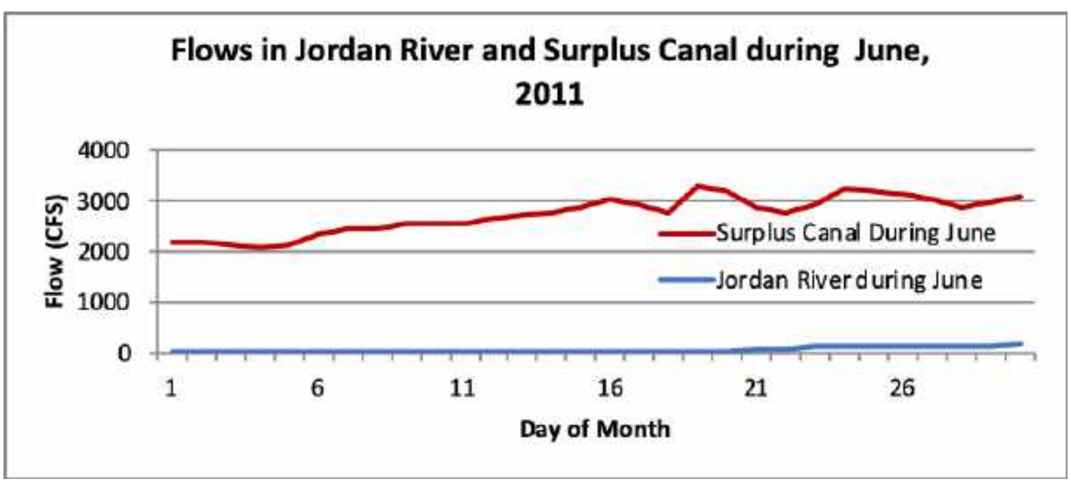
Figure 11, d and e. CPOM measurements and mean monthly flow at 300 W, approximately 800 m (0.5 mile) upstream from the confluence with the Jordan River. Note difference in axis scales between 2011 and 2012 graphs.

2012 was another low snowpack, low runoff year which resulted in much lower CPOM loading that during 2011. CPOM loads were directly correlated to flows and notably the fall loading that had occurred in Mill Creek and City Creek was not observed or was greatly diminished in both Little Cottonwood and Big Cottonwood Creeks. This may have been due to the timing of sampling or perhaps also due to the relatively low flows of late summer and fall of 2012. Also, as with Big Cottonwood Creek there are many 10s of thousands of kg of CPOM transported during the high spring flows and again, the creek picked up substantial amounts of CPOM as it flowed through the valley floor.

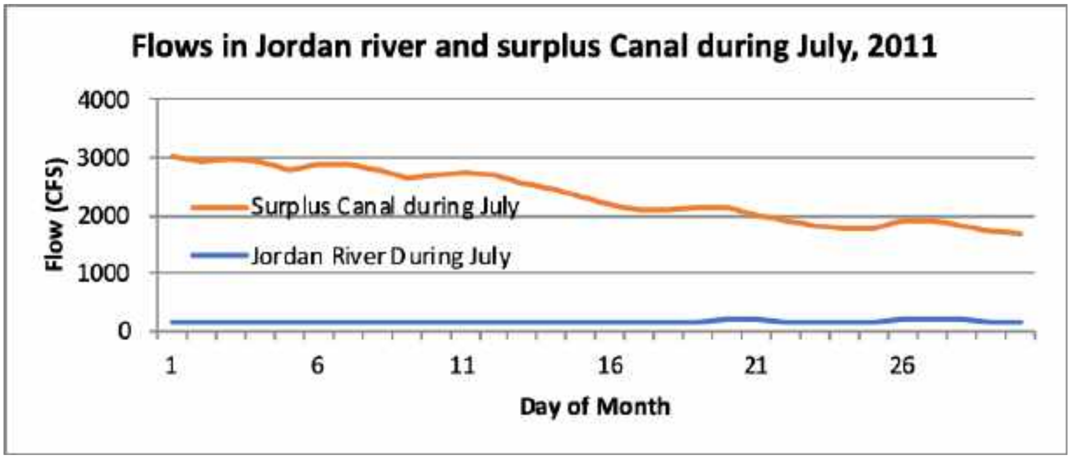
Jordan River

The Jordan River was sampled at several sites to understand the timing of delivery and the magnitude of CPOM loading to and transport within the lower Jordan River. For example, large quantities of CPOM are transported to the Jordan River upstream from the 2100 S diversion. Yet, most of this material is delivered during periods of high flow and particularly from those tributaries that join the Jordan River upstream from 2100 S. This presents an important and complicated conundrum. For example, it is during high flow events that up to 90% or more of the Jordan River is diverted to the Surplus Canal (Figure 11 a. and b). Under extremely high flow conditions, the gates are nearly completely closed (Figure 11). Initially this suggests that the great majority of CPOM is diverted with the majority of the flow. However, it is also important to note that the gate in the diversion dam provides only for a bottom release to the downstream river channel. This is opposite the top-water release of water diverted to the surplus canal. It is also important to note that on several occasions and throughout the Jordan River and its tributaries, we observed that even the freshly fallen leaves and twigs only require minutes to maybe an hour to become saturated and thereby quite rapidly sink to where the majority of CPOM is carried as organic bedload material. Therefore, a relatively smaller proportion of the CPOM may actually to pass over the top of the dam and down the Surplus Canal (depending on the local hydraulics and potential for upwelling at the weir itself). Alternatively, it is possible, that when the gate is open even slightly, a greater proportion of the organic bedload will continue down the channel rather than being diverted.

The reason why so much of the flow is diverted is that tributaries that deliver water downstream from 2100 S add considerable flows. These include the 1300 S and 900 S conduits from Emigration, Red Butte and Parleys creeks and the North Temple conduit that similarly transports City Creek water under Salt Lake City. Hence, flows are diverted to the surplus canal to provide channel capacity for these tributaries. These flows are apparent from the measurements made at 500 N (vs flow measured at 1700 S), which are those graphed and used to estimate downstream loads. Figure 13 illustrates the flows and CPOM loads in the lower Jordan River during 2011 and 2012.



a.



b.

Figure 50. A comparison of flows measured in the Surplus Canal at the SLC International Airport and the Jordan River at 1700 S, during June (a) and July (b).

