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Effects of Mining Reclamation on Sediment Yield and Organic Carbon Flux in First Order Watersheds

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Introduction

Coal mining has been a major industry in Kentucky for many decades and has changed the landscape, ecosystems, and watersheds in surrounding areas. Typically in eastern Kentucky, coal-mining practices have included mountain top removal and contour mining. In each practice, layers of vegetation, soil, and rock above the coal seems are removed to retrieve the coal. After mining has been completed, the soil returned to the site contains large amounts of crushed rock and coal (Shrestha and Lal, 2006; Wickham et al., 2007 in Fox, 2009). Any additional rock that remains from surface mining is placed into valleys. By adding additional material to the valleys, the watershed is drastically changed. These changes in the geography and properties of the area can cause drastic changes in the hydrologic behavior of an area.

In a study by Curtis in 1978, the hydrologic effects of coal mining in steep areas were studied. Typically, the peaks in a hydrograph of an undisturbed watershed in southeastern Kentucky tended to be sharper because of increased surface flow. This increased surface flow occurred because of the area's steep slopes, shallow soil layers, and impervious bedrock. In watersheds where mining had occurred, flow rates during storm events were higher than the flow in the undisturbed watershed. Base flows in mined areas tended to be lower since the broken rock and vegetation on reclaimed mine sites allowed for increased infiltration. However, this study was performed in 1977. In 1977, the Surface Mining Control and Reclamation Act (SMCRA) was passed. One of the main purposes of SMCRA was to reduce the likelihood of landslides on reclaimed mine sites by requiring the compaction of the soil placed on the land after the completion of surface mining. Compacting soils limited infiltration. Therefore, post-SMCRA coal mining practices increased the erosion downhill of the reclaimed mines, the hydrologic response to storm events, and the cut-back of stream banks (Phillips, 2004 in Fox, 2009).

Since mining and reclamation increases erosion of surrounding areas, a larger amount of sediment can be found in watersheds where these disturbances occurred. Large amounts of sediment can carry harmful chemicals and pollutants downstream, and increased sediment yields and turbidity caused by coal mining can limit the reproduction potential of aquatic species (Bonta, 200; Arnold, 1989). Several studies have investigated the affects of coal mining on the sediment flux in streams. In a study conducted by Curtis in 1978, sediment basins were constructed in several reclaimed mine sites to determine the amount of sediment yield. The study discovered sediment yield decreased by approximately half after sixth months of reclamation, and the half-life approximation was found to continue after the original six months. The study determined quickly increasing vegetative cover on the reclaimed mine sites lowered sediment yield. In the 2000 study by Bonta, multiple watersheds were monitored during three phases of mining. These phases included the undisturbed stage, the mining stage, and the reclamation stage. Sediment samples were collected throughout each stage. The mining stage was found to have the highest sediment yields, and the amount continued to decrease throughout the reclamation process. Reclamation processes were found to play a key role in the sediment yields. By removing diversions and increasing vegetation, sediment yield would decrease.

An additional concern to increased sediment flux in a stream is the impact of this change on the carbon cycle. Traditionally, the carbon cycle has been described as the interaction of the land, the ocean, and the atmosphere (Bolin 1981; Siegenthaler and Sarmiento 1993; IPCC 2001 in Cole et al). When fresh water systems were included, they served as direct transit devices of carbon from terrestrial areas to the ocean (Cole et al**)**. However, the export from terrestrial areas to inland water systems did not equal the amount of carbon entering the ocean, which proved carbon was not directly transported between the two sources (Cole et al). When studied, the carbon transport from terrestrial areas to freshwater was 1.9 Pg C y^{-1} (Cole et al). Of the carbon transferred to freshwater, approximately 0.8 Pg C y^{-1} returned to the atmosphere, and 0.2 Pg C y^{-1} remained trapped in sediment. Only 0.9 Pg C y^{-1} was transported to the ocean (Cole et al). Therefore, the impact of freshwater systems could not be ignored when studying the carbon cycle.

