THE EFFECTS OF STAND THINNING ON SOIL EROSION RATES AT JIM'S CREEK IN THE WILLAMETTE NATIONAL FOREST, OREGON

By

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The Effects of Stand Thinning on Soil Erosion Rates at Jim's Creek in the Willamette National Forest, Oregon

ABSTRACT

Surface sediment transport is an important geomorphic process which can be significantly altered by management activities in forested ecosystems. Disturbance of the soil surface may result in increased sediment delivery to fish bearing streams and degradation of soil structure. Selective thinning and low impact yarding techniques were utilized in an effort to restore oak savanna ecosystem structure to the Jim's Creek Savanna Restoration Project Area southeast of Oakridge, Oregon. This study monitored sediment transport rates following the thinning of nearly 90% of the existing 120 year old Douglas-fir stand within the project boundary. The study followed a before-after control-impact (BACI) design, in which the 12 sediment traps were monitored for 12 months prior to thinning, were removed during the logging activities, and then returned to the same locations following the thinning and monitored for an additional 2 year period. Estimated soil erosion rates derived from traps were then compared to baseline (pre-restoration) transport rates collected at the same locations in a previous study to assess change over time. Two control traps were included in the analysis and were placed in an area that did not undergo thinning activities during the study. The rest of the traps were place in areas in which thinning via skyline yarding techniques occurred (near the existing road network) or in areas where helicopter yarding was utilized to remove felled trees. Average estimated soil erosion rates from traps located in thinned areas declined from 983.5 g/m/yr to 379.8 g/m/yr following logging activities at the site; and rates declined from 156.5 to 84.1 at the two untreated reference plots. Previous work at the site suggests that rain- and throughfall-drop splash is the dominant surface soil erosion mechanism and that an alteration of canopy structure may influence this process. Reduced canopy structure can lead to a reduction in throughfall splash erosion. The hypothetical reduction in throughfall splash combined with possible loss of drop splash by fog drip as a result of

canopy thinning may explain the observed decrease in surface soil erosion following stand thinning. There is some indication of a difference in the seasonality of peak surface sediment transport following the site treatments. However, this comparison may not be valid due to the duration of the pre-treatment study not including the later summer months which were included in the post-treatment monitoring and consistently showed the highest transport rates. Surface soil transport was simulated using a non-linear diffusion model as well as a version of the web-based GIS WEPP erosion model. Simulated rates generally poorly represented observed rates, and the WEPP model consistently over-predicted surface sediment transport rates. Continuation of existing erosion boxes and addition of sites to sample a range of canopy cover conditions would increase understanding of effects of canopy influences and long-term effects of site disturbance. Acquiring a finer scale digital elevation model may facilitate more accurate modeling of surface erosion.

1. INTRODUCTION

The impact of forest management activities on hillslope processes is an area of research that has received much attention in locations where management practices have altered forested ecosystems. In the Pacific Northwest, a significant body of literature investigates the impacts of clear-cutting and other forestry techniques on sediment yields from steep hillslopes that characterize much of the Coast and Cascade Ranges (e.g., Brown and Krygier 1971, Swanson and Dryness 1975, Beschta 1978, Swanson et al. 1987, Johnson and Beschta 1980, Megahan et al. 1995, Luce and Black 2001). Spatial and temporal variability of sediment transport processes and variability in dominant transport mechanisms on watersheds in the Pacific Northwest lead to difficulty in detecting and modeling responses to forest disturbance in these landscapes (e.g. Brown and Krygier 1971). Despite this difficulty, it remains important to assess the implications of changing management regimes on sediment transport within forested ecosystems and watersheds.

Restoration activities at the Jim's Creek Savanna Restoration Stewardship Project site involve relatively low impact thinning activities, such as helicopter yarding, slash pile burning, and, eventually, prescribed burning at the site (Bailey 2006). Interest in the implications of these restoration activities on sediment transport regimes has been generated by the presence of endangered salmonid species in the Middle Fork of the Willamette River which receives sediment yielded from the Jim's Creek site (Bailey 2006, Adams 2008).

Prior estimates of sediment yields from the Jim's Creek site have utilized sediment trapping methods (Adams 2008) and the Water Erosion Prediction Project WEPP model developed by the US Department of Agriculture (Elliot et al. 2000, Bailey 2006, Adams 2008). Twelve sediment traps were deployed at the site prior to the thinning (Adams 2008) and then redeployed in the same locations following thinning activities (present study). Results from the previous studies were used as

baselines for evaluating sediment yields from the site, and were compared to field data collected for the present study. This study addresses the following questions regarding sediment transport and the influence of site treatment on sediment transport rates:

- Is there a difference between pre- and post-treatment sediment transport rates?
- What are the dominant sediment transport mechanisms?
- Do sediment transport rates fit a non-linear sediment transport model used to predict transport rates based on slope gradient?
- Does the web-based GIS Water Erosion Prediction Project Model (WEPP Web Interface found at http://milford.nserl.purdue.edu/) accurately predict sediment transport from Jim's Creek, and how do these results compare with prior WEPP simulations at the site?
- With changes in harvesting techniques made to lessen the disturbance caused by harvesting activities, can we expect erosion similar to historically observed erosion from currently harvested landscapes in the western Cascades of Oregon?

2. LITERATURE REVIEW

2.1. TRANSPORT PROCESSES ON FORESTED HILLSLOPES

Water and gravity play the dominant roles in sediment transport from hillslopes in the Pacific Northwest (McNabb and Swanson 1990). Surface erosion by splash erosion caused by rainfall and throughfall, and occasional sheet, rill or gully erosion can all be tied to interactions between these two forces. Sediment transport processes can generally be placed into to broad categories: hillslope processes and stream channel processes (Swanson et al. 1982). Hillslope sediment transport can be further divided into subcategories including, solution transport, litterfall, surface erosion, creep, debris avalanches, slumps, and earthflows (Swanson et al. 1982). The focus of the present research is specifically on the surface erosion component of hillslope transport processes (Figure 2.1). Although landslide activity also has a

potentially significant role in the sediment transport from the study site (Adams 2008), it is not quantified within this research.

Surface erosion can include overland flow, raindrop and throughfall drop impact, freeze-thaw induced sediment movements, dry ravel (Swanson et al. 1982) and bioturbation (Adams 2008). Of these processes, overland flow may be the least common within the Pacific Northwest. On undisturbed soils within this region, high infiltration rates, a thick duff layer and generally low rainfall intensities seldom produce situations where overland flow is the dominant surface sediment transport mechanism (McNabb and Swanson 1990). However, on disturbed slopes or road cuts where bare soil is exposed, overland flow may occur. Overland flow was observed in the Jim's Creek project area prior to restoration activates only along road surfaces (Adams 2008). As suggested by Adams (2008), rainsplash, dry ravel and animal activity (bioturbation) are likely the dominant surface erosion processes at the Jim's Creek site.

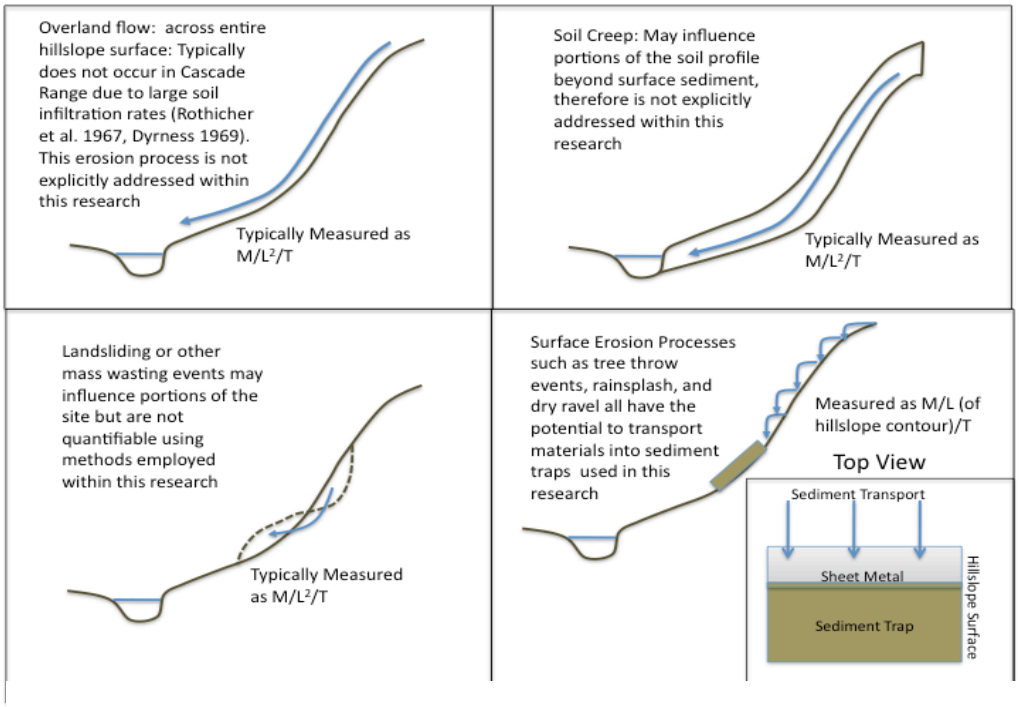

Figure 2.1. Methods of sediment transport. The lower right image shows the types of processes that are assessed in this study. The sediment trap has an opening of ~ 1.1 meters which faces up slope, while the trap itself rests on the hillslope surface

2.2. IMPACTS OF FOREST MANAGEMENT OF CATCHMENT SEDIMENT YIELDS

Much of the literature focused on sediment transport in managed forests highlights the influence of roads and prescribed burning on transport rates (e.g. Brown and Krygier 1971, Swanson and Dyrness 1975, Beschta 1978, Johnson and Beschta 1980, Megahan et al. 1995, subject reviewed for Pacific Northwest in Swanson et al. 1987, Moore and Wondzell 2005 and for worldwide literature in Croke and Hairsine 2006). Most of the publications reviewed suggest that sediment transport is likely to increase following forest management activities such as clear cutting, road construction and burning (Swanson and Dyrness 1975, Beschta 1978, Megahan et al. 1995, Croke and Hairsine 2006); however, it can be difficult to separate natural variability from increased transport caused by management activities (Brown and Krygier 1971, Ferguson et al. 1991, Houben et al. 2009). Variability in the impacts of harvesting within forested catchments is largely dependent on the harvest techniques utilized at the site and the climate conditions at the time of management activities (Croke and Hairsine 2006).

Johnson and Beschta (1980) investigated the impact of several harvesting techniques on infiltration rates and erodability in small catchments in the western Cascades. Results from the research suggest that only the most significantly disturbed areas (those that had undergone slash burning or along the skid tracks created by tractor logging) showed increases in erosion and declines in infiltration rates (Johnson and Beschta 1980).

It has been suggested that by using low impact thinning techniques, such as helicopter or skyline yarding and selective slash piling, increased sediment transport can be avoided following forest management activities (Hotta et al. 2007). Hotta et al. (2007) assessed the effects of low impact forest management techniques on suspended sediment yield from a small forested watershed in Japan. Management activities included timber harvesting using skyline yarding techniques to avoid significant disturbance of the soil and piling of branches in locations throughout the watershed

following the harvesting activities. Although an increase in stream discharge from the watershed was observed, suspended sediment yields from the site did not change following harvesting activities (Hotta et al. 2007). These results suggest that it is feasible to harvest within a watershed using low impact techniques and have little to no effect on sediment yields off of the harvested watershed.

The restoration treatment prescribed at Jim's Creek utilizes many low impact forest management techniques, including helicopter yarding to reduce soil disturbance and thinning of only younger smaller diameter trees. Relatively few publications assess the impact of selective thinning on sediment transport (e.g. Hotta et al. 2007), and even fewer address the impact of ecological restoration techniques within forested landscapes on transport rates (e.g. Devine and Harrington 2007 assesses restoration impacts on soil microclimate).

2.3. MODELING OF SEDIMENT TRANSPORT ON FORESTED HILLSLOPES

2.3.1 Gradient Dependent Sediment Transport Models

Given the difficultly and potential cost in long term monitoring of sediment transport, models have been used to simulate transport regimes in natural systems. Culling (1960) was first to establish a one-dimensional transport equation where sediment flux is proportional to the local slope. This confirmed earlier observations by Gilbert (1909) who postulated that the convexity of hillslopes was dependent on diffusive processes such as creep and that these processes varied with gradient (from Dietrich et al. 2003). The simplest form of the one-dimensional transport equation can be written as,

$$\widetilde{q_s} = -K\frac{\partial z}{\partial x} \tag{1}$$

where q_s is the volume of sediment transported over a unit contour length $L^3L^{-1}T^{-1}$, $-\partial z/\partial x$ is the local slope and K is a constant of proportionality with units of L^2T^{-1} (Dietrich et al. 2003). Roering et al. (1999) noticed that in areas with steeper slopes, the linear diffusion model may not adequately simulate transport where slopes are approaching the angle of repose. Observations suggested that landform morphology and transport processes within these steeper gradient systems differed from that which is predicted with the linear transport law. To account for this discrepancy Roering et al. (1999) proposed a non-linear slope dependent transport law with the form:

$$\tilde{q}_s = \frac{K\nabla z}{1-(|\nabla z|/S_c)^2} \tag{2}$$

where q_s is the volumetric sediment transport ∇z is the local slope, K is a transport coefficient, and S_c is the coefficient of friction. This transport equation has been used to model sediment transport from hillslopes where slope-dependent erosional processes are the dominant transport mechanisms (e.g. Martin 2000, Roering et al. 2001, Roering and Gerber 2005).

2.3.2 The (WEPP) Water Erosion Prediction Project Model

Prior to restoration activities at the Jim's Creek site, an Environmental Assessment was completed to study the potential implications of various restoration alternatives (Bailey 2006). In an effort to address concerns over increased sedimentation to local drainages, the USDA Water Erosion Prediction Project (WEPP) Model was used to simulate the impact of the treatment on rates of soil loss. Adams (2008) also utilized a web-based version of the Disturbed WEPP in order to compare observed sediment transport rates collected from erosion traps to those predicted by the model.

The WEPP model runs a continuous simulation to predict soil loss due to overland flow from rill or interill features on the hillslope surface. Hydrologic components of the WEPP model are based on solutions to the Green-Ampt Infiltration equation and kinematic wave equations (Flanagan and Nearing 1995), while climatic components are generated using CLIGEN, a stochastic weather generator, based on location based inputs from the user (Meyer et al. 2007). Additional components to model vegetation change and vegetative decomposition rates over simulation periods are use to assess the impact of changes in management techniques on modeled landscapes. Further details of the models used for each component of the WEPP model and fairly extensive documentation can be found in Flanagan and Nearing (1995).