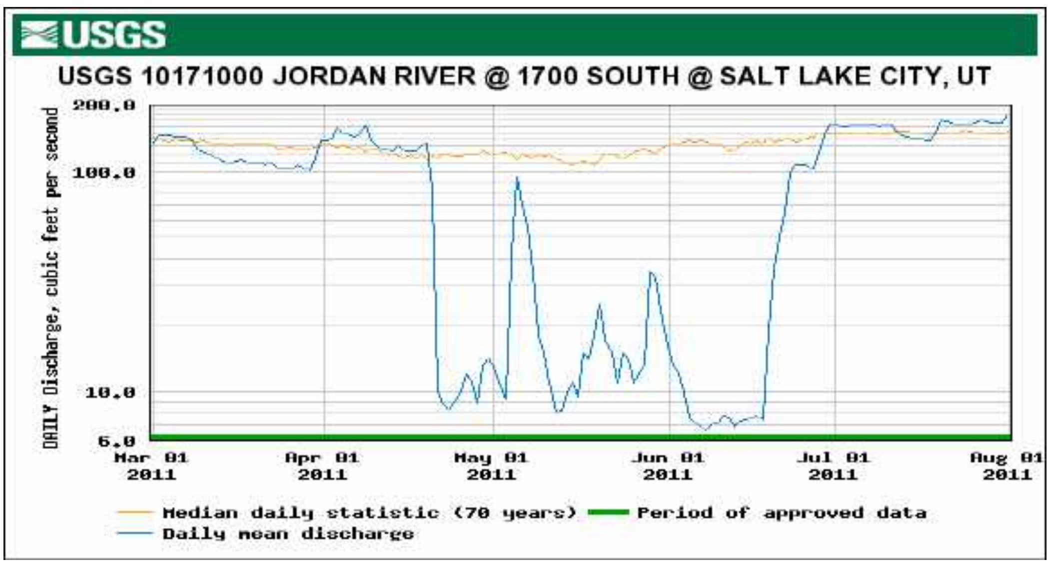


Figure 51. USGS flow data recorded at 1700 S from March through July 2011. Note how flow was restricted during the peak runoff months of May and June.

An example of a low water year was the 2012 (Figure 13). Snow pack during the winter 2011/2012 was at about 70% of average. This led to a much lower runoff and hence a much lower proportion of the Jordan River was diverted to the Surplus Canal. As a result, the CPOM loads were also much lower than the 2011 year (see below).

There are two distinct flow regimes associated with the 2012 season. The first is that the greatest flows during 2012 occurred from the end of January through April. Note that peak flows occurred in February and March, as more water was released from Utah Lake to provide additional capacity for possible additonal high runoff flows in 2012. However, spring runoff flows were much lower than expected prompting the water managers to change their management strategy and begin conserving water in Utah Lake, thus altering and restricting normal seasonal flows. Indeed, by June, when flows are normally peaking, they were very much less than 2011 values and had fallen to a stable range near 175 CFS at 1700 S (Figure 13). It is also informative to provide similar detailed daily flow for the months June and July. These are included in Figure 14. Comparison with Figure 11 reveals the dramatic differences in flow regime that can occur from year to year.

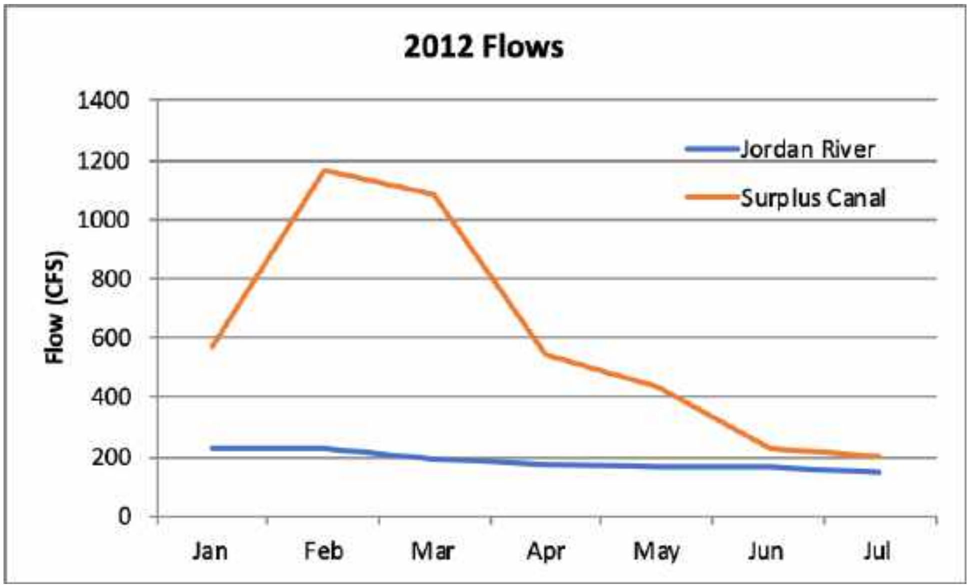
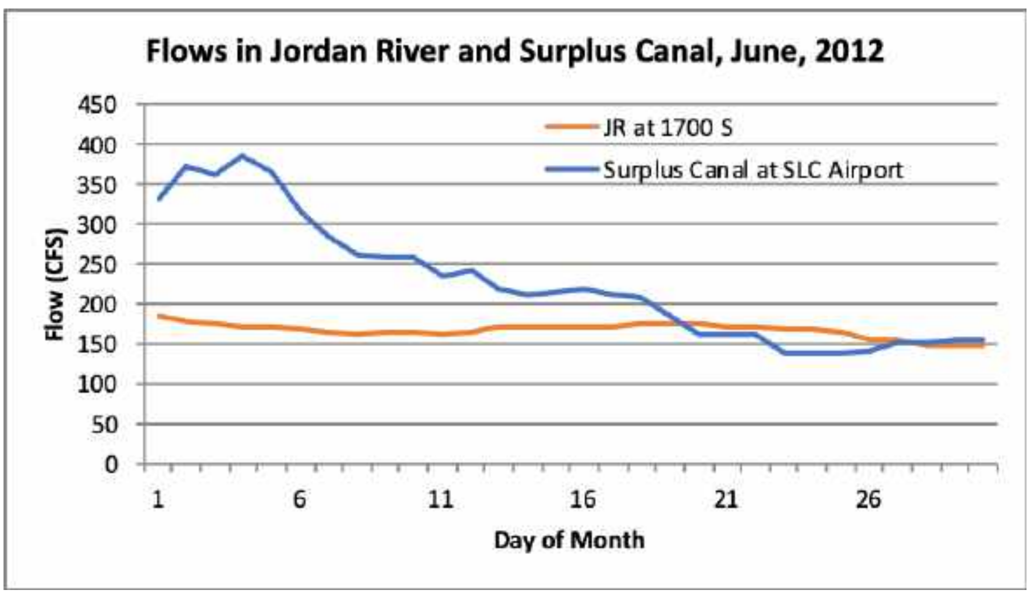