During mining processes, geogenic organic matter typically trapped in rock below ground is brought to surface, changing the amount and type of carbon in the area. Recent evidence has shown this matter may enter the carbon cycle by becoming a part of new plant matter (Chabbi et al, 2006 in Fox, 2009). A few studies have been conducted to investigate the affects of coal mining on the carbon cycle. In Fox 20009, carbon and nitrogen isotopes were used to assess the percentage of soil organic matter and the percentage of geogenic organic material in fine sediment. Due to the disruptive nature of coal mining, research needs to continue to access the changes in the carbon cycle caused by coal mining and determine the long-term results of these changes. The purpose of this study was to investigate the effects of coal mining on the carbon and sediment fluxes in first-order watersheds in Letcher County, KY.

Sites Selected

The two sites studied were the Whitaker and Island Branch watersheds located in Letcher County in southeastern Kentucky. According to Fox (2009), the Whitaker watershed was mined from late 1979 to 2003. Mining consisted of a mix between surface mining and ground mining. Underground mining was performed prior to 1998. The area was surfaced mined from 1982 to 1987 and again from 1988 to 2003. The Island Watershed underwent underground mining briefly in 1984. It was then surface mined from 1998 to 2006 (Martin, 2011). Both sites were reclaimed using traditional post-SMCRA techniques; the ground was highly compacted and planted with several types of grasses (Martin, 2011).

Methods

The sediment was collected using sediment traps constructed from PVC pipe. Water entered the tube through an opening 4 mm in diameter and continued into another pipe with a 10.16 cm diameter. The increased diameter in the middle portion of the sediment trap caused the velocity of the water to decrease. This decrease in velocity allowed the sediment to settle to the bottom of the trap. The water then exited the sediment trap through an opening with a 4 mm diameter. The samples from the tubes were collected approximately weekly depending on rainfall events and placed into buckets and taken to the lab to be processed. The samples were placed into the centrifuge to separate the sediment from the water. Excess water was removed by freeze-drying the samples. The sample was then wet sieved with a # 270 sieve. This separated the fine sediment (<53 microns) from the rest of the sample. The sample was centrifuged again and excess water was decanted. The remaining moisture was removed by freeze-drying. The sample was then ground to create finer sediment. This sediment was then run through an isotope ratio mass spectrometer and the amount of organic carbon was evaluated.

After finding the relative contributions of each source to the sediment sample, the sediment yield was needed in order to calculate the total carbon flux at each site. The sediment yield at each site was found by using an ISCO Automated Sampler. The ISCO was programmed to take samples every 15 minutes after the water level rose 0.007 m. The ISCO bottles were collected after rainfall events. The samples were processed in the lab by measuring the volume of the sample and then filtering the sediment from that sample. The mass of this sediment was measured. The ratio of the sediment mass to the sample volume yielded the concentration of the sediment in the stream.

Analysis

After determining the concentration of the sediment in the stream, the discharge was needed to determine the suspended sediment flow rate and the sediment yield. As shown in the following equation, the sediment flux (Q_s) was directly proportional to the average concentration of the sediment ($\bar{C}$) and the flow rate (Q).

$$Q_s = \bar{C}Q$$

The base flow of the stream will be assessed using the volumetric flow rate equation supplied below.

$$Q = Av$$

In this equation, the variable v represents the velocity of the stream. The velocity of the stream was estimated using Manning's Equation given below.

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

The roughness coefficient, n, was determined using the following equation developed by Lane and Carlson (1953) for canals paved with gravel.

$$n = \frac{(d_{75})^{1/6}}{39}$$

The variable R stood for the hydraulic radius, which was defined as the ration of the cross sectional area and the perimeter. Land surveying equipment was used to map cross sections in both sampling sites. By using the cross section map and the stage data recorded by the bubbler module on the ISCO, an estimate of the area and perimeter of the stream was made each time a sample was taken.

The variable *S* represented the slope of the channel, which was found for each site by using an observed velocity from each site. The velocity at base flow was measured by first finding the amount of time it takes several floating objects to travel a specified distance. The velocity was calculated by dividing the distance by the recorded time. For the reclaimed 2003 watershed, the slope coefficient was .037. The watershed reclaimed in 2006 had a slope coefficient of .009.

After finding the suspended sediment flow rate for each sample, the sediment yield was found using the following equation.

$$S_y = \frac{\int_{t_1}^{t_2} Q_{ss}}{A_w}$$

The A_w in the equation refers to the area of each watershed. The integration for each event was performed using Riemann sums.