2.4. HISTORICAL VEGETATION OF THE WILLAMETTE VALLEY AND LOWER ELEVATION WESTERN CASCADES

The vegetation that existed prior to European settlement in the Willamette Valley and lower elevations in the Western Cascades, such as the area around the Jim's Creek site, consisted of five major vegetation zones: oak opening, oak forest, Douglas-fir forest, bottomland forest and prairie (Habeck 1961). In ecosystems classified as "oak opening" neighboring trees are greater than 50 feet apart. In stands where neighboring trees are closer than 50 feet, the ecosystem is designated as an oak forest (Habeck 1961). The differences between oak savannas ("oak openings"), woodlands, and forests are addressed within the literature (Habeck 1961, Agee 1993). For the purposes of this paper the term oak savanna will generally be applied to areas that Habeck (1961) would classify as "oak opening", where oak occurs as an open canopy and may co-dominate a site with other species such as Douglas-fir (*Pseudotsuga mensiezii*) and Ponderosa pine (*Pinus ponderosa*).

Studies suggest that most of the Willamette Valley, prior to European settlement, was dominated by oak opening (savanna) and prairie ecosystems. These

ecosystems have at present been largely replaced by agricultural or grazing operations (Habeck 1961), or have been invaded and overtopped by coniferous species (Agee 1993).

The existence of these open oak savannas prior to European settlement is generally attributed to the land management techniques employed by Native Americans. Prescribed burning was commonly practiced according to many of the landscape descriptions of the time (Johannessen et al. 1971). Evidence of this practice has been found in tree ring records, suggesting frequent fire prior to settlement, followed by a decrease in frequency in the 1850s (Habeck 1961). Fires within oak savanna ecosystems were likely flashy low intensity burns, which would kill low lying herbaceous vegetation and smaller seedlings of savanna tree species, but would not harm the larger mature oaks (Agee 1993). Following the arrival of the European settlers and the suppression of Native American prescribed burning practices, conifer seedlings intruded onto many of the historical oak savanna sites (Johannessen et al. 1971). Without prescribed burning, the shade intolerant oak were in many cases overtopped by invading coniferous species, leading to a transition from open canopy oak savanna to a closed canopy forest stand dominated by Douglas-fir (Agee 1993).

2.5 OAK SAVANNA RESTORATION

There have been increasing efforts to restore oak savanna ecosystems, especially in areas where these systems are in decline. Agee (1993) found that Oregon white oak stands in the southern portion of the range are more stable than those to the north; the latter including the remnant populations of Oregon white oak (*Quercus garryana*) in the Willamette Valley. The restoration of oak savanna ecosystems generally involves a combination of thinning of overtopping tree species and the reestablishment of a prescribed fire regime similar to what might have existed prior to European settlement (Agee 1993). In a study assessing the impact of oak release from overtopping coniferous species Devine and Harrington (2006) showed that oak trees

which had undergone a full release had 194% greater diameter growth than in unreleased trees. Restoration of Oregon white oak savanna is currently occurring in many locations throughout Oregon, including the proposed study site at Jim's Creek in the Willamette National Forest (Oregon Oak Communities Working Group 2010).

3. STUDY SITE

3.1 THE JIM'S CREEK SAVANNA RESTORATION STIE

The Jim's Creek oak savanna restoration site is located south-south-east of Oakridge, Oregon in the Willamette National Forest (43° 30' 41.32", -122° 24' 52.78"), on a tributary to the Middle Fork of the Willamette River (Figure 3.1). The site encompasses a total of 278 hectares, most of which was occupied prior to restoration activities by a dense younger age class (~100 year old) stand of Douglas-fir with scattered older trees that hint at the savanna-like structure prior to European settlement (Bailey 2006). The closed canopy structure was the result of increased fire suppression efforts and grazing exclusion from the site since European settlement (Bailey 2006).

Elevation at the site ranges from 600 to 1000 meters, and slope aspect is largely south or southeast. Mean annual precipitation at Oakridge (~25 km north of site) is 116 cm, most of which occurs between November and April (Day 2005). Several first-order streams drain the restoration site. Jim's Creek, the only named first-order drainage, flows from the site southwest directly into the Middle Fork of the Willamette. The site is bounded on the east by Deadhorse Creek a second-order stream that enters the Middle Fork of the Willamette just under 1 km upstream from the outlet of Jim's Creek (Figure 3.1). The Middle Fork of the Willamette borders the site on the southwest and flows northwest toward the town of Oakridge.

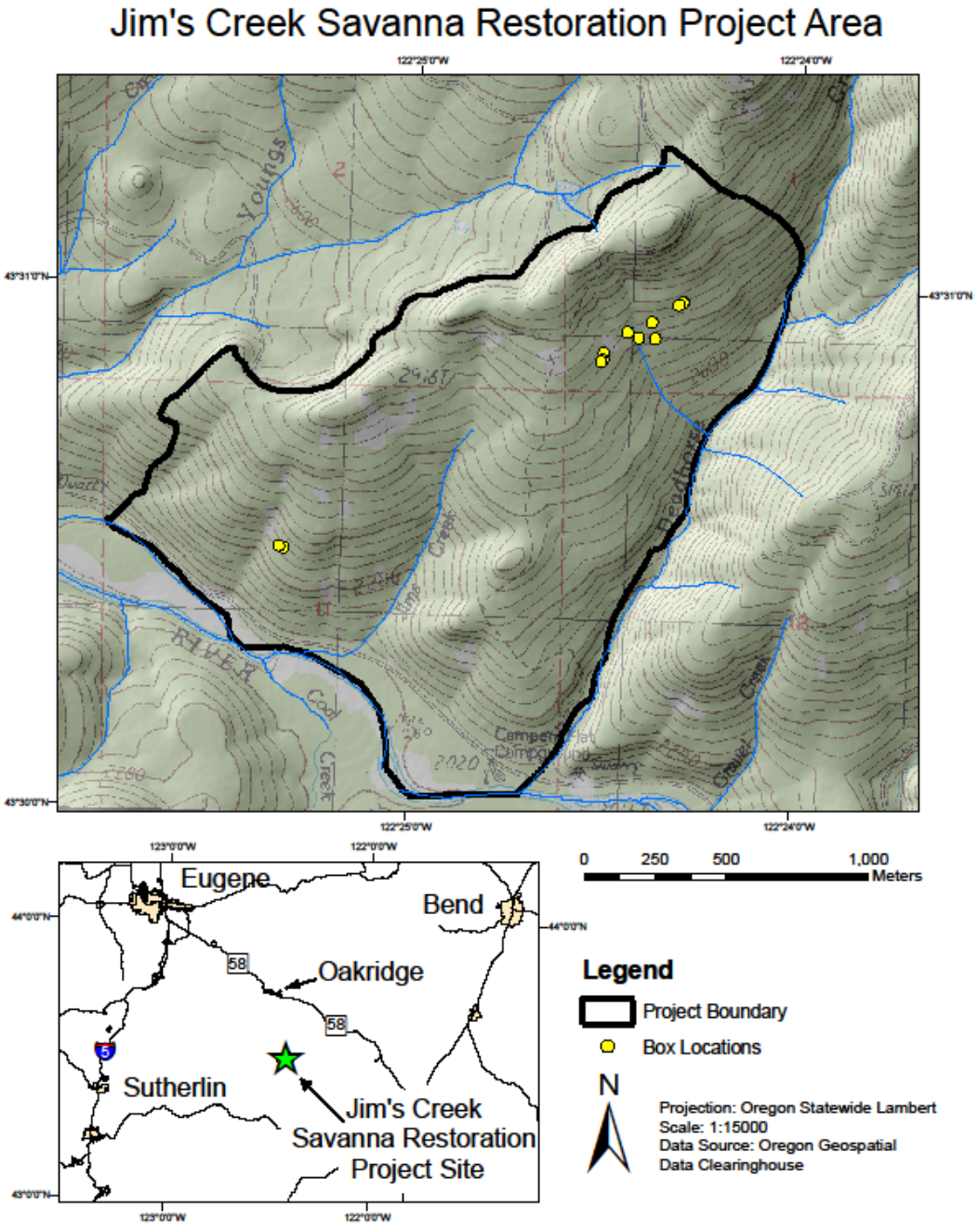

Figure 3.1. Map of Jim's Creek and Vicinity

3.1.1 Vegetation and Soil

Prior to the initiation of restoration activities, Day (2005) performed plot assessments of the forest succession at the Jim's Creek site by aging a large number of trees within the restoration boundary (plot locations shown in Figure 4.1). Results from the study indicated that although oaks are still present at the site, there was no evidence of oak establishment in the past 75 years. Instead, a 100 to 130 year old Douglas-fir cohort dominates the community with an average density of 320 trees/hectare within the project boundary (Bailey 2006). Shrubby understory vegetation includes oceanspray, poison oak, tall Oregon grape, and hazelnut, with a sparse herbaceous component consisting of bracken fern, Oregon grape, woodland star and tarweed (Bailey 2006).

Plant associations occurring within the project area are largely Douglas-fir/poison oak as well as Douglas-fir/oceanspray/grass (Bailey 2006, McCain and Diaz 2002). These associations typically occur in dry areas (the driest of the Douglas-fir series) with southern or western aspects, and usually support only a sparse understory (McCain and Diaz 2002). Slopes of this association average 39% and soils are typically relatively thin and rocky or thick with high clay content (McCain and Diaz 2002).

Legard and Meyer (1973) mapped four different soil units within the Jim's Creek Project boundary. The most extensive unit is characterized by well drained loams and silt loams, derived from breccias and tuffs, and a smaller portion consisting of gravelly to very gravelly loams derived from fractured andesite and basalt. Litter (or duff) consisting of needles, twigs, and other decomposing organic matter on the surface of these units ranges from one to two inches in thickness (Legard and Meyer 1973). A soil resources inventory GIS dataset developed for the Willamette National Forest (USDA 2010) was also utilized to assess general soil characteristics within the project area. All sediment traps are located in areas classified as having moderately severe to severe surface erosion potential, which is a qualitative measurement of soil

loss if all vegetation is removed (USDA 2010). The stability rating (a rating of the relative potential for mass movement of mapped units) for units containing trap locations ranged from moderately stable to stable (USDA 2010).

3.1.2 Fire within the Jim's Creek Site

According to Bailey (2006) there have been seven wildfires within the Jim's creek site since 1970. Portions of the Jim's Creek site were burned more recently in the 1996 South Zone Complex fire covering 52 hectares in the northwest corner of the site where the majority of sediment traps are located (Adams 2008). Only traps 7, 8, 10, and 11 are located outside of the burn area (Figure 4.1). There was a significant potential for stand-replacing crown fire within the project area (Bailey 2006) which has been substantially reduced as a result of restoration activities discussed below.

3.2. JIM'S CREEK SAVANNA RESTORATION STEWARDSHIP PROJECT

Restoration activities within the Jim's Creek Site began following the approval of the treatment regime in 2006 (Bailey 2006). The treatment consists of the removal of 87 percent of the younger age class overtopping Douglas-fir. This thinning (nearly completed as of August 2010) will lead to a stand density of around 20 trees per acre which is similar to the estimated tree density prior to European settlement (Bailey 2006). The treatment calls for the restoration of oak savanna ecosystem structure to all areas within the mapped planning area that were not previously impacted by harvesting activities (Figure 4.1). In areas close to existing roads, skyline yarding was performed. This yarding technique involves suspending at least one end of the harvested log above the forest floor to minimize disturbance of the soil surface. In areas where skyline yarding techniques were not feasible, helicopter yarding was utilized to further minimize the impact of the timber harvesting (Bailey 2006). The treatment did not require the creation of new roads within the project area.

4. METHODS

4.1. SEDIMENT TRANSPORT MEASUREMENT

Surface sediment transport at the Jim's Creek site is estimated using data from twelve sediment traps which were placed within the project area prior to the current research. Trap deployment locations were chosen to represent a range of cover and slope classes (Adams 2008). Traps were placed in the 1996 South Zone Complex wildfire burn area partly because there was significantly less moss cover in comparison to unburned portions of the site. It was postulated that measurable erosion would be more likely to occur in these areas due to decreased thickness of the duff layer related to the wildfire (Adams 2008). Two control traps where placed in locations that were not impacted by the 1996 burn and in an area that did not undergo thinning during the data collection period for the current research. It should be noted that; boxes 7 and 8 are the two controls (no-thinning activities occurred in the area), boxes 1-9 and 11 and 12 are all located within the 1996 burn area, and boxes 10 and 11 are just outside the burn (Table 4.1 and Figure 4.1).

Box#	Fire 1996	Helicopter Yarding	Skyline Yarding	Aspect Adams 2008	Aspect (DEM)	Slope Gradient Adams (2008)	Slope Gradient McFadden (2010)
1	yes	yes	no	180 S	South	0.51	0.38
2	yes	yes	no	125 E/SE	South	0.65	0.51
3	yes	yes	no	140 E	Southeast	0.49	0.54
4	yes	yes	no	106 E	Southeast	0.41	0.38
5	yes	no	yes	110 E	Southeast	0.44	0.30
6	yes	no	yes	146 E/SE	South	0.42	0.45
7	no	none	none	225 W	Southwest	0.6	0.55
8	no	none	none	233 W	Southwest	0.65	0.54
9	yes	yes	no	110 E	Southeast	0.6	0.51
10	no	no	yes	169 S	Southeast	0.53	0.45
11	no	no	yes	126 E/SE	South	0.56	0.54
12	yes	yes	no	156 S	South	0.53	0.51