Figure 52. Mean monthly flows in the Surplus Canal and in the Jordan River at 1700 S During 2012. Note unusual peak flows occurred during February and March rather than during normal timing for spring runoff. See text for more details.



a.

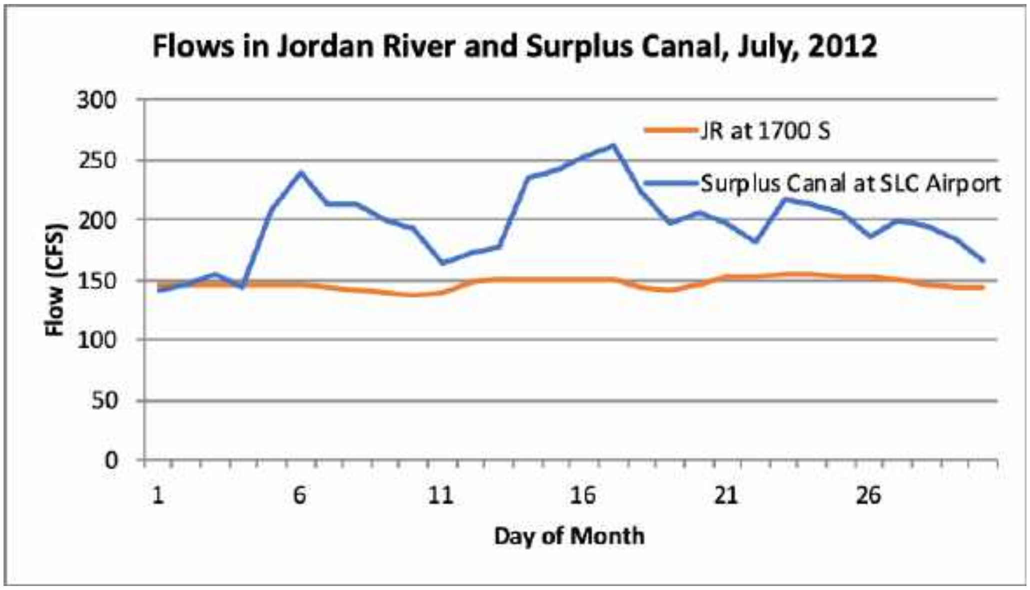
b. 

Figure 53. USGS flow recordings in the Jordan River at 1700 S and the Surplus Canal during June (a) and July (b) of 2012.

CPOM loads responded as expected to these different flow regimes. Flow and CPOM loads in the Jordan River during 2011 are illustrated in Figure 15. CPOM loads were generally correlated to flows. Some notable characteristics include; 1) Total flows (combined Surplus Canal and the 1700 S flows) remained near or above 3000 CFS for about 3 weeks during June and July (Figure 11). Yet, a greater proportion of water was allowed down the Jordan River channel starting on about June 23 and continuing throughout July. This greater flow down the channel apparently carried a greater load of CPOM, even though total flow began to diminish after the first week in July. This is likely related to the point made above, wherein the bottom discharge of the diversion dam leading to the lower Jordan River is carrying a disproportionate higher load of CPOM relative to the actual total flow because the CPOM is primarily being carried as bedload and hence is more easily directed to the bottom release of the gate leading to the river channel. Contrarily, the flow diverted to the Surplus Canal flows over the top of the weir which is about 2 m above the stream bottom. Overall, several hundred thousand kg of CPOM were likely transported to the lower Jordan River.

Figure 15 also reveals the immense quantities of CPOM that settled out of the water column during 2011 between 1700 S and 300 N, even though there were additional tributary contributions from Red Butte, Emigration and City Creeks. For example, 40,000 to 70,000 kg of CPOM typically passed 1700 S while only 8,000 to 16,000 kg passed the 300 N site per month. Many tens of thousands of kg of CPOM settled to the bottom of the Jordan River each month during 2011. The implications of this mass settling is discussed in Chapter 5.

During 2012 the sampling effort was increased to included monthly samples. Overall flows were much less than during 2011, although similar flow-related patterns of CPOM were observed during 2012 (Figure 16). Again, despite the diversion of most of the flows, a considerably elevated load of CPOM was associated with the increase in spring flows. For example, there were two CPOM samples collected during January, 2012. The first was collected January 5, when total flows (1700 S and Surplus Canal flows totaled 595 CFS) and the CPOM load was measured at 1.2 mg/ft3 at 1700 S. If flows had been sustained at this value, the total CPOM load for January would have been 511 kg. However, the second CPOM sample was collected on January 25, one day after flows had increased by 50% to 879 CFS. These were the highest flows experienced by the river since the spring of 2011 and hence it is likely that this increase had begun to pick up additional CPOM lying in backwaters or on the banks. If this flow and CPOM load had been sustained for the entire month of January, the total monthly CPOM load would have been estimated to be 10,367 kg. The mean of these two values was 5,439 kg (Figure 16), perhaps an accurate reflection of actual January loads. These data further support the idea that, although the great majority of water is diverted to the Surplus Canal during high flows, there are considerable quantities of CPOM that continue moving down the channel as well as additional quantities delivered by Immigration, Parley's, Red Butte and City Creeks and the downstream reaches of the main stem that flow through the Rose Park neighborhood and North Salt Lake. In turn, and contrary to the January peak in CPOM, the June CPOM peak was likely due to the natural runoff and increase in CPOM loading from the tributaries (Figures 8, 9 and 10). CPOM values measured during autumn were elevated once again and were correlated to the annual leaf fall from riparian zones along tributaries, storm drains and the main stem. Notably, these autumn values were similar to those measured during 2011 – as was the actual stream flow.