After calculating the sediment yield for each event, the POC flux was determined by multiplying the percentage of organic carbon obtained from the isotropic ratio mass spectrometer analysis.

$$\Phi_c = \%C_{avg} S_y$$

The percent organic carbon used was an average value based off of data from the last two years.

Results

Figure 1 is hydrograph and sedigraph results from an event on June 9, 2011 at the watershed where reclamation occurred in 2003.

Figure 1

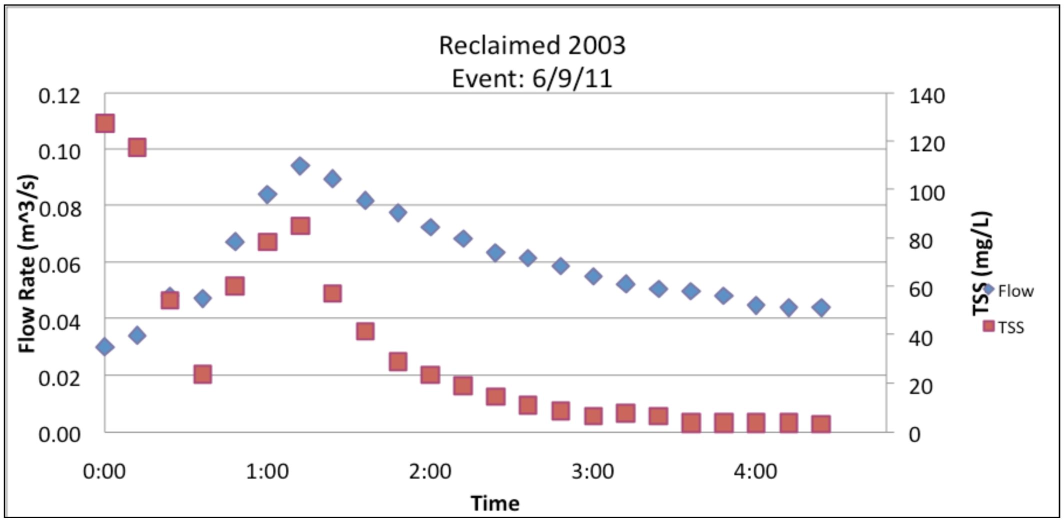
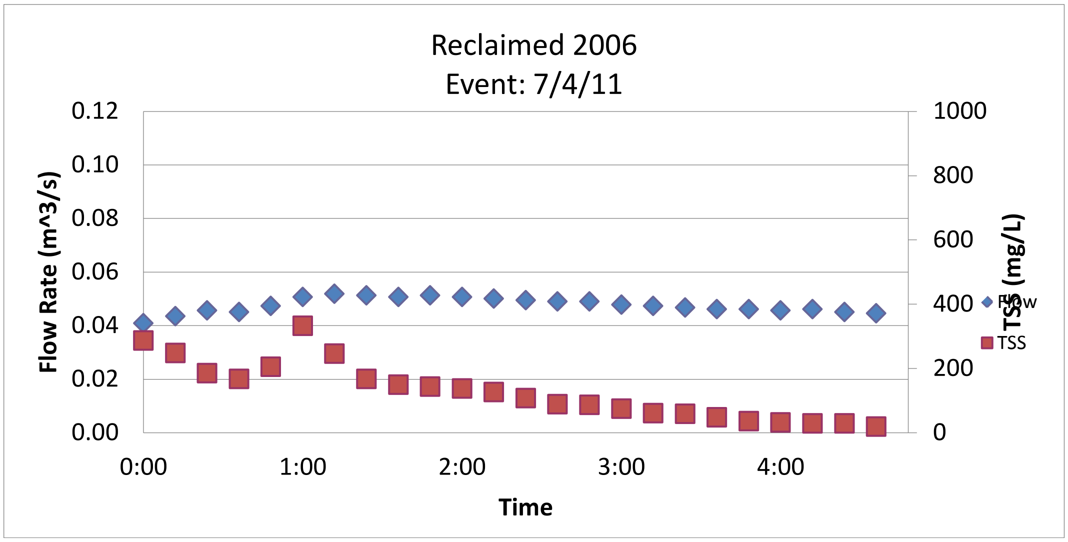


Figure 2 displays the changes in flow rate and sediment concentrations in the event on July 4, 2011 in the watershed where reclamation occurred in 2006.