Table 4.1 Site conditions at trap locations

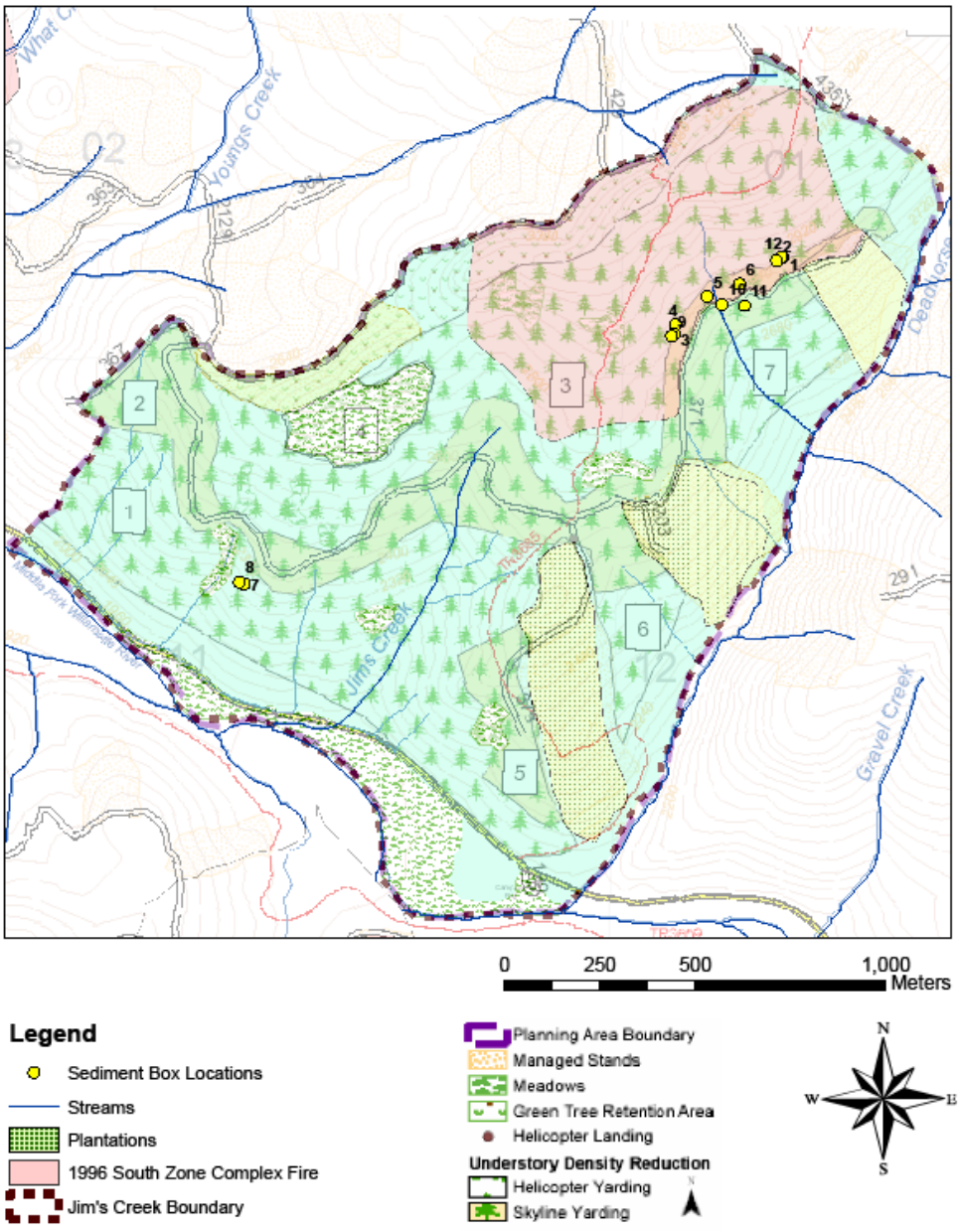

Figure 4.1. Shows the Jim's Creek Savanna Restoration Stewardship Project boundary, along with an overlay of management plans taken from Bailey (2006), sediment trap locations (GPS coordinates).

The sediment trap (see Figure 4.2) is a box constructed from plywood and support beams that is opened on the upslope side and closed on the down slope end.

The opening of the trap is approximately 1.15 meters in length, running parallel to the contour of the slope (Table 4.1). A piece of sheet metal is attached to the front of the box and the upslope end of the metal is inserted into the hillslope to allow for a flush surface for sediment to be transported over and into the box. All traps were constructed prior to the current study (Adams 2008); however, one of the boxes was replaced after being destroyed in a tree fall event.

Surface sediment transport results in deposition within the trap. This accumulated sediment was collected every other month on average from the site starting in January of 2009 and proceeding until August of 2010 for the present study. Traps were redeployed on 10/14/2008 following logging activities at the site to avoid damage caused by falling debris, however five of the traps (numbers: 4, 5, 6, 10, 11) had to be placed in slightly different locations following thinning due to heavy slash cover or inability to locate flagging denoting the original trap location (Adams pers. comm.). To remove accumulated materials a hand broom and dust pan were used. In keeping with the methods employed by Adams (2008), sticks larger then a centimeter, and mineral clasts larger than approximately 3 cm diameter (rarely found in traps), were not included in the collected sample. These larger materials were left out of the original analysis due to the postulation that fine grained mineral sediment erosion from the site would have the most significant impacts on stream reaches (Adams pers. comm. 2008). The hand broom collection method described above was sufficient when sediment within the trap was dry. In a few instances standing water was found in the traps, particularly after large

Figure 4.2 Example Sediment Trap

precipitation events, as seen in Figure 4.2. In these cases, water was carefully siphoned from the trap in the field until the sediment could be collected using a gardening trowel and the dust pan.

The first sample collection date from each of the study periods is not used in the analysis of sediment transport from the site. It was postulated that there is likely a lag period for the traps to equilibrate to the hillslope and disruption of the soil surface during installation (Swanson pers. comm. 2010). Therefore, the first sample collection may include some sediment derived from the initial installation and hillslope disturbance. Other problems with sample collection included limited access to the site due to logging activities or snow, animal disturbance, and disconnection of the sheet metal from the hillslope over time. However, samples collected during periods in which these disturbances occurred were still included within the analysis (shown in more detail in Table 4.2).

Box #	21-Nov-2008	23-Jan-2009	28-Feb-2009	18-Apr-2009	23-May-2009	20-Jun-2009	26-Jul-2009	22-Aug-2009	3-Oct-2009	1-Nov-2009	7-Feb-2010	28-Feb-2010	29-Apr-2010	27-Jun-2010	29-Aug-2010
1	L	F										W			
2	L	F													
3	L	F								W, P	W	W	P	W	
4	L	F				P				W				P	P
5	L	F									D	D	D	D	D
6	L	F													
7	F	F		W							T	T	T	F	D
8	F	F								W			W	M	
9	L	F								P		W	P	W, P	
10	L	F											D		
11	L	F										W	W	W	
12	L	F				P						P		P	
All				S							S			S	

Key
F=First Sampling Date after installation (samples not used in analysis)
W=Standing Water (from rainfall and snowmelt on the metal apron of the entrance of trap)
P=Elk fecal material found in trap
T=Tree Fall (missing values)
M=Moles (dead) found in trap (single instance) (sample not used in analysis)
D=Box Disconnected from slope
L= Logging Prevented collection
S=snow during collection period

Table 4.2 . Shows the occurrence of various disturbances at each trap locations. Note that only codes F, T, and M resulted in missing values in the analysis

4.2. SEDIMENT TRAP SOURCE AREA ESTIMATES

Various techniques were employed to characterize the source area for each of the twelve traps. GIS analyses using datasets available from the Willamette National Forest GIS Data Dictionary were performed at all trap locations (USDA 2010). Information derived from these datasets includes broad scale vegetation stand age and character, soil inventory information, and fire history.

The relationship between slope and sediment flux is an important component of many sediment transport models (e.g., Culling 1960, Roering 1999). Slope steepness and curvature data were derived from a 10 meter digital elevation model (DEM) (Oregon Geospatial Data Enterprise Office 2010) within ArcGIS. This same 10 meter DEM was also used for modeling sediment transport from the site using the Roering (1999) nonlinear diffusion equation and will be discussed in detail later.

In some cases the local slope at the sediment trap locations varied on a relatively small spatial scale and these subtle slope variations were often not captured in the 10 meter DEM. To obtain a more accurate measurement of slope, a Silva clinometer was used in the field at each trap location. Three measurements were taken to characterize the local slope at each trap location, one a meter below the downslope edge of the trap, the second on the same contour as the trap, and the third one meter above the trap opening. These three values were averaged and were plotted against sediment transport rates for collected data to assess the slope dependence of surface transport from the site.

Photopoint locations were established two meters from the downslope edge of each of the trap locations and images were collected as often as possible using a digital camera. Only a few collection dates have a full set of photos (from every trap location), but most sampling dates had some photo documentation. These photos along with field notes are used to perform a semi-quantitative analysis of cover and surface roughness characteristics at each trap location over the course of the study.

Lastly, to assess the distance of transport at each trap location, marking paint was used to mark a line one meter from the trap opening. Transport distances were then analyzed by carefully searching for painted particles down slope from the painted line during the next collection date.

4.3. SAMPLE PROCESSING

Sediment samples were collected from the Jim's Creek site approximately every other month. On a few occasions, logging activities or snow prohibited the collection from the traps. This lag time in collection dates is accounted for by normalizing the data by the duration of the accumulation period. Samples were transported from the site to the lab and were air dried for at least 24 hours. Initial sample weights (to the nearest 0.1 of a gram) were recorded and the entire sample was then dried in a laboratory drying oven for at least 24 hours at 60°C. Following oven drying, the samples were re-weighed and a total "dry" weight was recorded for every sample.

Immediately after dry weights were recorded, coarse organic, coarse mineral, and fine organic and mineral fractions were separated from each of the samples. A 2-mm #10 US Standard Sieve was used to separate coarse and fine fractions following the methods described in Adams (2008). These fractions (coarse > 2mm and fines < 2mm) were both weighed and values for each were recorded. The coarse (> 2mm) fraction was then separated into organic and mineral fractions. This was accomplished by carefully determining the organic and mineral components of the sediment by eye and hand separating the materials. The coarse (>2mm) organic and mineral fractions were then weighed separately, again to the nearest 0.1 g, and the values for each were recorded. The methods described above produced three separate fractions: mineral > 2mm, organic > 2mm and mineral and organics < 2mm (fines). Sediment transport rates were then estimated for all three sample fractions and for the total dry mass using the conversion factors in Table 4.3 (discussed in detail below).

4.4. PRECIPITATION DATA

Precipitation and snow water equivalent (SWE) data were collected from the Railroad Overpass SNOTEL site in order to maintain consistency with Adams' (2008) experimental design and allow for comparison of the results from the two studies. Adams (2008) determined that the Railroad Overpass site was an adequate analogue to weather at Jim's Creek. The SNOTEL site is located at a similar elevation in the Cascade Range 23 km to the northeast of the Jim's Creek Project Area. Precipitation data were downloaded for the entire collection period and then subdivided into the time intervals between sampling dates. Sediment transport rates from the site were then plotted against total precipitation for each collection period to assess the relationship between precipitation and sediment flux.

4.5. CALCULATION OF SEDIMENT TRANSPORT RATES

Following the sample processing discussed above, each recorded sediment mass was used to calculate sediment flux into the traps. Sediment flux was calculated in units of $ML^{-1}T^{-1}$ in this case, mass in grams transported over 1 meter of hillslope contour over a year. Sediment flux is often expressed as $ML^{-2}T^{-1}$, however, in this study it was difficult to accurately delineate the contributing area to each trap. It was also unclear over what spatial scale surface sediment transport mechanisms were occurring at the site, and therefore the areal sediment flux was not obtainable with the data currently available.

To calculate sediment flux, each sample mass was multiplied by a year conversion factor and a 1 meter contour length conversion factor. The latter is necessary because all trap openings are slightly over a meter (Table 4.3).

Table 4.3. Conversion Factors for Transport Rate Estimation

Box #	Opening (m) from Adams 2008	Hillslope Conversion factor (1 meter/length of trap opening)
1	1.15	0.87
2	1.15	0.87
3	1.15	0.87
4	1.15	0.87
5	1.15	0.87
6	1.16	0.86
7	1.16	0.86
8	1.15	0.87
9	1.16	0.86
10	1.15	0.87
11	1.16	0.86
12	1.16	0.86
Collection Date	**Number of days since previous collection**	**Year Conversion Factor (365 day/ number of days in collection period)**
28-Feb-2009	35	10.4
18-Apr-2009	48	7.6
23-May-2009	34	10.7
20-Jun-2009	28	13.0
26-Jul-2009	36	10.1
22-Aug-2009	26	14.0
3-Oct-2009	41	8.9
1-Nov-2009	28	13.0
7-Feb-2010	97	3.8
28-Feb-2010	20	18.3
29-Apr-2010	59	6.2
27-Jun-2010	58	6.3
29-Aug-2010	62	5.9

4.6. MODELING SEDIMENT TRANSPORT

In an attempt to model sediment transport at the Jim's Creek site using the nonlinear transport equation developed by Roering et al. (1999) (Eq 2), slope values from a 10 meter digital elevation model (DEM) were used to create a map of modeled sediment transport rates for each pixel of the 10 meter grid. The transport coefficient

(K) was calculated by solving the for the K value, using transport rates from Adams (2008) as inputs for q_s in equation 2, and using a critical slope S_c value of 1. Sediment transport rates were calculated for each pixel within the project area, and an interpolation surface of the Jim's Creek area was constructed (Figure 5.6). Modeled sediment transport values at each of the sediment box locations were then compared with rates generated from data collected by Adams (2008) to evaluate model predictions.

Following the use of the Roering (1999) non-linear diffusion equation, a second model, the WEPP model, was used to simulate erosion for the Jim's Creek Site. For the current research the WEPP Web Interface, WEPP GIS model (USDA, NSRL 2010) was used. This model allows a user to run a watershed simulation using a DEM to generate channel and the watershed area using the Topographic Parameterization Software (TOPAZ). Land use information may also be input to simulation from the 1992 USGS National Land Cover Dataset (NLCD). Ten separate model runs were completed for the Jim's Creek Site. Five runs were completed using land cover specified by the NLCD, which classified most of the project area as forest. Five additional runs were completed after changing the land cover to bare soil to simulate a clearcut condition at the site. Of these runs, only six corresponded to areas with existing sediment transport data and are therefore able to be analyzed using observation from the present study.

5. RESULTS

5.1 AVERAGE SEDIMENT FLUX PRE- AND POST-TREATMENT

The average soil erosion rate estimated from boxes in thinned areas from Adams (2008) was 983.5 ± 479.3 g/m/yr while the average estimated erosion rate from the thinned areas in the present study is 379.8 ± 283.9 g/m/yr. Estimated transport rates from the control boxes (boxes 7 and 8 which did not undergo thinning) were

156.5 ± 2.2 g/m/yr for the Adams (2008) study and 84.1 ± 6.2 g/m/yr for the present study. Average sediment transport rates for all collection periods from each trap location and for all trap locations for each collection period are shown in Table (5.2). It should be noted that the duration of study as well as the sample collection periods differed between the pre- and post- treatment studies. Adams' (2008) study does not include a collection period during July or August (Figure 5.1). Also, five trap locations may be slightly different (placed as close to the original location as possible) due to slash cover and location marker destruction following thinning activities.

Average sediment flux, as a measure of total accumulated material in the sediment trap, has decreased since thinning activities began in 2008 for every box location except for Box #4 (Figure 5.2). Boxes 1, 5, 6, and 10 experienced particularly large declines following the thinning activities. Average flux of mineral materials greater than 2 mm, and fines (organic and mineral), decreased in a similar fashion to the total material flux, with box 4 again showing the only increase in transport following the site disturbance. The flux of coarse (> 2mm) organic materials showed post-treatment increases in boxes 1, 3, 4, 8, 9, and 12, and declines in boxes 2, 5, 6, 7, 10, and 11. The control boxes, 7 and 8, generated consistently the least amount of sediment throughout both study periods (Table 5.1).

Sediment transport rates declined by as much as a factor of nine at trap locations following site disturbance. However, Box 4 showed an average increase of nearly 50% in all size and content fractions. The largest declines in sediment transport rates were seen in the post-treatment coarse mineral sample faction, while the largest increases were seen in the post-treatment coarse organic flux. The fines (organic and mineral < 2mm) followed a similar trend to the combined flux of all materials, showing declines for all boxes except box 4 (Figure 5.2).