We continued sampling for CPOM during 2013, 2014 and 2015. These additional data were collected in order to capture additional potential variability due to flows streamside management or changes in land use. Notably, drought, with very low flows continued throughout these years. As a result, CPOM remained quite consistent with 2012 data, all of which represented a smaller CPOM load compared to that collected during 2011. Nevertheless, many thousands of kg of CPOM are delivered annually to the Jordan River. For example the 2014 data for Big Cottonwood Creek shows both the effectiveness of the large debris basin at the mouth of the canyon, the effectiveness of that debris basin in reducing CPOM loads and yet the large addition of CPOM as the Creek passes through urbanized neighborhoods toward the Jordan River.

The early years of data raised concern by the Utah Division of Water Quality as to the quantity of CPOM delivered to the lower Jordan River and the link to the SOD. Therefore, UDWQ contracted to Dr. Michelle Baker of USU to perform a similar study to ours during 2013. We shared our sampling methods with Dr. Baker and although we sampled similar sites on the main stem, Dr. Baker's group did not sample tributaries. Also Dr. Baker's group sampled less frequently and at different times than us. Nevertheless, our results were quite similar. Table 2 shows the difference between the two teams. Our group consistently showed higher loads, but with the high variability in this type of sampling (one or two twigs in the sample net can easily double the quantity of CPOM. For this reason, our team always collected at least triplicate samples and determined the mean. In addition, we often sampled twice per month during spring runoff to ensure we were appropriately characterizing flows and loads.

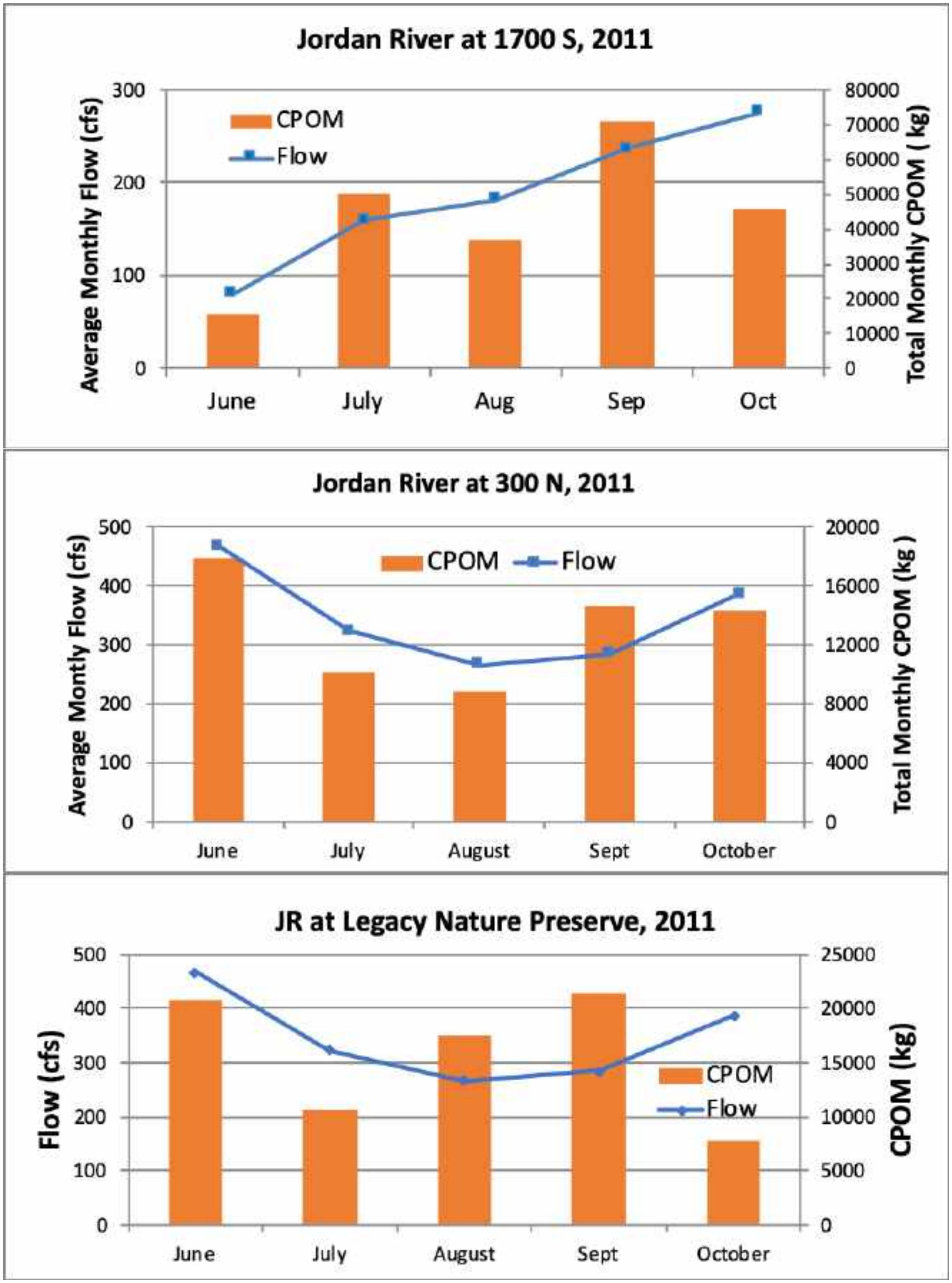


Figure 54. Flow and CPOM measurements made at 1700 S (a.), 300 N (b.), and Burnham Dam (c.) during 2011. Flow measurement data was collected from the Salt Lake County gage at 500 N.