Figure 2



While these events occurred on different days and on different sites, the behavior of the flow and sediment concentrations was quite similar. In each graph, a first flush of sediment occurred causing higher concentrations of sediment at the beginning of the event. The first flush involved washing any material that had been loosened from wetting and drying processes. After eroding the loosened sediment, both graphs displayed equilibrium transport behavior. As the flow rate increased, the concentration also increased because the flow energy was very high. Once the flow rate began to decrease, the flow energy decreased, limiting the amount of suspended sediment.

The sediment and POC flow rates are displayed in figures 3 and 4.

Figure 3

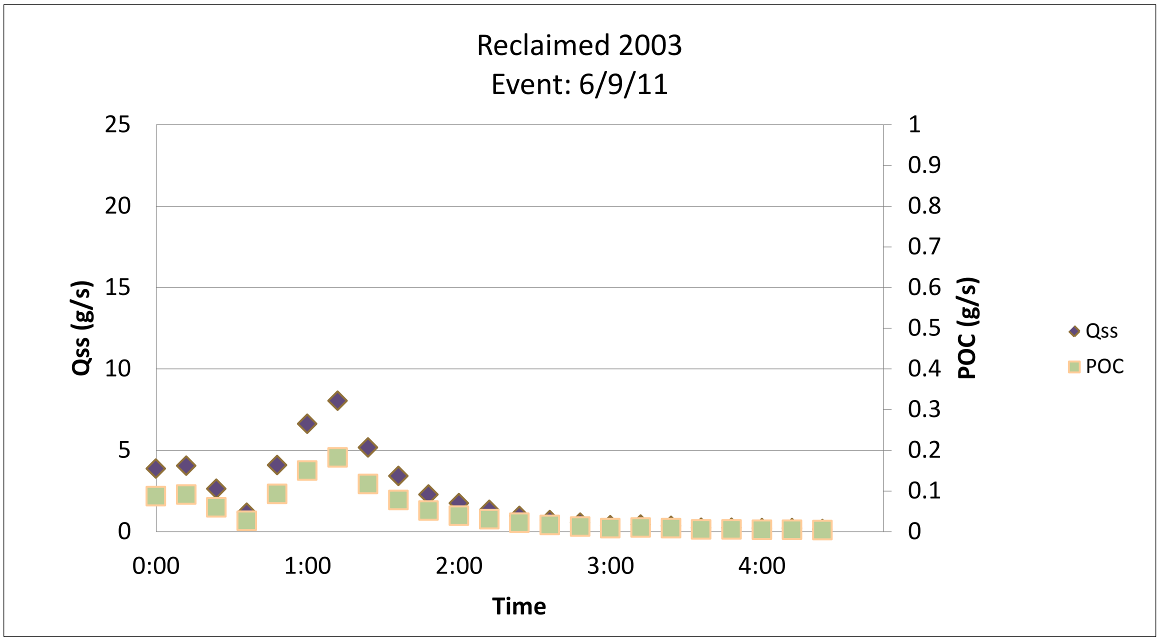
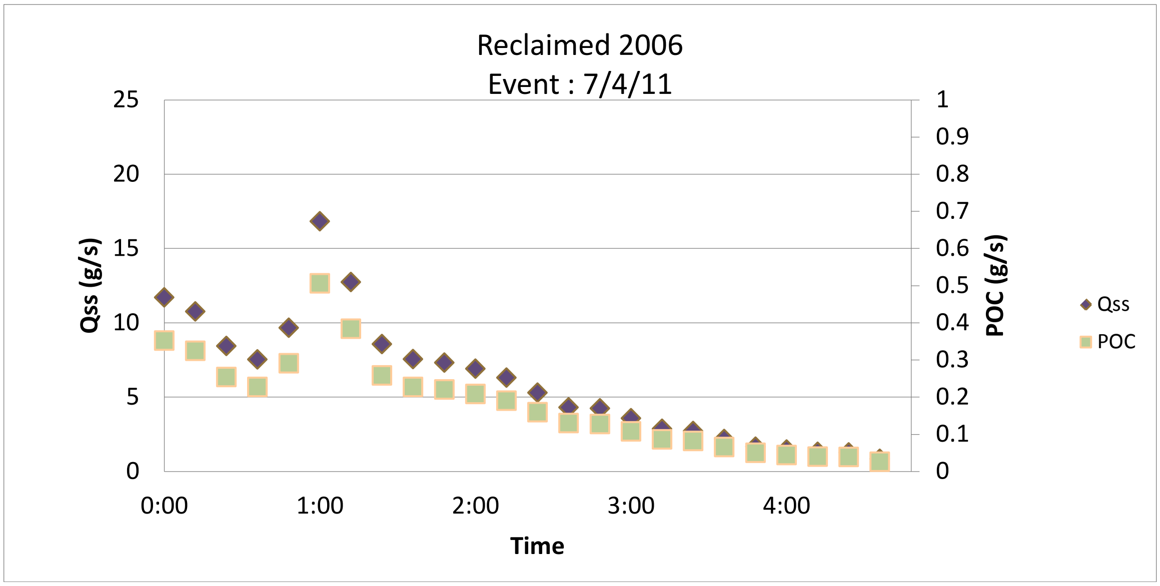