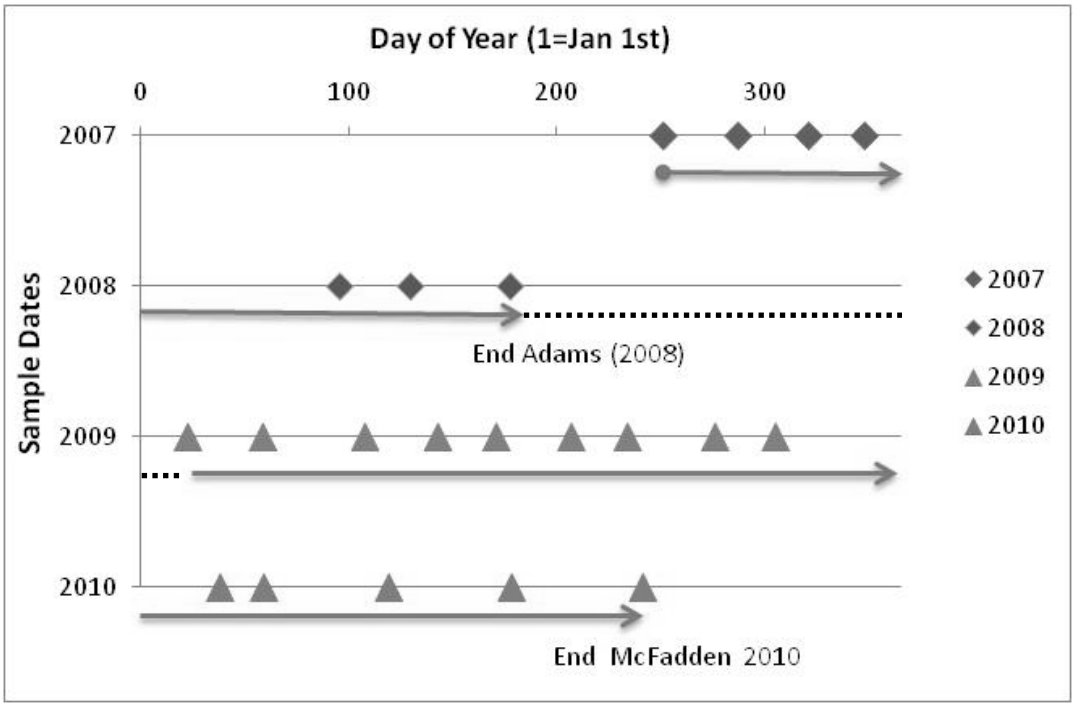

Figure 5.1. Displays collection periods from Adams (2008) study years 2007 and 2008 and the present study years 2009 and 2010. Note that no data were collected during July and September for the pre-treatment (Adams 2008). Dashed line represents gap between Adams (2008) and the present study during which logging operations were conducted. Data markers represent dates of collection from trap locations.

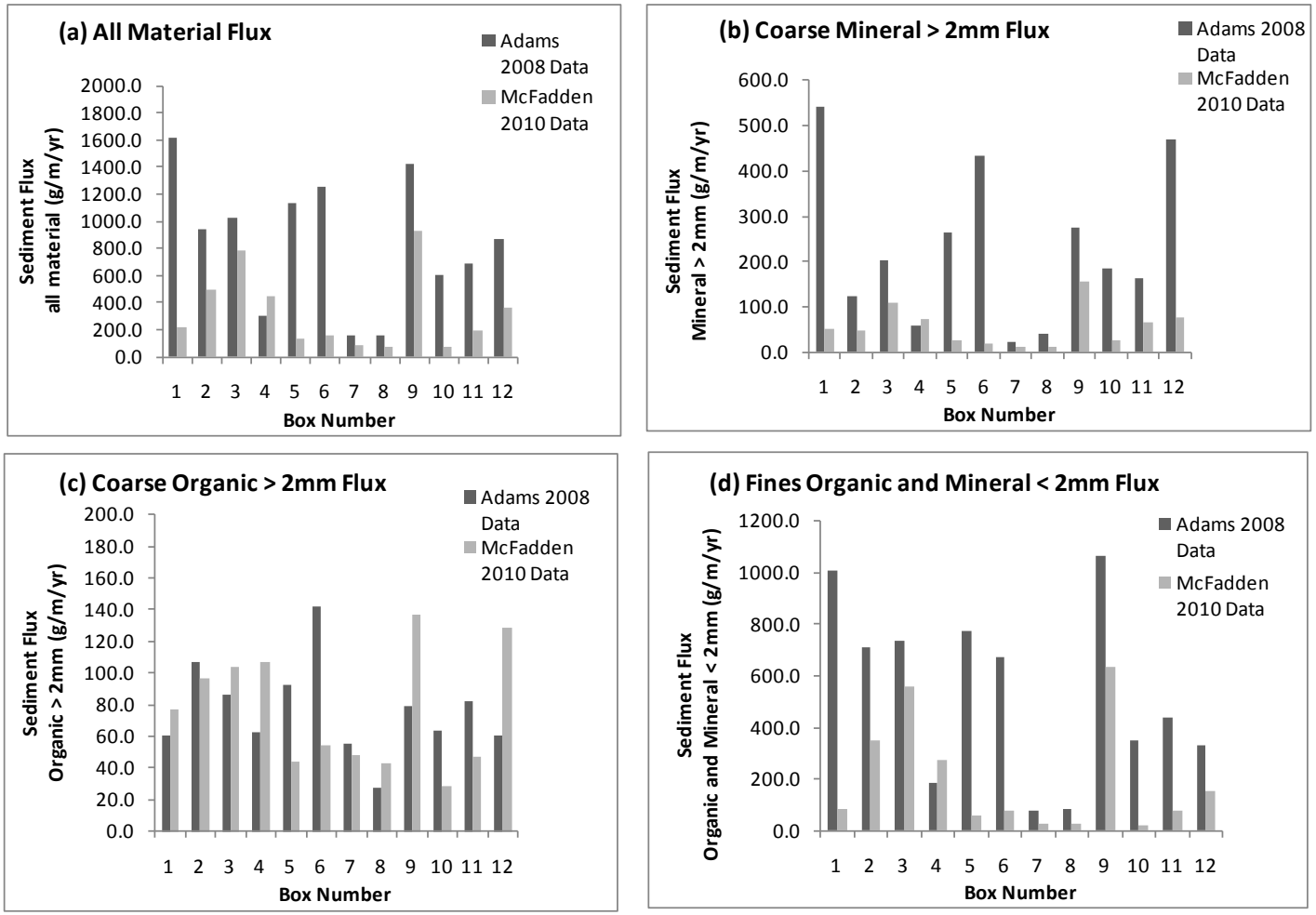

Figure 5.2. Plots show the average sediment flux from Adams (2008) and the current research at each box location, for total accumulated material (organic and mineral) (top left) and the three other size fractions.

A.

Adams 2008

Box #	1	2	3	4	5	6	7	8	9	10	11	12
All Material	1613.2	941.5	1027.0	307.8	1128.3	1250.2	158.1	154.9	1417.3	599.4	686.6	864.1
Min > 2mm	541.6	122.2	202.4	58.6	263.9	435.0	22.2	41.0	273.3	185.6	162.1	470.9
Org > 2mm	60.8	106.7	86.5	62.4	92.4	141.8	55.9	27.6	78.8	63.2	82.0	60.6
Fines < 2mm	1009.5	711.9	737.0	187.0	771.3	672.4	79.8	85.9	1063.9	349.8	440.3	332.5

McFadden 2010

Box #	1	2	3	4	5	6	7	8	9	10	11	12
All Material	214.7	496.6	784.6	453.0	133.2	154.0	88.4	79.7	931.6	75.9	194.8	359.6
Min > 2mm	52.9	49.6	109.3	73.9	26.1	19.6	10.7	11.0	155.4	25.6	66.0	77.3
Org > 2mm	76.8	97.1	103.6	106.8	44.5	54.3	48.2	43.2	136.5	28.4	47.4	128.2
Fines < 2mm	86.9	349.7	560.1	272.7	61.3	78.5	27.3	25.6	635.9	21.8	81.4	156.6

B.

Adams 2008

Collection Date	10/14/2007	11/17/2007	12/14/2007	4/5/2008	5/9/2008	6/26/2008
All Material	1171.2	1426.1	1240.2	425.3	402.9	408.5
Min > 2mm	325.4	308.8	291.5	140.0	123.5	200.2
Organic > 2mm	106.1	94.4	88.9	45.8	79.5	44.6
Fines < 2mm	738.9	1021.6	858.1	239.0	199.2	163.8

McFadden 2010

Collection Date	2/28/2009	4/18/2009	5/23/2009	6/20/2009	7/26/2009	8/22/2009	10/3/2009
All Material	179.2	193.9	317.8	1092.0	387.8	281.1	223.3
Min > 2mm	17.8	36.9	47.8	108.2	78.1	55.9	42.4
Organic > 2mm	26.0	35.9	77.0	211.2	102.1	56.1	71.6
Fines < 2mm	106.0	120.1	192.8	771.0	206.9	171.7	111.6

Collection Date	11/1/2009	2/7/2010	2/28/2010	4/29/2010	6/27/2010	8/29/2010
All Material	322.6	153.7	175.2	178.8	342.1	449.1
Min > 2mm	79.3	39.9	14.8	44.6	69.4	98.7
Organic > 2mm	104.9	39.9	32.0	71.0	83.3	79.9
Fines < 2mm	140.5	75.0	128.9	64.7	191.7	273.4

Table 5.1. A.) Average soil erosion rates from each box location for all collection periods from both the McFadden 2010 study and the Adams 2008 study. B.) Average soil erosion rates from all boxes for a given collection period.

5.2 SOIL CHARACTER, COVER, AND TRANSPORT OVER TIME

Plots of the magnitude and seasonality of sediment transport rates from both Adams' (2008) data and the current study suggest a change in the transport regime following thinning activities (Appendix A). As suggested by the Figure 5.2 above, the sediment transport rates are larger for the pre-treatment period in most cases. However, some trap locations display only minor changes in transport rates over the course of the studies. Examples of this include box 3 and the control boxes 7 and 8 which all show a comparatively minor decline between 30 and 45% following the

thinning (Appendix C). The coarse organic component of sediment transport as a relative proportion of the total dry sediment weight increased from an average of 13% to 32% following thinning. However, the relative proportions of coarse mineral and fine fractions decreased by 7% and 13%, respectively, following thinning. In both studies, the fine mineral and organic fraction made up the largest proportion of each sample, averaging around 50% in the current study and 61% in Adams' (2008) samples.

Pre-treatment transport rates seem to peak during the winter months November and December 2007. Conversely, post-treatment transport seems to be largest during the summer months (June through August of both 2009 and 2010). This seasonality of transport is difficult to verify definitively, given the relatively short duration of sampling (see Figure 5.1), but the trend seems to be consistent through most of the plotted data (Appendix A).

Cover vegetation varied widely between trap locations. There was some seasonal variability manifest largely in the sprouting of herbaceous cover during the summer growing season (Table 5.3). In general, traps located below slopes of bare soil experienced the largest transport rates, while the control traps which were consistently observed to have litter, moss, and herbaceous cover generated the smallest transport rates (Table 5.2, for examples see Figure 5.3).

Analysis of lines painted one meter above trap openings in nearly all cases showed little to no movement of painted materials over the course of the sample collection period (~ one month). This suggests that surface sediment transport is likely occurring over short distances.

Box #	1/23/09	2/28/09	4/18/09	5/23/09	6/20/09	7/26/09	8/22/09
1	L, B	NA	NA	NA	NA	L, B	NA
2	L	NA	NA	L, B	NA	B, H	NA
3	B	NA	NA	B	B	B, H	B, H
4	L	NA	NA	L, B	L, B, H	L	NA
5	L	L	NA	L	NA	NA	L
6	L, B	NA	L, B	L	NA	L, B	L, B
7	L, M, H	NA	L, M, H	NA	L, M, H	L, M, H	NA
8	L, M, H	L, M, H	NA	NA	L, M, H	L, M, H	NA
9	B	B	L, B	B, H	NA	B, H	L, B, H
10	L	NA	NA	L	L	L	L
11	L, M, H	NA	NA	L, M, H	L, M, H	L, H	L, H
12	L, B	NA	NA	L	NA	L, B	L, B
Box #	**10/3/09**	**11/1/09**	**2/7/10**	**2/28/10**	**4/29/10**	**6/27/10**	**8/29/10**
1	NA	L, B	L, B	NA	NA	L, H	NA
2	NA	L	B, H	NA	B, H	B, H	NA
3	NA	L, B, H	L, B	NA	L, B	B	NA
4	NA	L	L, B, H	NA	B, H	L, B	NA
5	NA	NA	L	NA	L	L	NA
6	NA	L, B	L, B	NA	L	L, B	NA
7	NA	Destroyed	Destroyed	NA	Re-deployed	L, M, H	NA
8	NA	L, M, H	L, M, H	NA	NA	M, H	NA
9	NA	L, B	B	NA	NA	L, B, H	NA
10	NA	L	L, H	NA	L,H	L	NA
11	NA	L, H		NA	L, B, H	L, H	NA
12	NA	L, B, H	L, B	NA	L, B	L, B	NA
Dominant Cover: L=litter, B=bare, M=moss, H=herbs							

Table 5.2. Semi-quantitative analysis of cover from sampling dates, derived from photos at each trap location. NA values are assigned to dates that lack photo coverage. Dominant Cover type is divided into four categories and visual estimates of dominance were performed. Where multiple codes occur the cover type is co-dominant. Note the 1/23/09 collection date is not included in the rest of the analysis as it was the first collection of the study.

Figure 5.3. Shows contrast between control trap locations (left) and a more heavily disturbed site within the thinned section of the project area (right). Box# 8 is shown on the left and Box #3 is on the right. Note larger amounts of exposed bare soil in Box #3 compared to the control Box #8.

5.3 SEDIMENT TRANSPORT AND PRECIPITATION

Average daily precipitation, a normalized measure of precipitation for each sample period, ranged from 2.38 to 6.27 mm/d for the pre-treatment data and from 0.14 to 6.40 mm/d for the post-treatment study. The lower minimum values in the present study are likely due to differences in duration of collection periods during the summer months; more sample points during the dry, summer periods during the present study contributes to the lower minimum value. Mean average daily precipitation was larger for the pre-treatment study (4.5 mm/d Adams 2008) compared to the current study (3.2 mm/d). Despite the apparent decrease in precipitation between the two study periods, the difference is not significant (t-test $P > 0.05$). The

largest precipitation events generally occurred during the winter months, although two large events did take place in October of 2009. Maximum daily precipitation values (the highest recorded daily precipitation value for a given collection period) ranged from 5 to 53 mm/d for collection periods during the two studies and were not well correlated with sediment transport. Average maximum daily precipitation during the collection periods was not significantly different between the pre-and-post treatment studies (t-test $P > 0.05$).