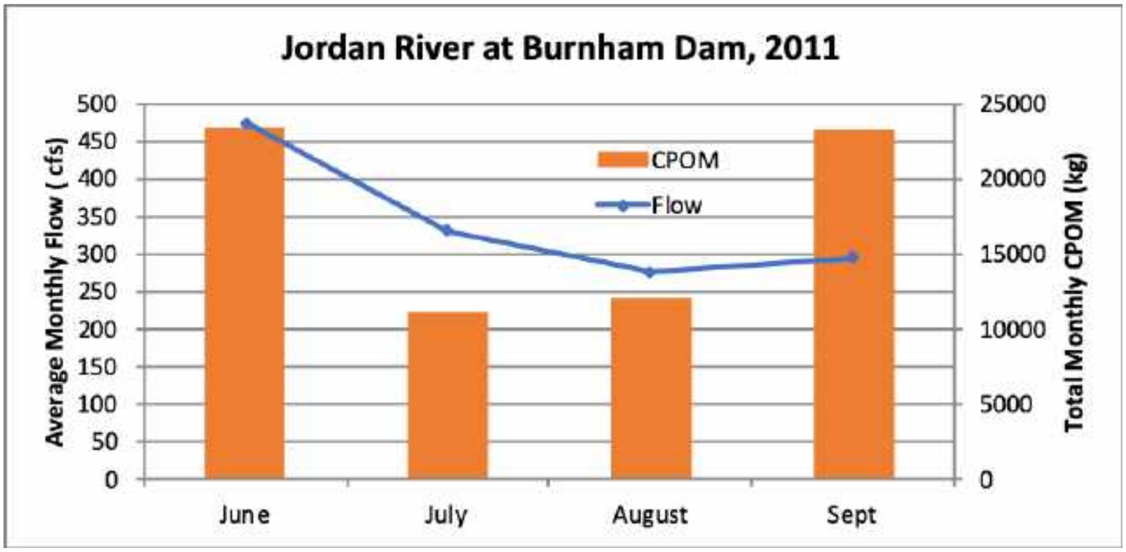


Figure 15. Continued.

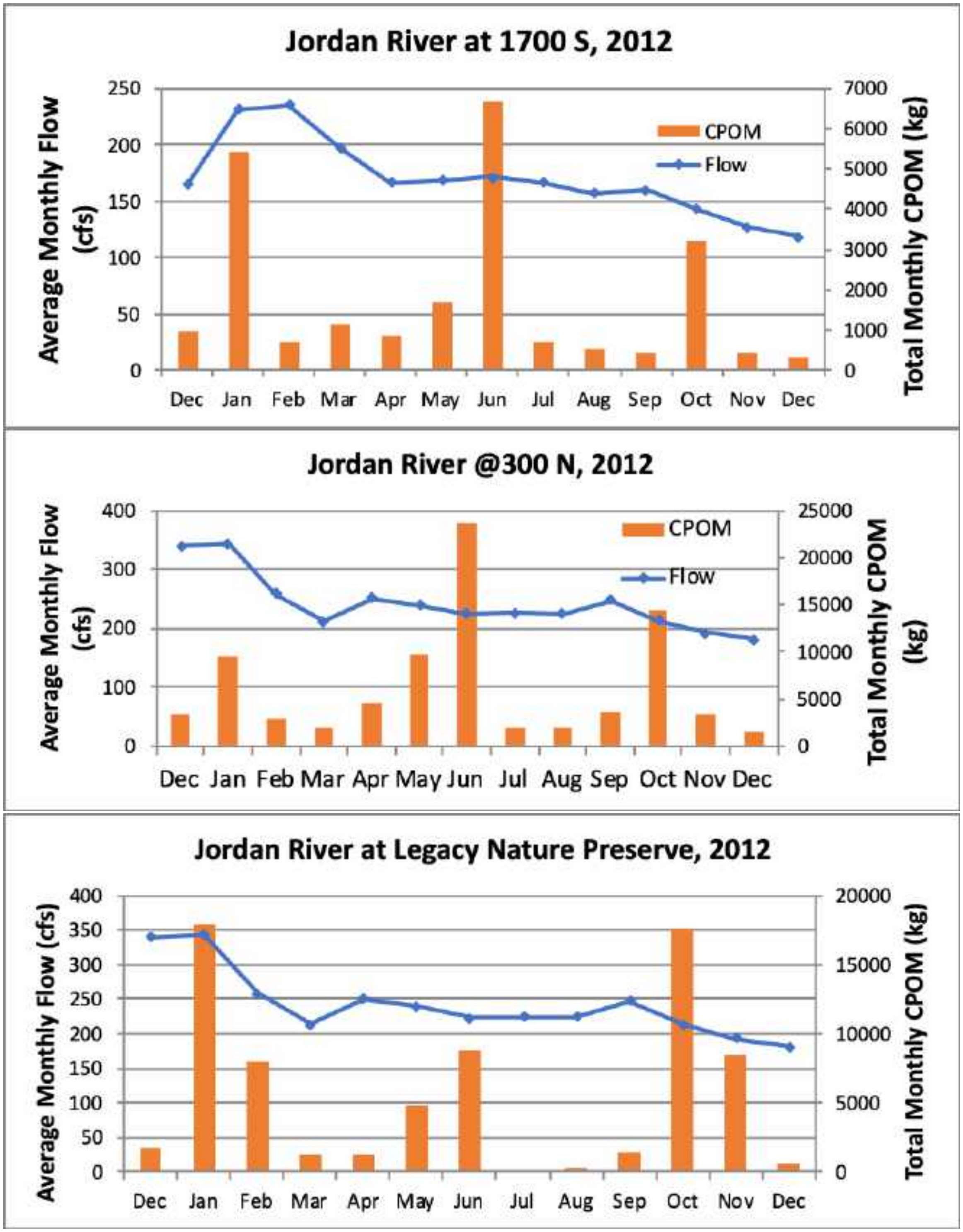


Figure 55. Monthly measurements of flow and CPOM at 1700 S (a.), 300 N (b.) and Legacy Nature Preserve (c.) during 2012. During the higher flow periods of January, February and March, and during August, September and October, CPOM samples were collected twice monthly.