Figure 4



In figures 4 and 5, the data from the rainfall event on June 26, 2011 was recorded. The ISCO's at both sites collected samples at the same time.

Figure 5

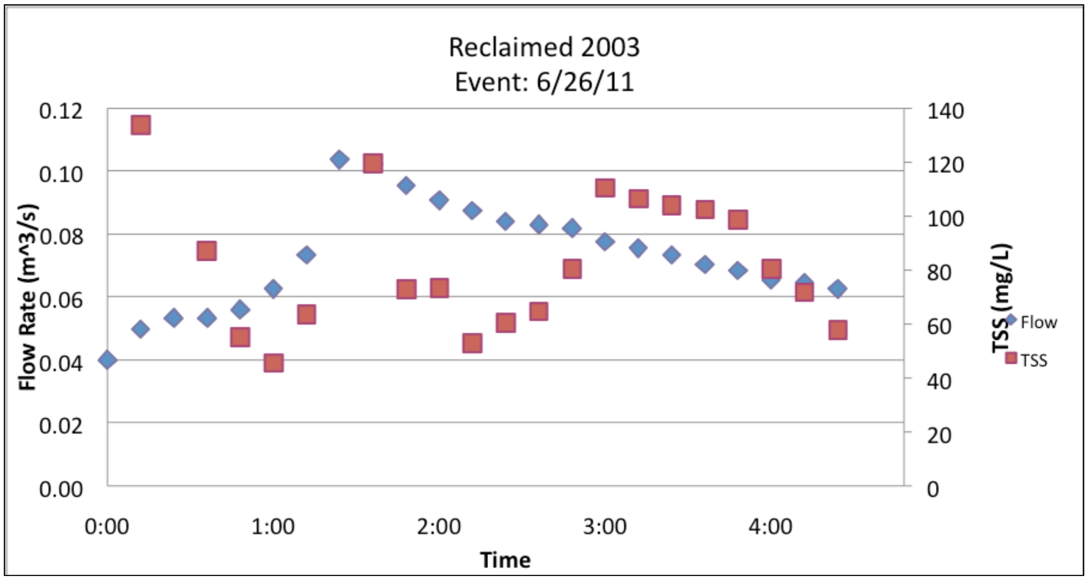
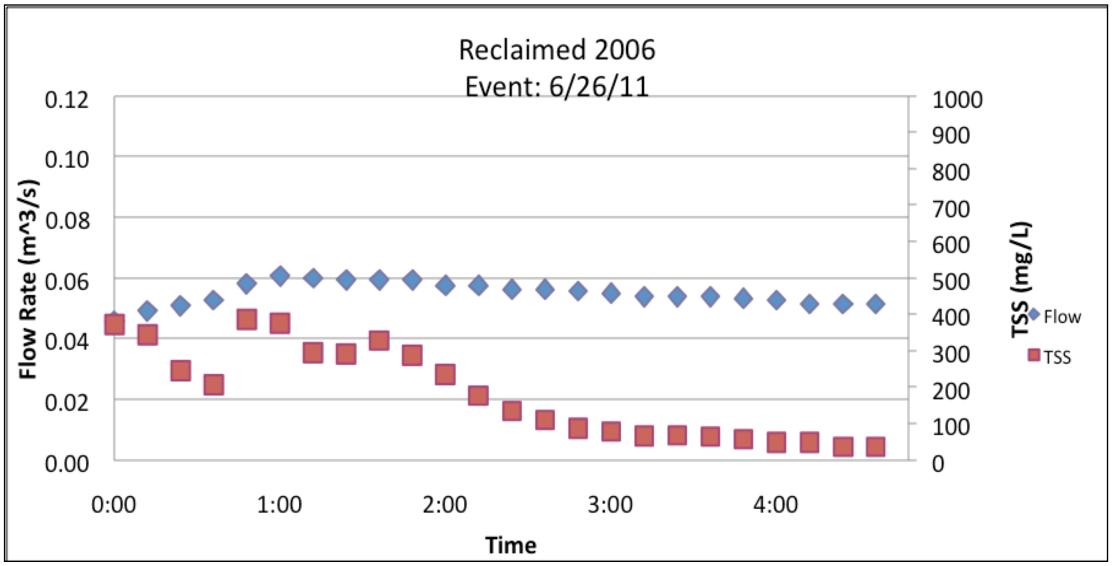