Precipitation and sediment transport are not well correlated during either study. Appendix B shows plots of total flux and flux of each fraction of the samples and precipitation since the previous sampling date. Precipitation values were also normalized using the value of precipitation since previous collection divided by the number of days in the collection period (Appendix B).

The total number of days with measurable snow cover (SWE at the SNOTEL Site of < 0) differed between the two study periods. During Adams' (2008) study the SNOTEL site measured a total of 66 days with snow cover through the winter months (Sept 2007- March 2008). This is in contrast to the 40 total days with snow cover at the site for Sept. 2008-March 2009, and 27 days from Sept. 2009-March 2010. Assuming snow cover suppresses erosion, we can estimate this effect for the wet season (duration: 7 mo X 30 d/mo = 210 days). During the pretreatment period snow was on the ground 31.4% of the time (66/210 days) of time and only 12.9% of time in the 2009-2010 wet season.

Average daily dry season precipitation, defined as the precipitation during the months of May and June, was highest for the 2010 season (4.8 mm), and lowest for the 2009 season (2.7 mm). The average dry season rainfall for the pre-treatment study period fell in the middle of these values at 3.1 mm (Table 5.3). Dry season averages were not extended further into the summer months because the Adams' (2008) study extended through only the early summer months (Figure 5.1).

Average daily wet season precipitation (precipitation during Oct-April) was highest during the pre-treatment study and lowest in the latter half of the post-treatment study (Table 5.3). However, in contrast to average daily precipitation, maximum daily precipitation values were highest during the 2008-2009 post-treatment wet season, and lowest during the 2007-2008 pre-treatment wet season (Table 5.3).

Dry season Precipitation May-June

	2008	2009	2010
Average daily (mm/d)	3.1	2.7	4.8
Max daily (mm/d)	30.5	27.9	40.8

Wet Season Precipitation Oct-April

	2007-2008	2008-2009	2009-2010
Average daily (mm/d)	5.7	5.1	4.7
Max daily (mm/d)	40.6	55.9	53.3

Table 5.3. Dry and wet season rainfall values for pre- and post- treatment study periods

5.4 INFLUENCE OF GRADIENT ON SURFACE TRANSPORT

Gradient data were collected both from a 10 meter DEM of the study site as well as from clinometer measurements taken at each trap location (Figure 5.4). In general, DEM derived slopes are less than those measured by clinometer at the site. A linear regression was performed on both sets of data. Relatively little of the variability in the clinometer measurements from the current study is explained by the regression relationship (r^2=0.29); however, Adams' data have better fit to the regression with an r^2 value of 0.64. The differences may be due to discrepancies in measurement techniques as well as minor adjustments to box locations which may have occurred following redeployment after logging activities at the site (Figure 5.1). Clinometer measured gradients were used for the remainder of analyses of the influence of slope

on surface transport regimes, except for the non-linear sediment transport model, which was performed using the 10 DEM dataset.

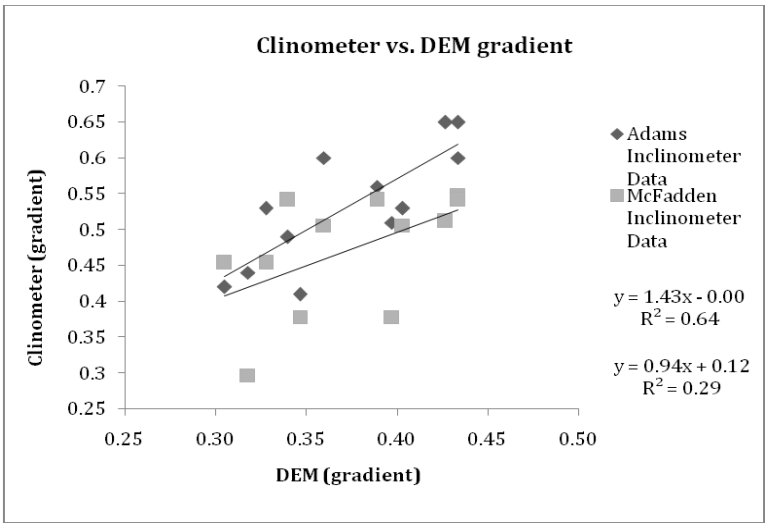

Figure 5.4. Plot shows measured clinometer gradient against DEM gradient and linear regression lines, equations, and r-squared values for each study.

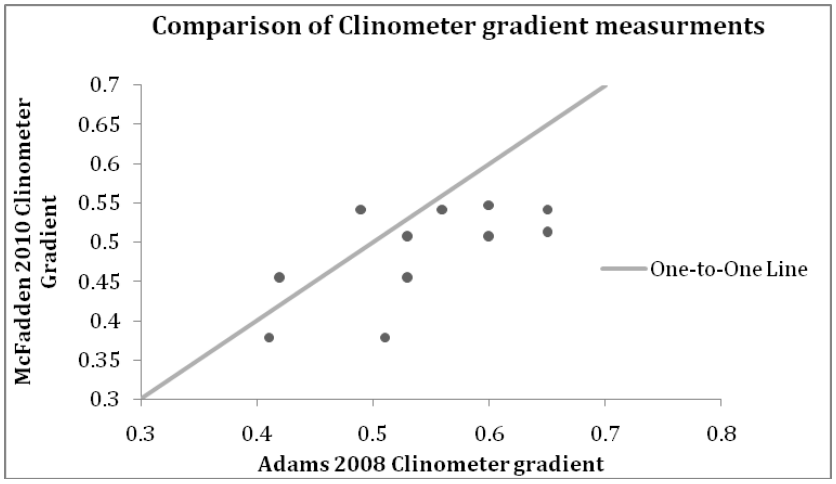

Figure 5.5. Clinometer gradient measurements from the two studies at each trap location

Plots of sediment transport rates and slope are displayed in Figure 5.6. The regression analyses in most cases show a poor fit, suggesting that slope is not well correlated with sediment transport rates in either study. R-squared values are low for the regression analysis for each size fraction, ranging from 0.02 to 0.15, from the current study and from Adams' (2008) data. This may suggest that slope is not the primary mechanism driving sediment flux at the Jim's Creek site.

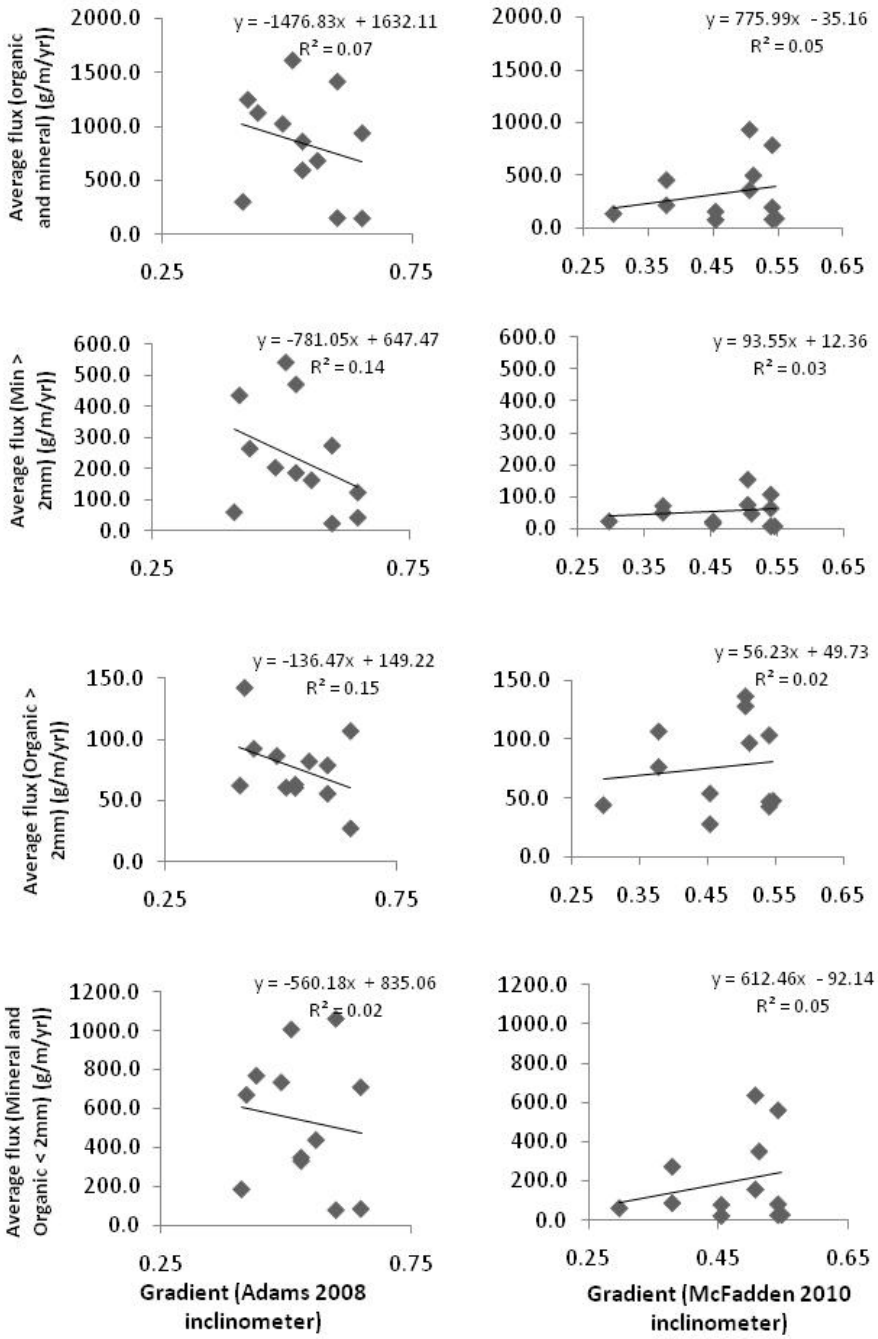

Figure 5.6. Average sediment transport rates from each trap location and for each sample fraction plotted against gradient from Adams (2008) and present study.

5.5 MODELED SEDIMENT TRANSPORT

5.5.1 Modeling using Non-linear Diffusion Model

Using equation (1), pre-treatment transport rates, and gradient derived from a 10 meter DEM, sediment transport was simulated for the Jim's Creek Restoration Project area. Each 10 meter pixel is assigned a transport rate based on the Roering et al. (1999) non-linear transport equation and the gradient derived from the 10 meter DEM. Sediment transport values for each pixel were then projected back into ArcGIS as a raster dataset and to generate a map of simulated sediment transport for the site (Figure 5.7).

Some areas in the map show sediment transport values that are well beyond measured results (shown in red in Figure 5.7). These areas have high gradients that approach the specified critical slope value of 1 where sediment transport increases rapidly due to processes related to slope failure.

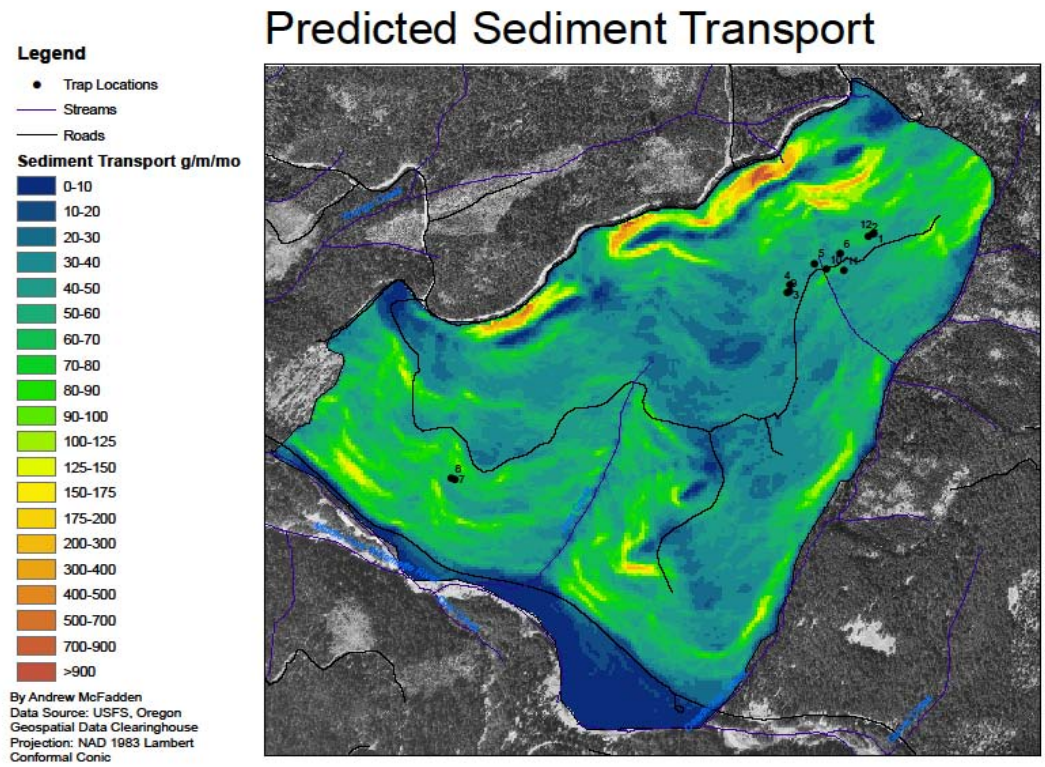

Figure 5.7. Map of simulated sediment transport and the Jim's Creek Site, using the non-linear transport model from (Roaring et al. 1999).

Simulated transport is within the same order of magnitude as observed transport values from pre-and-post treatment data analysis. However, the spatial variability of sediment transport rates is not well simulated by the model. Simulated results suggest that the boxes with the highest transport rates are numbers 7 and 8 (the two controls). However, as shown in Figure 5.2, observational data for these two boxes show that they consistently have the lowest transport rates.

Simulated transport rates are under-predicted by the model in 7 of the twelve boxes for pre-treatment data, and are over-predicted in nine of the twelve boxes in the current study (Figure 5.8).