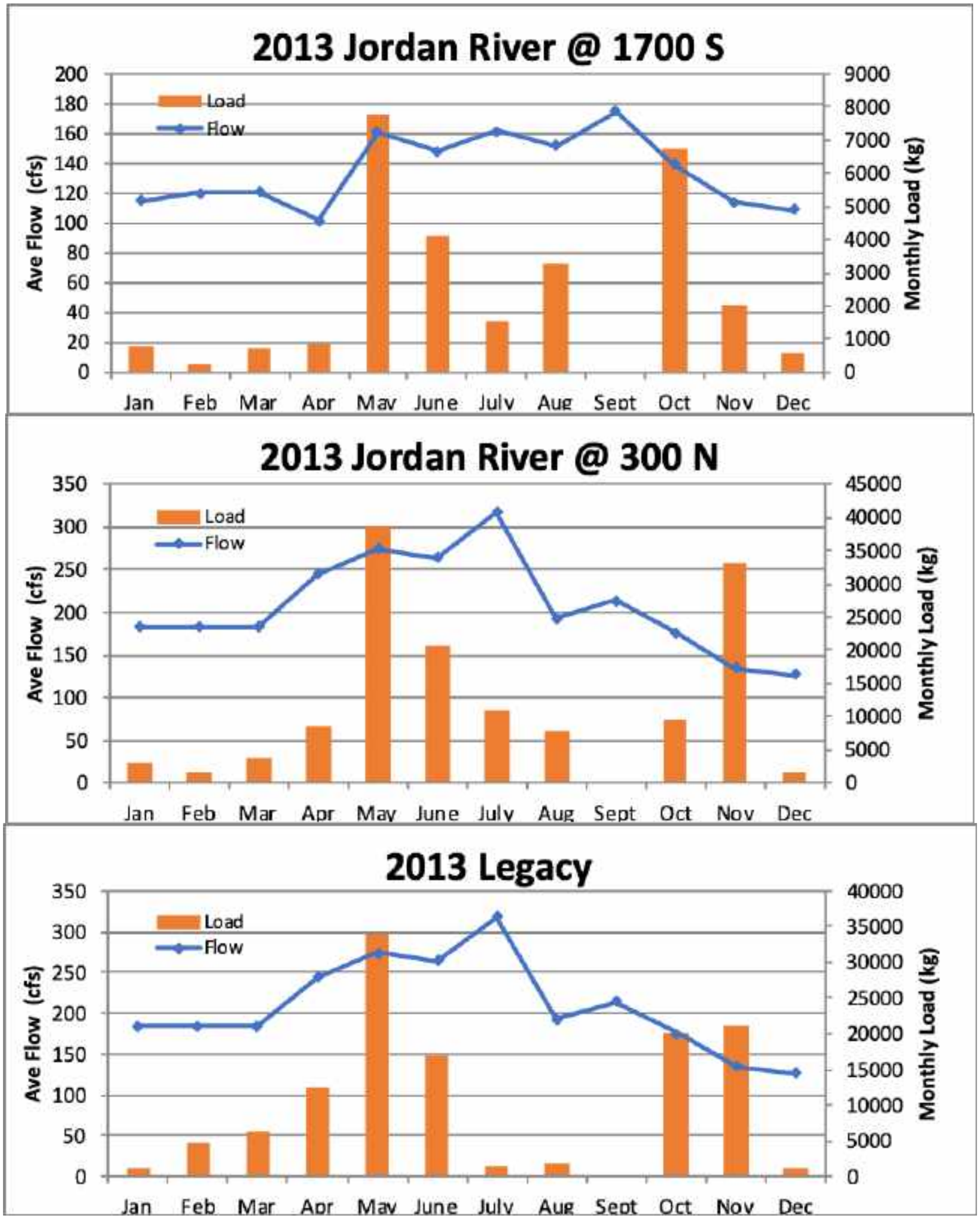
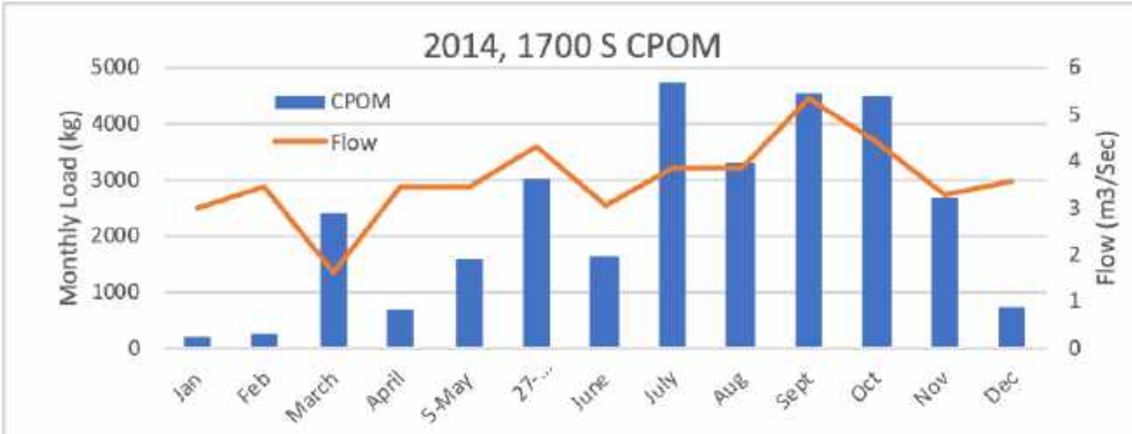
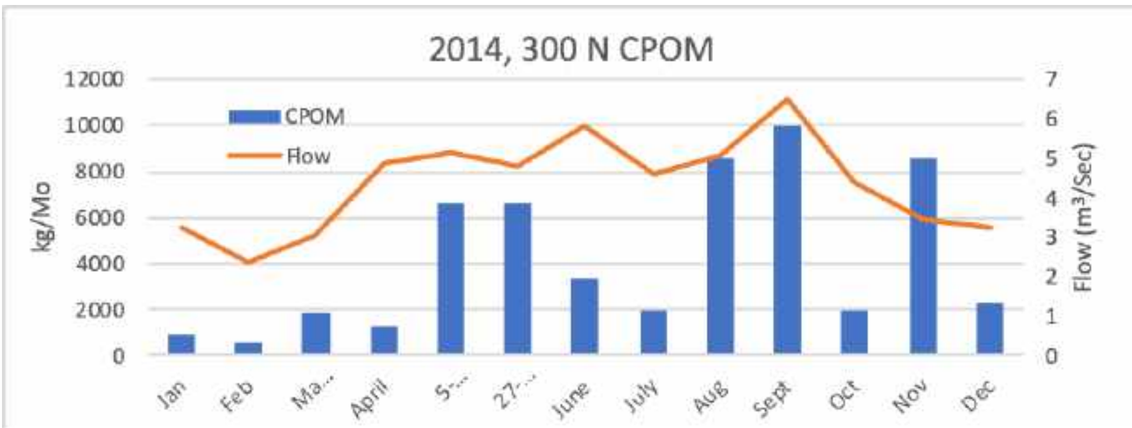


Figure 56. Monthly measurements of flow and CPOM at 1700 S (a.), 300 N (b.) and Legacy Nature Preserve (c.) during 2013. CPOM loads predictably increased during the higher flow periods of April, May and June.