Figure 6



Figures 5 and 6 follow the same trends shown in the preceding graphs. The first flush and equillibrium transport were evident in both graphs. However, during this event, both sedigraphs displayed a third peak which was not present in the other events. Rainfall data from the previous week consisted of three days with percipitation. Of these three days, two of the rain fall events were 0.9 inches and 1.5 inches. For the other events, precipitation did not occur for at least a week before the events. Since there were several rain fall events before June 26, 2011, the antecedent moisture content of the soil would have been greater during that event. The higher antecedent moisture could explain the additional peak in the graphs from June 26, 2011. Because the antecedent moisture conditions were higher during the event on June 26, 2011, soil infiltration rates were lower. This may have caused more water to run off of the terrestrial areas and errode more sediment. The peak of the graph could represent the additional sediment coming from the reclaimed mine lands. The delay in concentration values displays the amount of time it took for the sediment to travel from these areas. Further investigation needs to be carried out to assess the validity of this hypothesis.

In the following figures, the suspended sediment and POC flow rate were provided for the June 26, 2011.

Figure 7

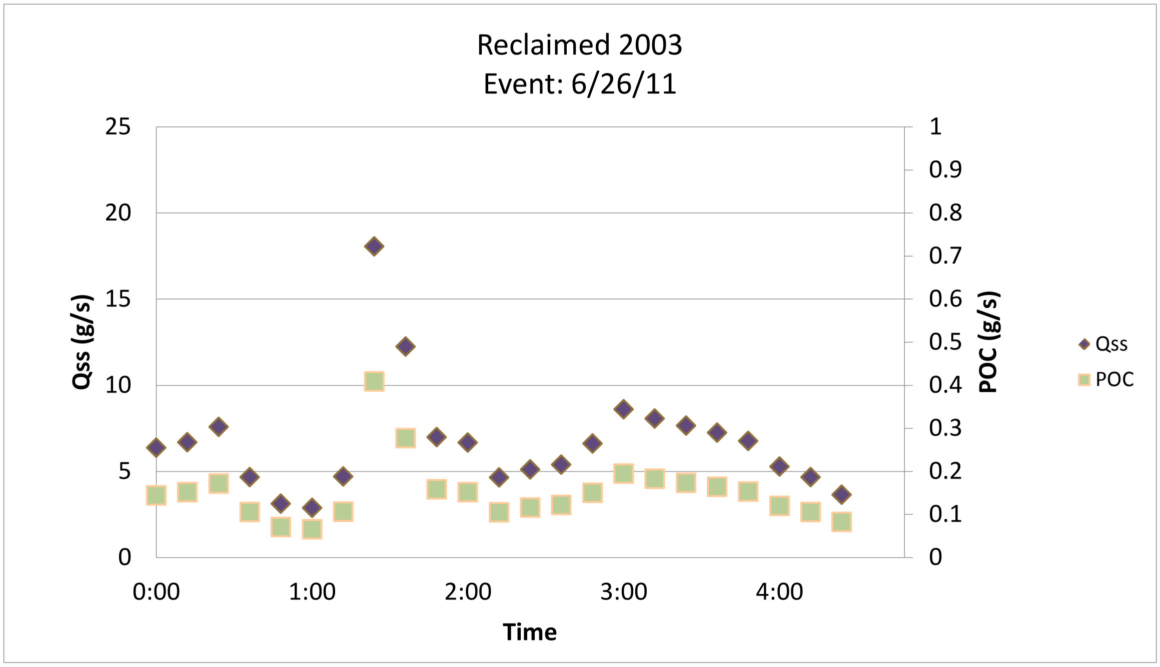
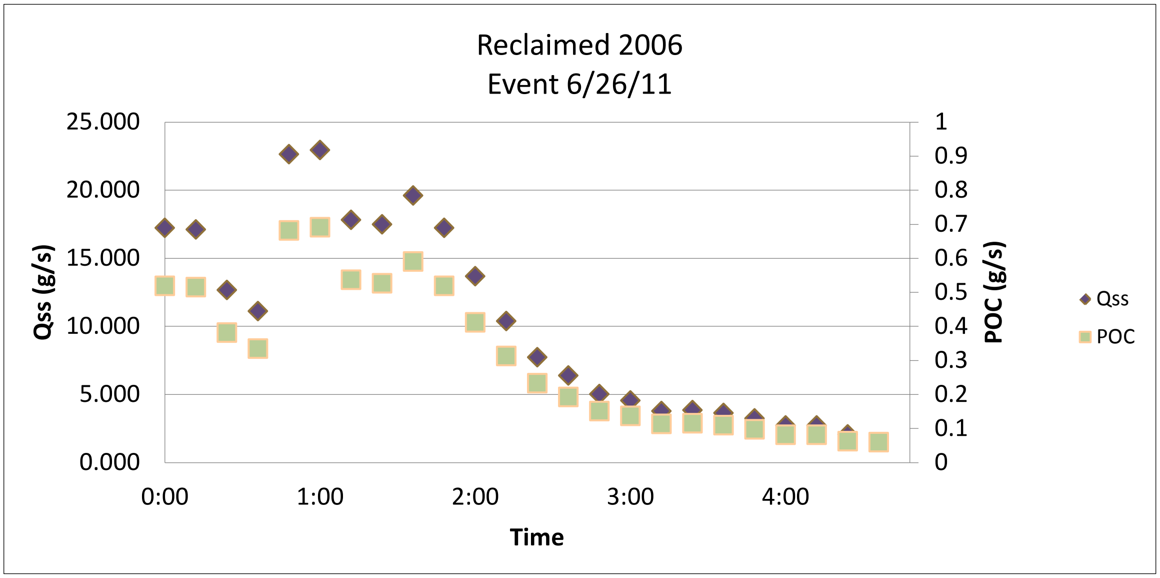


Figure 8



When comparing the suspended sediment and POC flow rate of the two sites, the recently reclaimed site had larger initial rates. However, the site reclaimed in 2003 had greater rates in the latter part of the event.

Chart 1

Site	Date	Sediment Yield (g)	POC Flux (g)	Rainfall (cm)
Reclaimed 2003	6/9/11	9913.34	224.18	1.27
Reclaimed 2003	6/26/11	31,865.06	720.58	1.27
Reclaimed 2006	6/26/11	79,841.45	2403.67	1.27
Reclaimed 2006	7/4/11	47,013.09	1415.36	1.40

When considering the sediment yields contained in chart 1, the sites reclaimed in 2006 had a higher sediment yield and POC flux than the site reclaimed in 2003. This probably occurred because vegetation was less established on the site reclaimed in 2006.

Areas of Future Research

While the data collected displays several trends, too few events were studied to draw strong conclusions. Further research needs to focus on gathering more data during more events. This data should be compared to the current findings to determine if trends continue. The events studied were minor. Gathering samples during large rainfall events would provide a more complete representation of the watershed's behavior.

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