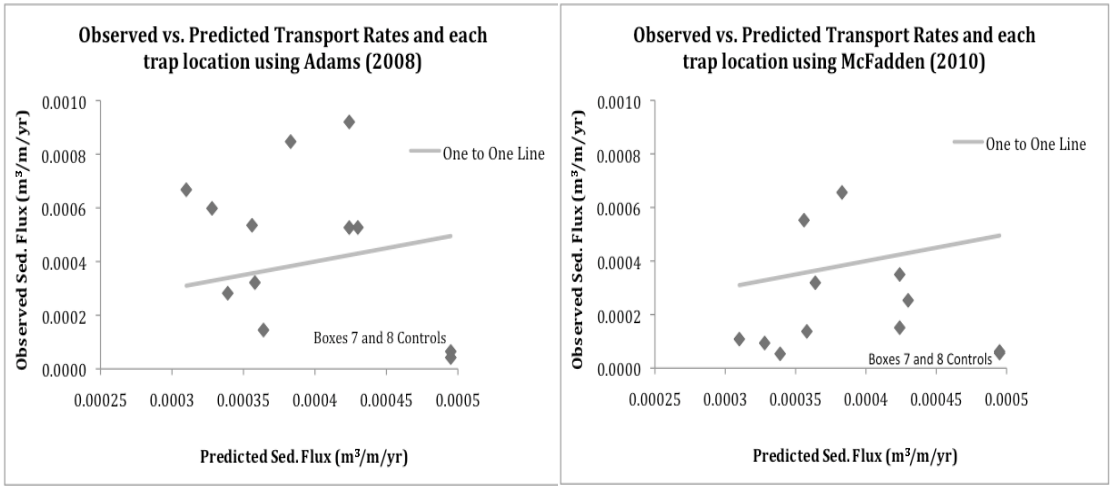

Figure 5.8. Shows observed sediment flux plotted against predicted flux using the non-linear transport model from (Roering et al 1999). The line within the plot is a one-to-one line to show over and under prediction by the model. Note the two control boxes in the lower right hand corner of the plot indicating model over-prediction for both studies.

5.5.2 Modeling using WEPP

Model runs using the WEPP web interface were completed for three separate watersheds within the Jim's Creek site. Watershed delineation was completed using TOPAZ and channel reaches were modeled using topographic information from a DEM. Not all modeled channels correspond to perennial streams; therefore, some of the delineated watersheds are more of an expression of landscape drainage systems and may have intermittent streams present in the lower portions of the drainage area. This is especially true of the smaller delineated watersheds. These watersheds were chosen because each contains two or more sediment traps that are used to compare simulated transport to observed values (Figure 5.9). Two different cover classifications were also simulated for each of the three watersheds, one representing the natural forest cover, and a second assuming bare soil for a total of six model runs.

Model output from the WEPP web interface over-predicts sediment transport observed at the site in all cases (Table 5.1). It should be noted that WEPP output generates an areal estimate (e.g., tones/hectare/yr), while estimates from traps measure flux across a unit of contour length. To bring output from these two approaches into comparable terms output values from the WEPP model were converted to sediment delivery from the watershed by multiplying the WEPP output rates by the watershed area and expressing them as g/yr. To estimate sediment production for the same area based on data from the field sampling, observed sediment transport rates (g/m/yr) from sediment trap locations were multiplied by stream perimeter and expressed as g/yr (Table 5.1). The WEPP model performed better when the USGS NLCD classifications were used to simulate a forested watershed. Output generated for the forest scenario is two to three orders of magnitude higher than observed values of sediment production. The model run for bare soil conditions generated transport rates is four orders of magnitude above observed values. Overall, the WEPP model seems to over-predict sediment transport rates from the site, similar to observations in the previous study regarding the use of this model (Adams 2008).

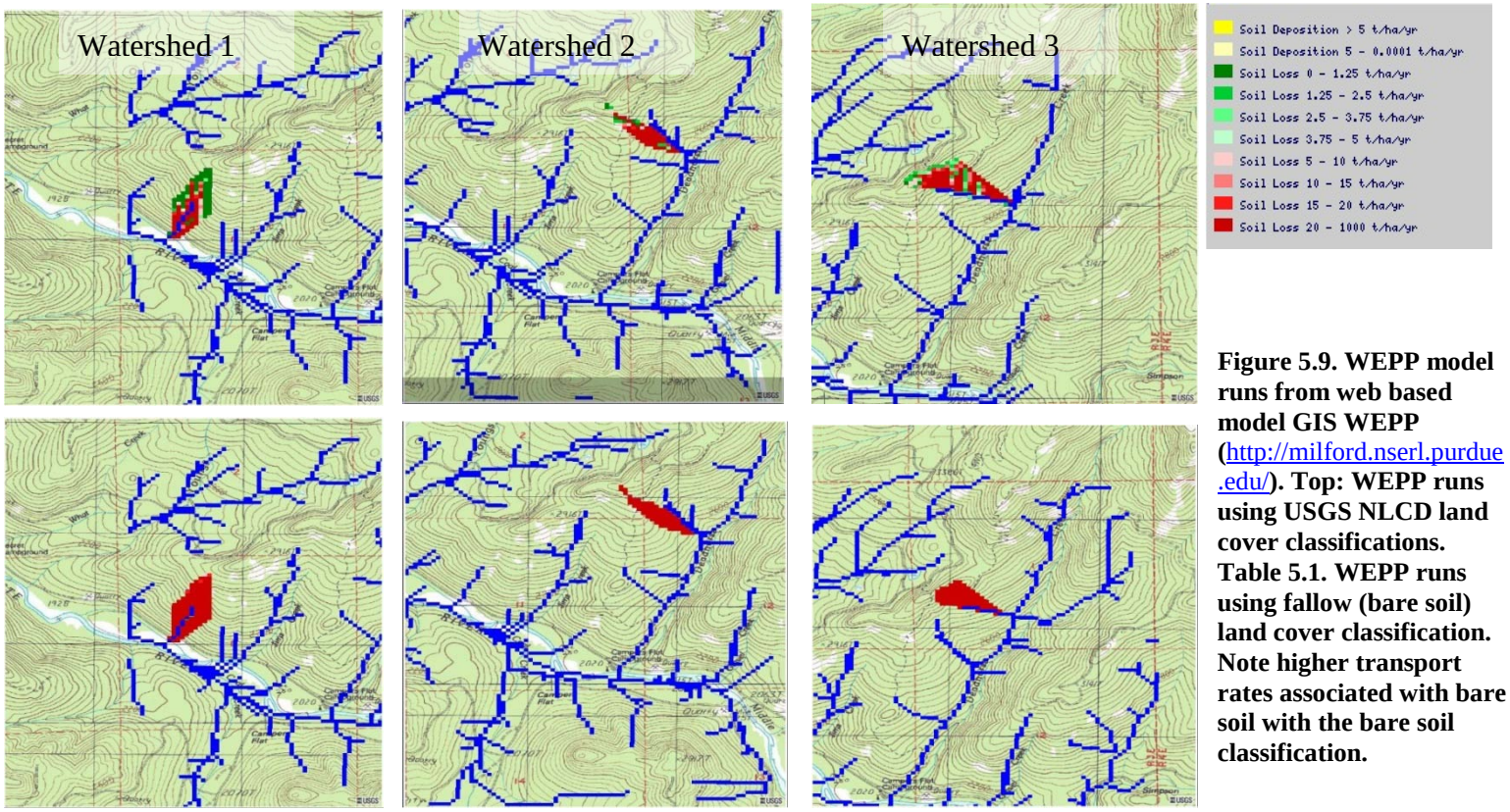

Figure 5.9. WEPP model runs from web based model GIS WEPP (http://milford.nserl.purdue.edu/). Top: WEPP runs using USGS NLCD land cover classifications. Table 5.1. WEPP runs using fallow (bare soil) land cover classification. Note higher transport rates associated with bare soil with the bare soil classification.

		Adams (2008) Avg estimated sed. delivery to stream perimeter (g/yr)	McFadden (2010) Avg estimated sed. delivery to stream perimeter (g/yr)	WEPP Forested estimated delivery from watershed (g/yr)	WEPP Bare soil estimated delivery from watershed (g/yr)
Watershed 1	*7, 8*	1.986E+05	1.067E+05	7.59E+07	6.83E+09
Watershed 2	*3, 4, 9*	4.394E+05	3.463E+05	1.72E+08	6.44E+09
Watershed 3	*1, 2, 5, 6, 10, 11, 12*	1.284E+06	1.115E+05	1.77E+08	6.63E+09

6. DISCUSSION

Box Number	1	2	3	4	5	6	7	8	9	10	11	12
Adams Avg Flux (g/m/yr)	1613.2	941.5	1027.0	307.8	1128.3	1250.2	158.1	154.9	1417.3	599.4	686.6	864.1
McFadden Avg Flux (g/m/yr)	214.7	496.6	784.6	453.0	133.2	154.0	88.4	79.7	931.6	75.9	194.8	359.6
Roering etal. Simulated Values (g/m/yr)	424	424	356	364	328	310	495	495	383	339	358	430
WEPP Output Forested watershed (g/yr)	1.77E+08		1.72E+08		1.77E+08		7.59E+07		1.72E+08	1.77E+08		
WEPP Output bare soil (g/yr)	6.63E+09		6.44E+09		6.63E+09		6.83E+09		6.44E+09	6.63E+09		

Table 6.1 Summary of pre-treatment, post-treatment estimated erosion rates, and simulated surface transport rates from the Jim's Creek Site. Note WEPP output values are generated for sub-watersheds containing each sediment trap, values repeat for boxes in the same sub-watershed.

6.1 SEDIMENT FLUX PRE- AND POST-TREATMENT

Pre- and post-treatment observed sediment fluxes are low, but are similar to estimated transport rates from another forested watershed in the western Cascades of 190 g/m/yr (Swanson et al. 1982). Observed transport rates from this study also fall within the range estimated from a forested site in Colorado of 12-2700 g/m/yr. Much higher transport rates have been observed in the region. Estimated transport rates of 320-3600 kg/m/yr following clear-cutting and hot slash burning at the HJ Andrews Experiment Forest in the western Cascades of Oregon were observed in a study by Mersereau and Dyrness (1972). Low magnitude surface sediment transport is likely the result of a combination of forest litter, and vegetation cover on the soil surface, generally low intensity rainfall events, and shallow hillslope gradients leading to short transport distances for soil particles. A painted particle assessment during one sample period from the current study revealed little observable movement of soil particles over a one month period. However, sediment was collected at all trap locations for the same one month period suggesting surface transport occurs on a small spatial scale and that a longer duration painted particle analysis is likely necessary to observe measurable transport from trap locations.

Contrary to some previous studies on the impacts logging on sediment transport regimes, surface sediment transport rates estimated at the Jim's Creek site

showed considerable declines following logging (Figure 5.2). Post-treatment average sediment transport rates were lower at all trap locations except for Box #4. Average surface sediment transport rates (all material) for thinned areas decreased from 983.5 g/m/yr from Adams' (2008) study to 379.8 g/m/yr following thinning activities, a 60% decline. Prior to discussing potential mechanisms for a decline in transport rates, differences in trap locations and the role of the metal apron as causes of differences in transport rates between the two studies will be addressed.

A potential explanation for the differences in surface sediment transport rates between the two studies is a slight alteration in the location of boxes as a result of removal and subsequent replacement of traps post-treatment. A difference in the hillslope gradient at a new trap location could cause a difference in observed transport rates. Locations of boxes 4, 5, 6, 10, and 11, were all shifted following the treatment due to slash coverage or loss of original trap location markers (Adams pers. comm.). Care was taken to replace all boxes, including those displaced by thinning activities, in locations as close as possible to the original pre-treatment locations, however there were differences in measured hillslope gradients (Table 4.1). Despite potential changes in gradient due to shifts in trap locations between the two studies, the relationship between sediment transport and hillslope gradient for both pre- and post-treatment values was shown to be poor. This suggests that other non-static mechanisms such as ground cover and precipitation may have a more important role in soil erosion form the site, and that slight differences in slope are not a significant cause of discrepancies of observed erosion values between the two studies.

Observations during field collections also suggest that the width of the metal apron may have been altered in a few cases due to a failure at the connection points between the apron and the interior of the trap. The volume of sediment transported across the apron would likely vary with apron width due to the influence of rainsplash on the apron surface. Unfortunately, detailed accounts of changes in apron width were not obtained during either study and it is therefore difficult to quantify the effect of these differences between the two studies. However, in the case of systems driven by raindrop splash, such as the Jim's Creek area, the effect of box-apron separation may be minimal since the splash process projects soil particles through the air and the soil

is not transported by water flowing over the surface, which would make it possible for transported soil to fail to enter the box when the aprons are detached.

A comparison of the pre- and post-treatment sediment transport rates suggests that transport rate declined by nearly 60% in areas that underwent thinning activities. One possible mechanism for lower apparent post-treatment sediment transport rates is the lower precipitation in the second study period relative to the first study period. Mean average daily precipitation was higher during Adams' (2008) study, 4.5 mm/d compared to 3.2 mm/d, but the difference in precipitation between the two studies is not statistically significant (t-test $p>0.05$). Maximum daily precipitation during collection periods was higher during the pre-treatment study (average 30.48 mm/d compared to 23.1 mm/d in the current study), but was again not significantly different between the two study periods (t-test $p>0.05$). Wet season average daily precipitation (Oct.-April) was also larger during the pre-treatment study period (Table 5.3), which could be related to higher transport rates observed during the winter months in the pre-treatment analysis. However, precipitation and sediment transport rates do not show significant correlation (Appendix B), suggesting that a difference in measured precipitation was not likely the cause of sediment transport rate declines. Maximum daily precipitation values for each collection period and transport rates estimated for both pre- and post-treatment studies showed poor correlation as well (R^2=0.08 and 0.1 for pre-and- post treatment relationships respectively). These data seem to suggest that differences in precipitation are not the driving mechanism for soil transport declines at the site, which is further supported with the analysis of snow cover from the two study periods.

The duration of snow cover during winter months (September-March) for the pre-treatment study was 66 days compared to the 40 days of snow cover for the first winter of the post-treatment study and 27 total days during the second winter. In the previous study Adams (2008) suggests that anomalous snow cover may have dampened the effect of rain and throughfall splash. Given that splash erosion is likely a dominant transport mechanism at the site (Adams 2008), erosion rates may have been larger during the previous study if the snow cover duration was reduced. This suggests that the difference between pre- and post-treatment erosion rates may have

been more pronounced if the duration of snow cover was closer to values observed in 2009 or 2010. However, no observations were made assessing the effects of thinning on snow cover duration. In future studies it would be useful to make a detailed assessment of the effects of snow on sediment transport and more precise measurement of the duration of snow cover at the Jim's Creek site.

Another possible mechanism for declines in sediment transport rates following thinning activities could be due to a reduction in fog from the forest canopy at the site. Fog drip (the interception of cloud water droplets on vegetative surfaces, which may accumulate and fall to the ground as large throughfall drops (Harr 1982, Swanson pers. comm. 2010) droplet inputs are typically not accounted for in forest hydrology studies because in many locations it is assumed to be insignificant and also precipitation measuring devices are generally not placed under canopy. The elimination of canopy infiltration surfaces due to thinning activities has the potential to reduce water delivery to the soil surface. Harr (1982) found that net precipitation was 17% larger under canopy than in adjacent clearcut areas in the Bull Run watershed near Portland, Oregon, and that this reduced water input to a site may be responsible for observed reductions in water yield following clearcutting. Throughfall from fog drip was shown to be sufficient to both offset interception and evapotranspiration losses from the canopy cover and add to the precipitation occurring in unlogged catchments within the Bull Run watershed (Harr 1982). Recovery of water yield was observed five to six years after the clearcut and was likely due to vegetation recovery and reestablishment of the fog drip throughfall (Ingwersen 1985). However, at the Jim's Creek site, recovery of this water input is unlikely as the establishment of young conifers will not be permitted due protocol outlined in the savanna restoration plan.