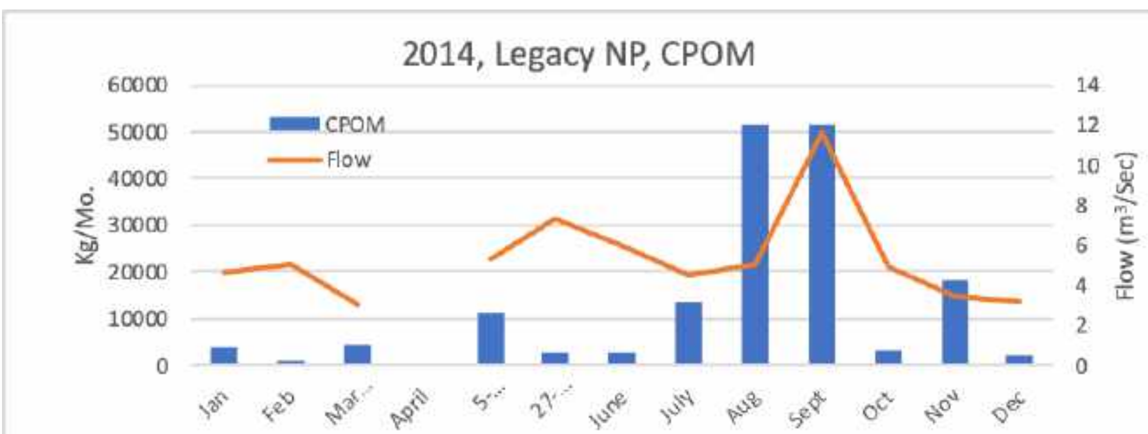


Figure 57. Monthly measurements of flow and CPOM at 1700 S (a.), 300 N (b.) and Legacy Nature Preserve (c.) during 2014. Notice the relatively low spring flows and concomitant low POM loadings. August and September flows increased, dramatically increasing the CPOM loading during fall.

The general pattern appears to be driven by the magnitude of spring runoff in combination with seeds, grass litter and other urban refuse deliberately or inadvertently running down storm drains or over the backyard fence. Secondly, there is commonly a fall surge of CPOM that accompanies late summer storms where flood flows reach bankfull and pick up additional litter that had fallen during spring and summer and particularly where spring flows were below normal.

Table 4. Comparison of CPOM measurements between a high runoff year (2011) and a low runoff year (2013) and between CPOM measurements between two different teams.

	2011 WFWQC		2013 WFWQC		Epstein et al 2013
	AFDM	kg C	AFDM	kg C	kg C
1700 S	218712	72175	33954	11205	6023
300 N	62119	20499	139433	46013	8592
Legacy	74836	24696	121547	40110	14373

Except for the June samples of 2012, CPOM loads downstream from 1700 S fell considerably, indicating that large quantities settled out of the water column. There was very little change in CPOM between Legacy Nature Preserve and Burnham Dam. Overall, however, it is apparent that the CPOM loading during 2012 was much lower than 2011 and this was most likely due to the general lower flow conditions.
Overall, monthly sampling reveals a bi-modal pattern of elevated CPOM loads. These are: 1) during spring runoff when elevated stream flows pick up/mobilize additional organic debris (leaves, twigs, seeds, grass, etc.), that fell onto stream banks during the previous autumn or perhaps tossed onto stream banks by adjacent land owners; and 2) during the autumn season when deciduous trees are losing their leaves. The total annual - as well as seasonal transport of CPOM varies directly with the magnitude of the spring runoff or the occurrence and magnitude of autumn rain events. Based upon the magnitude of such flows, the total annual CPOM delivered to and carried by the Jordan River may exceed 200,000 kg per year. This estimate should be considered conservative during high runoff years – particularly based on the fact that generally only one sample event was performed per month and such sampling occurred at random with respect to when peak flows actually occurred. this estimate may also be considered excessive during low runoff year as much of the leaf litter will remain on the banks until higher flows occur.

A general trend seems to be that the highest loads are at the mouth of the canyon and at the confluence with the Jordan River. We only have data at the confluence for the three larger tributaries due to the 2010 oil spill in Red Butte Creek. A total load estimate for the combined flow of the smaller tributaries, City Creek, Emigration, and Parleys and Red Butte would be 20,000 kg/year, but this is with the assumption that Parley's and Red Butte Creeks have roughly the same load as the City Creek and Emigration Creek.
The total combined load at the canyon mouth sites for Big Cottonwood, Little Cottonwood, and Mill creeks may reach 100,000 kg/year during normal to high runoff years. A reasonable estimate of the combined CPOM loading at their confluence sites is

200,000 kg/year during normal to high runoff years. Conversely, loads may be half or less of these amounts during low runoff years.

While there is evidence that even small debris basins can be quite efficient at removing CPOM, (for example, in Mill Creek and Big Cottonwood Creek) it is also evident that considerable maintenance is required to maintain these removal rates. Further, despite the effectiveness of these debris basins, considerable CPOM enters these tributaries downstream of the debris basins and enters the Jordan River.

Finally, these data provide clear evidence that there are huge quantities of CPOM being delivered to the many tributaries, storm drains and main stem of the Jordan River and that this CPOM is being delivered and deposited throughout the lower reaches of the river. In turn, disintegration and decomposition of this organic matter in depositional areas is in sufficient quantities and rates as to cause the elevated SOD values that have been observed in the Lower Jordan River.