Adams (2008) speculated on the potential implications of restoration of oak savanna at the Jim's Creek site and suggested that fog drip and increased formation of throughfall droplets resulting from precipitation may have been higher under the higher canopy cover before thinning, resulting in greater drop splash soil erosion before thinning. The larger droplet size of canopy throughfall has been shown to have 1.5 times greater kinetic energy than that of rainfall drops (Mosley 1982).

Therefore, the change in erosion by drop splash after 90% removal of canopy cover may be disproportionately greater than the effects of fog/cloud water interception on total water input to the site. Although changes in droplet size distributions were not directly observed at Jim's Creek, substantial declines in sediment transport following canopy removal may be the result of a decline in fog drip and throughfall splash erosion at the site.

6.2 SEASONALITY AND CHARACTER OF SEDIMENT TRANSPORT

6.2.1 Shifts in Transport Mechanisms

Transport rates were shown to be highly variable seasonally and among trap locations during the two study periods. The highest pre-treatment transport rates coincided with wet season rain events, and were likely a result of rain- and through fall-drop splash. Evidence of rill erosion was present only along roads within the study area and was not observed at trap locations at any point. Similar to Adams (2008) study sediment was found deposited on the roof and inside walls of traps at the site, indicating rainsplash activity. Standing water was found inside traps on a few occasions (Table 4.2). This was probably caused by rainfall impact directly on the sheet metal apron of the trap that then flows into the box. On several occasions, animal tracks (likely deer or elk) were found in close proximity to the trap openings, suggesting that biogenic activity is common at the site and may represent an important mechanism for soil transport. Observations by Adams (2008) and the present study at the Jim's Creek site suggest that the dominant mechanisms of sediment transport are rainsplash, dry ravel and biogenic activities. Adams (2008) postulates that larger diameter (> 2mm) mineral particles collected in traps are likely the result of biogenic or dry ravel activity, while smaller particle sizes may be associated with rainsplash. Root throw and small shallow mass movements may also occur on the site, but were not sampled systematically in Adams (2008) or this study.

There is some indication that the timing of peak surface sediment transport into traps at the Jim's Creek site may have shifted from the winter in Adams' (2008) pre-treatment study to the summer in the present study (Appendix A). However, due to a

lack of pre-treatment data from the later summer months a change in peak transport seasonality is speculative. Pre-treatment transport rates were likely influenced largely by rainsplash and to a lesser extent by dry ravel and other mechanisms such as treethrow and biogenic activities. Evidence supporting this is derived both from the occurrence of peak transport during the rainy season, as well as the dominance of fine materials (averaged ~61% of collected samples) in samples collected prior to thinning (Adams 2008).

Following the thinning, peak sediment transport rates at most box locations were observed during the summers (dry season) of 2009 and 2010. Differences in dry season precipitation, especially between 2008 and 2010, may explain some of this shift, as average precipitation was higher during the summer (May-June) of 2010 than in 2008 (Table 5.3). However, peak soil transport was also observed during the dry season in 2009, which had lower average precipitation in comparison to 2008 (Table 5.3). This seems to indicate that additional changes in transport mechanisms may have occurred. The potential shift in the seasonality of surface sediment transport could also suggest that dominant transport mechanisms have changed following the thinning activities. The occurrence of peak transport during the dry season may be related to increased soil transport by dry ravel. This is also supported by a significant (t-test $p > 0.05$) reduction in the averaged proportion of fine (<2mm) rain-splash derived material, from 61% to 49% following thinning activities. Dry ravel can be initiated by a variety of phenomena, but is commonly initiated as a result of biogenic activity or the removal of vegetation (Gabet 2003), both of which have occurred at the study site. Again, it should be noted that there were no pre-treatment observations of sediment transport rates for July and August, so dry ravel derived sediment transport may not have been completely accounted for in the pre-treatment data. Also, dry ravel is more common on steep semi-arid slopes (Gabet 2003) which approach or exceed the angle of repose. Slopes measured at trap locations are shallower than these values, therefore other transport mechanisms are likely more prominent.

High rates of transport due to dry ravel were seen in a study following clearcut logging and hot slash burning in a steep watershed in the western Cascades at the HJ Andrews Experimental Forest (Mersereau and Dryness 1972). Observed sediment

transport was considerably higher during the summer dry season. Soil loss was also shown to be 380% greater on south facing compared to north facing slopes (Mersereau and Dryness 1972). However, slopes in the Mersereau and Dyrness (1972) study were much steep than those measured at the Jim's Creek site. The aspect of the Jim's Creek site is primarily south and southwest, suggesting that with the removal of the canopy, soils may receive more insolation. A transition to drier conditions on these slopes caused by increased insolation could lead to dry ravel becoming a more dominant mechanism of surface sediment transport, as post-treatment data collected from the sediment traps seems to indicate.

6.3.2 Transported Sediment Character Over Time

The composition of samples collected at trap locations varied between study periods, but seemed to follow trends similar to total sediment transport in most cases. The average proportion of fine grained mineral and organic sediment as well as coarse mineral material decreased following thinning activities. Contrary to the observed trends in the other sample fractions, transport rates of coarse organic materials increased post-treatment. This increase in transported organics may be a result of thinning activities at the site. Following initial harvesting activities, photos taken from each trap location reveal large amounts of slash left after logging. The highest proportion of coarse organics in the samples occurred during the fall of 2009, following the more intensive stages of harvesting.

Quantitative assessments of cover vegetation were not performed at the study site due to time constraints. However, a semi-quantitative analysis from photos taken at trap locations (Table 5.3) revealed similar results to those obtained by Adams (2008). Soil transport rates for all materials were highest for traps with consistent bare soil exposure while lower transport rates were associated with significant moss, litter, and herbaceous vegetation cover. Increases in herbaceous cover could be seen during the first growing season after thinning at non-control trap locations, but did not have an apparent impact of transport rates.

6.4 INFLUENCE OF PRECIPITATION AND GRADIENT

Observed pre-treatment surface sediment transport rates seemed to correspond with the precipitation regime. Highest rates of sediment transport tended to occur during the wettest collection periods (Adams 2008). Despite the apparent relationship, linear regression of both normalized and non-normalized precipitation data and sediment transport values during each sampling period of both the previous and current study revealed no significant correlations. This may suggest that other mechanisms are operating in addition to precipitation to transport surface materials at this site. Adams (2008) suggested that dry ravel and biogenic activities might play an important role in surface transport as well. However, both studies have a small sample size and precipitation and snow cover are highly variable both spatial and temporally.

Total and average precipitation between the two studies was not significantly different, making it difficult to attribute changes in transport rates to variability in precipitation. However, the duration of snow cover was much longer in Adams' (2008) study which may have had a dampening effect on rainsplash, thereby reducing soil transport during the previous study (Table 5.3). The paucity of snow cover during the winter seasons of 2009 and 2010, coupled with lower average wet season precipitation than the pre-treatment study suggest that precipitation may explain only part of the post-treatment decline in transport.

Linear regression analysis of the correlation between gradient and sediment transport reveals no significant correlation for pre- or post-treatment soil transport. Poor correlation suggests that sediment transport is not solely a slope dependent process at the Jim's Creek site. Variability of transport rates both between boxes and between the two study periods suggests that microscale transport controls may have important implications for surface sediment movement (Morris and Moses 1987).

6.5 SIMULATED SEDIMENT TRANSPORT AT JIM'S CREEK

Simulated sediment transport using the non-linear diffusion equation from Roering et al. (1999) produced values of the same order of magnitude as observed transport rates from the site. In general the observed variability in sediment transport between trap locations was poorly resolved by simulated outputs. The non-linear

diffusion model was originally derived in an effort to model hillslope profiles, which in steep soil mantled landscapes were poorly predicted by linear transport equations (Roering et al. 1999). The model seeks to predict hillslope evolution and therefore accounts for processes influencing this evolution including surface transport via rainsplash and biogenic activity, as well as, processes such as soil creep or landsliding. While landsliding and soil creep may be occurring at the site, these processes were not accounted for in the pre- or post-treatment studies at Jim's Creek, which limits the applicability of the model in this case.

Hillslope transport processes on a whole may follow the non-linear slope dependent equation from Roering et al (1999), but surface soil erosion from the Jim's Creek site is not well reproduced by the model. This may also be due to the model assumption that transport rates are dependent on slope. Data from the two study periods show no significant correlation between slope gradient and sediment transport rates. Given the influence of other micro-scale variability (vegetation cover, surface roughness, duff thickness, etc.), it would be difficult to apply this model without first quantifying these variables. The potential to apply this model could likely be improved with an increase in the number of sample locations and a higher resolution terrain model, such as a LiDAR generated DEM, as well as further quantification of transport processes not accounted for such as creep or landslide activity. This would allow slope input values to better capture small scale variability at the site and may help illuminate the role of processes that were not quantified in the present study.

The web-based WEPP GIS generated outputs assuming a forested watershed were two to three orders of magnitude larger than observed values from both studies. Interestingly, forested model transport rates for the watershed where the control boxes 7 and 8 are located were the lowest, which is consistent with observed rates. Bare soil WEPP model output also simulated the highest transport rates in the watershed containing boxes 3, 4, and 9 which is consistent with observations from the site. Soil data from the USDA (2010) Soil Resource Inventory GIS data layer shows that the least stable soils in the project area occur in the area around boxes 3, 4, and 9, while the control boxes 7 and 8 are located on relatively stable soils. However, modeled results are over-predicted in all cases, as was seen in Adams' (2008) study. This is

especially apparent when cover classification was changed from forest to fallow (bare soil) to simulate a clearcut.

Outputs generated using a fallow (bare soil) land cover classification produced sediment transport rates as much as three orders of magnitude larger than observed values. Adams (2008) found the simulated transport from the Disturbed WEPP model, a slightly different version than what is used in this study, produced transport estimates that were almost 25 times larger than observed values. WEPP assumes that overland flow and interrill and rill erosion processes are operating on the modeled hillslope (Flanagan and Nearing 1995). These processes are rarely observed in the Pacific Northwest due to high soil infiltration rates and may only occur in highly disturbed sites. Over-prediction of sediment transport may be due to these incorrect assumptions about the processes operating. These processes have been observed only along road surfaces at the Jim's Creek site and not around sediment trap locations.

7. CONCLUSIONS

Observed transport rates from both studies are low in magnitude, but are comparable to similar studies on moderate slopes without hot prescribed fire in forested watersheds in the western Cascades. This suggests that both pre- and post-treatment litter and vegetation cover play a significant roll in reducing erosion from such sites as suggested by Adams (2008). Coupled with low intensity rainfall and relatively shallow hillslope gradients, transport rates remained low following the thinning activities at the site. Average observed surface sediment transport rate estimates from both treated and control sediment trap locations at the Jim's Creek site declined following thinning activities. The decrease in transported materials is not well explained by differences in the precipitation regime, as estimated from the Railroad Overpass SNOTEL site. No significant differences were found between pre- and post-treatment values of average daily precipitation or average maximum daily precipitation. Post-harvesting studies in other Pacific Northwest sites have shown declines in water yield from the clear-cut sites due to a loss of fog drip inputs from the canopy structure (Harr 1982). This process may be responsible for observed declines

in transport rates at Jim's Creek; however, to verify this hypothesis, additional monitoring of precipitation and throughfall in thinned, completely open, and full-canopy control areas would be necessary.

Peaks in sediment transport may have shifted from the wet season during the pre-treatment study to the dry summer months following thinning activities. A change in seasonality could indicate an alteration of the dominant sediment transport mechanism at the site. With increases in solar insolation due to a thinner canopy, dry ravel may have a larger for surface sediment transport at the site. This observation is supported by a significant decrease in fine grained sediment transport associated largely with rainsplash following thinning activities. However, the pre-treatment study did not sample into the later summer months; therefore, despite the consistency of peaks in sediment transport during the dry season in the post-treatment study and an apparent winter peak in soil erosion in the pre-treatment study a change in seasonality following thinning activities at the site is speculative.

Sediment transport was poorly correlated with precipitation and gradient for both the previous and the present study. This may indicate that other variables operating on relatively small spatial scales are important in determining surface sediment transport rates. Adams (2008) suggests that ground cover vegetation seemed to be an important control of transport. Observations of Adams (2008) suggesting that trap locations with bare soil typically experience the highest rates of soil transport were confirmed during the present study. Semi-quantitative analysis of photos also revealed that sites with large amount of moss, herbaceous and litter cover had the lowest estimated soil transport rates.

Modeled sediment transport rates using a non-linear diffusion model (Roering 1999, Eq. 2) did not do well in reproducing observed surface transport rates. This may be due to the fact that the model accounts for processes that were not assessed in this study, such as, soil creep and landsliding. This suggests that if finer scale elevation data could be acquired and additional processes operating to cause hillslope evolution at the site were better quantified, the Roering (1999) model could be a more viable option.

The WEPP model greatly over estimated transport rates in all cases, similar to results from Adams (2008). Results using a forested land cover classification produced values two to three orders of magnitude larger than observed results. WEPP output from the bare earth land cover classification produced sediment transport rates up to four orders of magnitude larger than observed rates. Over-prediction of transport rates is likely related to model assumptions regarding rill and interrill transport mechanisms, which do not occur at the Jim's Creek site away from road surfaces. For this reason, the WEPP model may not be applicable in landscapes similar to Jim's Creek with high infiltration rates and low precipitation intensity.

Results from Adams (2008) and the current study suggest that surface sediment transport has not increased as a result of thinning activities at the site. Generally, surface sediment movement measured at box locations is highly variable and has, on average, decreased compared to observations by Adams (2008). Data collected during the present study may indicate that dry ravel has a more significant role in sediment transport at the site in comparison to observations from the pre-treatment study. This shift may be related to the combined thinning effects of reduction of throughfall drop splash and increased insolation to the predominantly south-facing slopes at the site. This study suggests that the initial processes in this type of savanna restoration project may cause only minor shifts in surface sediment transport regimes, if low impact management techniques similar to those used at Jim's Creek are utilized.