One of the most important points to understand in the study of CPOM transport and settling and subsequent oxidation is that there are different types of decomposition. For example, the QUAL2Kw model assumes that all organic carbon oxidation is performed aerobically. Yet, as we have discovered through surveys and the seminal work by Hogsett, (2015; Chapter 6), is that considerable decomposition includes the ultimate reduction of organic carbon to methane. In addition, all sites downstream from 1700 S are characterized as soft, organic rich anaerobic sediments that continue for at least 1 m. In this condition OM is converted to methane. This is critical in that the oxidation of methane requires 6.7 times or oxygen than the oxidation of glucose (Figure 19) Therefore, the assumption in the Phase I report (Cirrus 2010), that, according to the QUAL2Kw model, all organic carbon is oxidized aerobically, is false. Moreover, data on TSS and VSS and BOD (Chapter 2), indicates that the VSS does not settle and the BOD in the water column remains virtually the same throughout the river. Finally, the work performed by Hogsett (2015) has identified SOD as the primary source of oxygen loss in the river (Figure 20).

Oxidation of Glucose

$$C_6H_{12}O_6 + 6O_2 \qquad 6CO_2 + 6H_2O$$

Based on Mass

=212 g of glucose + 128 g O_2 or 0.6 g O_2 / g glucose

Oxidation of Methane

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

16 g of CH_4 /mole needs 64 g (2 moles) of O_2

or 4 g O_2 / g methane or 6.7 X more oxygen/g than for glucose

Figure 58. Display of the basic chemical reactions and oxygen demand in the oxidation of glucose and the oxidation of methane. Note the oxidation of methane requires 6.7 times more oxygen per gram for complete oxidation than glucose.

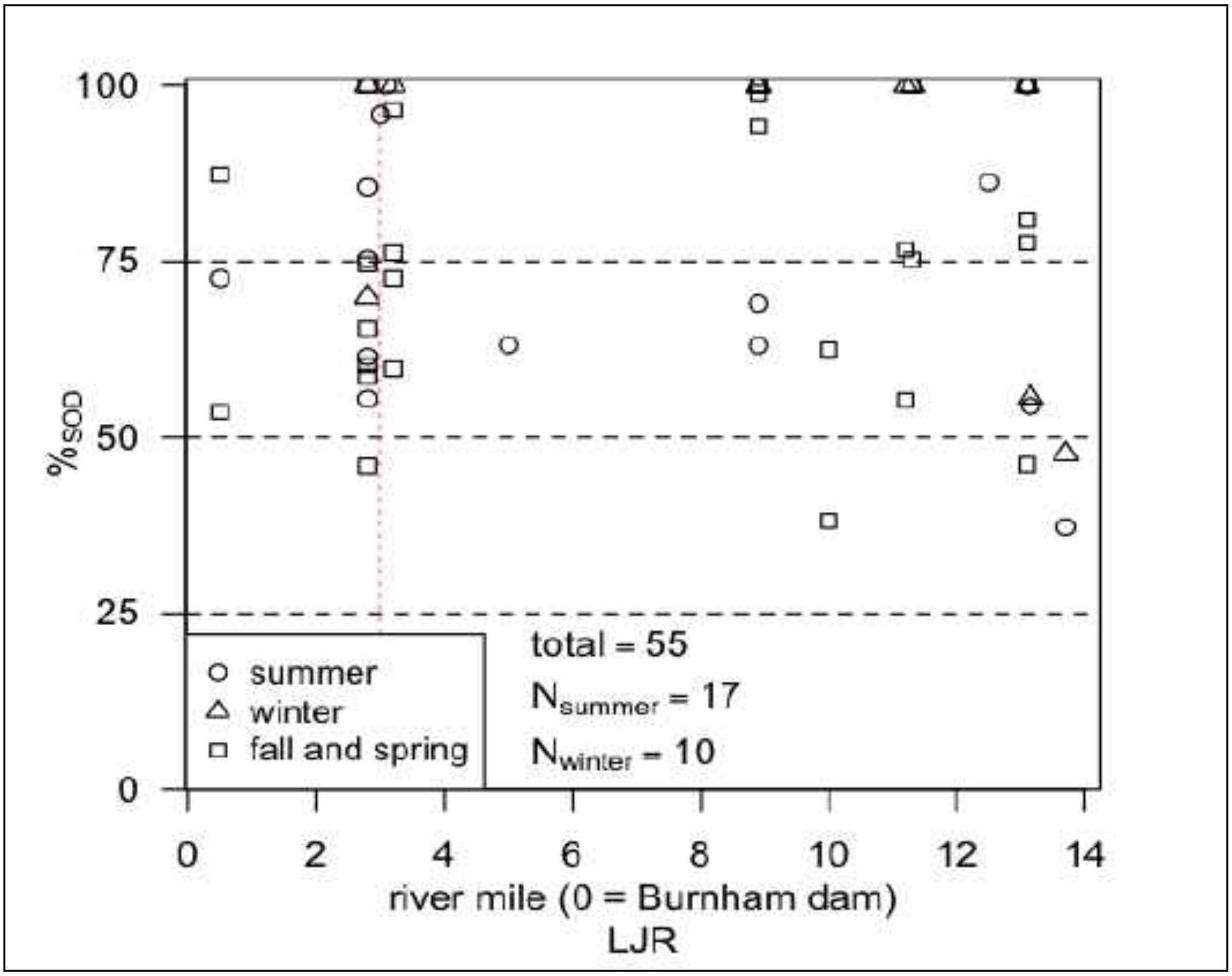


Figure 59. Measurements of SOD in the Lower portion of the Jordan River. Note that the vast majority of oxygen depletion in the river is the direct result of SOD (From Hogsett, 2015)

Out of 57 SOD sampling events, all but 5 demonstrated SOD as the primary source of oxygen loss and several sites demonstrated 100% of oxygen loss was due to SOD. Moreover, Hogsett, measured methane flux to the water column. These data and observations clearly demonstrate that the settled organic matter (i.e. CPOM), causing the production of methane and subsequent SOD, is the primary cause of oxygen depletion on an everyday basis. Finally, under normal flow conditions, even this large delivery of CPOM and SOD does not typically cause the DO to fall below the acute or even chronic DO criterion. Rather, the low DO events are due to the period storm events that mobilize sediments and methane; or the occasional event where the Surplus Canal diversion gate is lowered in order to prevent flood flows from entering the lower Jordan River in anticipation of a flood event and such flood flows do not occur – leaving the lower Jordan River in a series of mostly stagnant pools.

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