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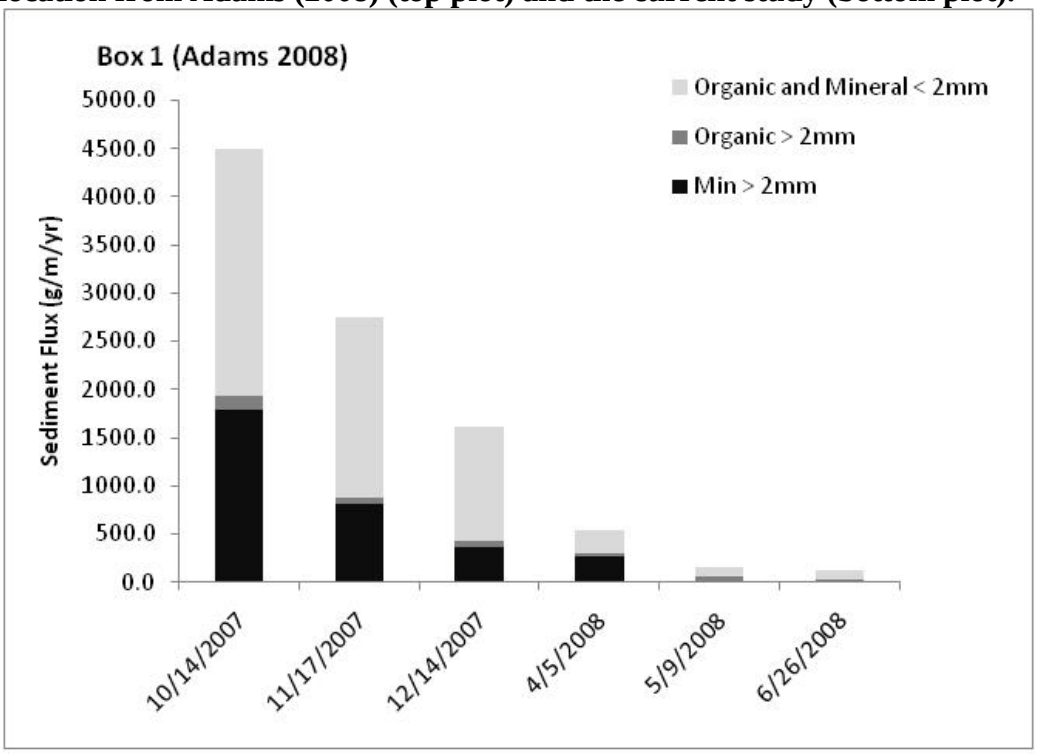
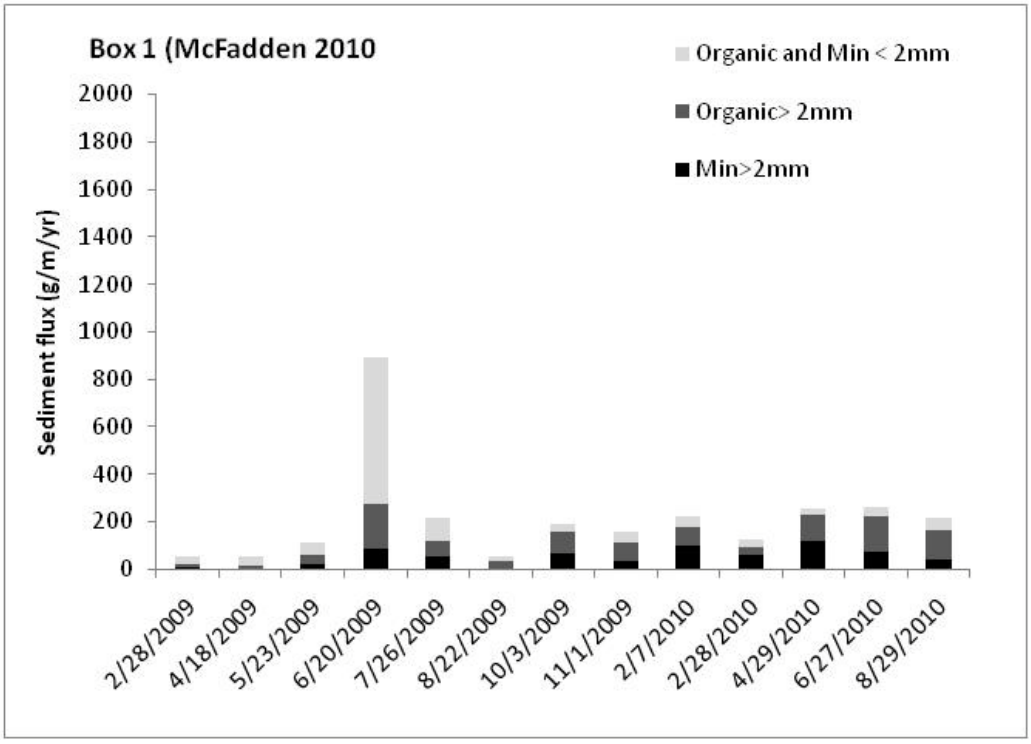
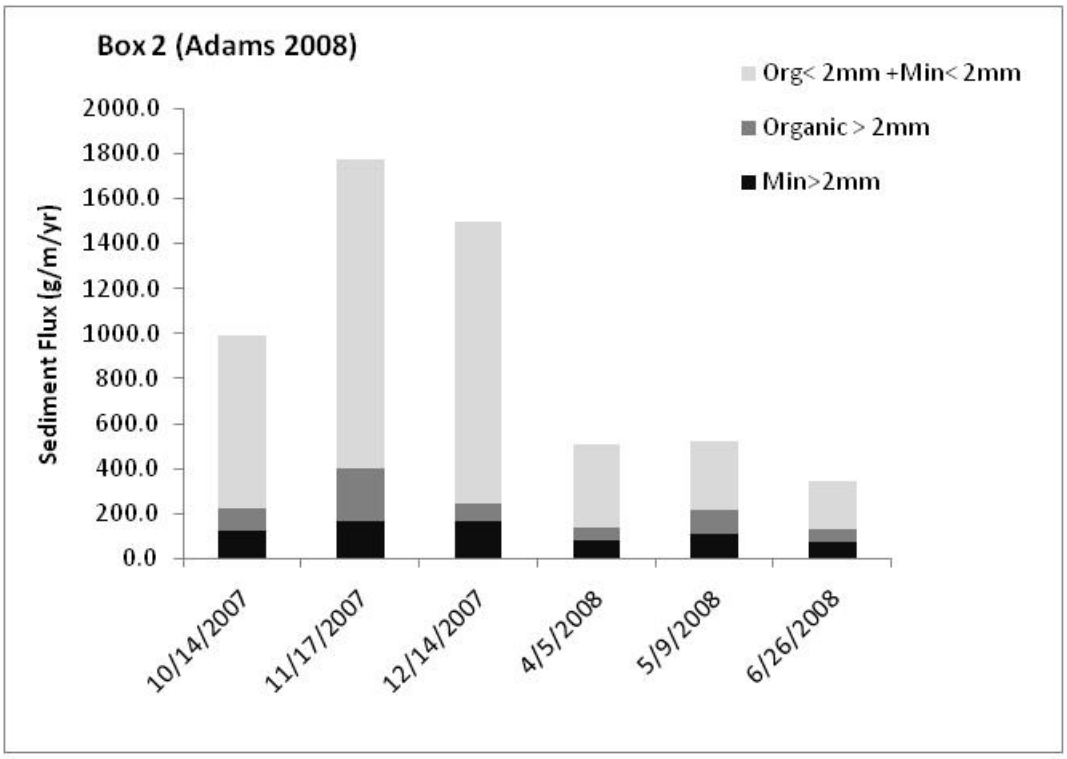
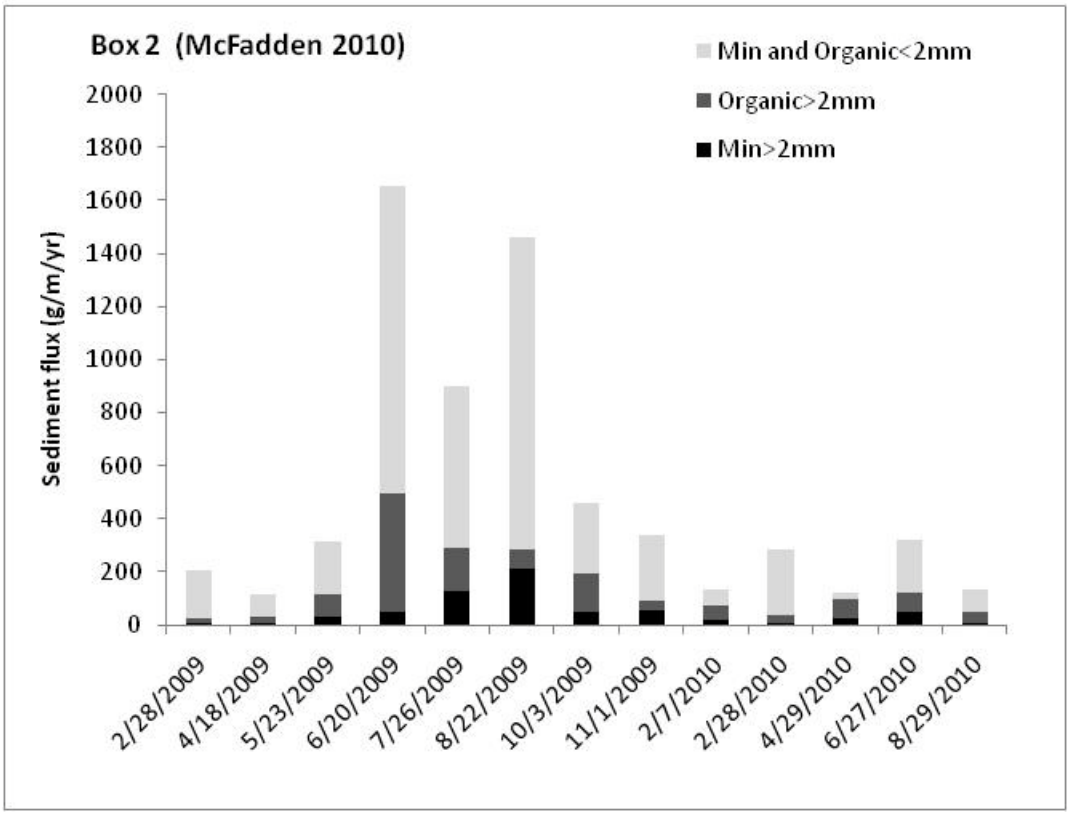
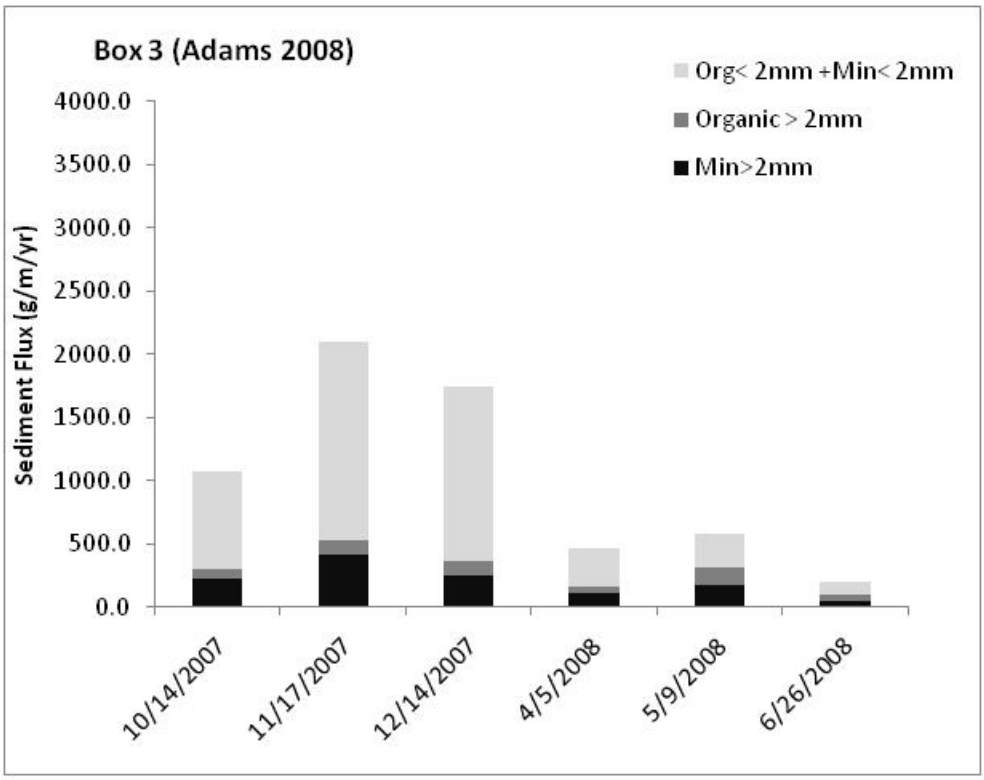
Appendix A. Seasonality and proportion of different size fractions at each trap location from Adams (2008) (top plot) and the current study (bottom plot).

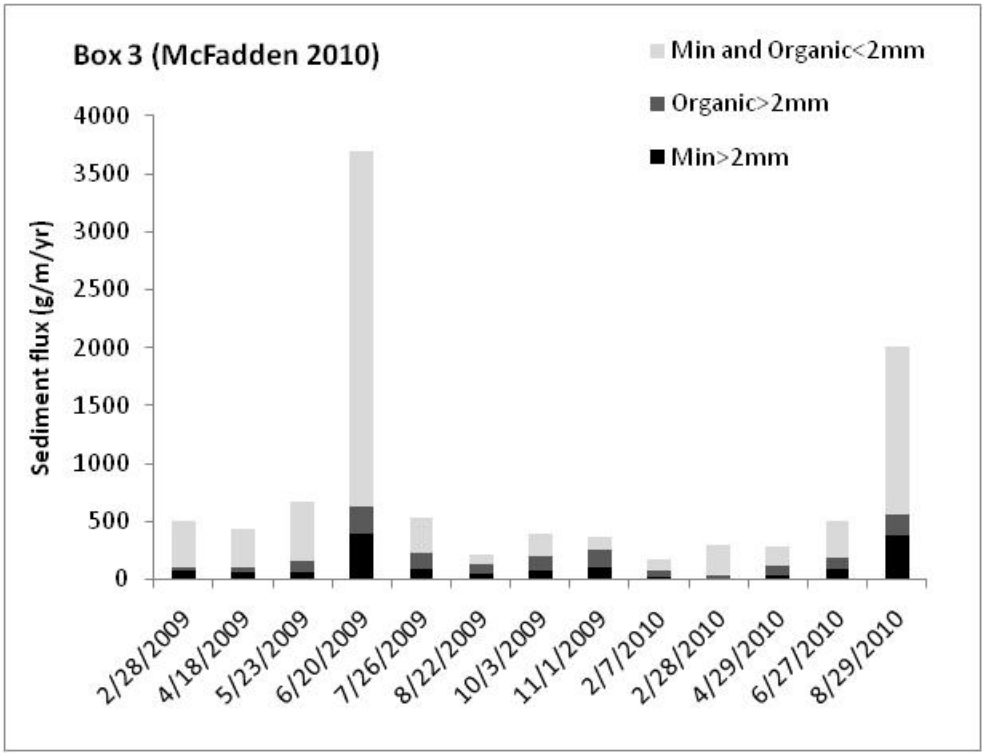


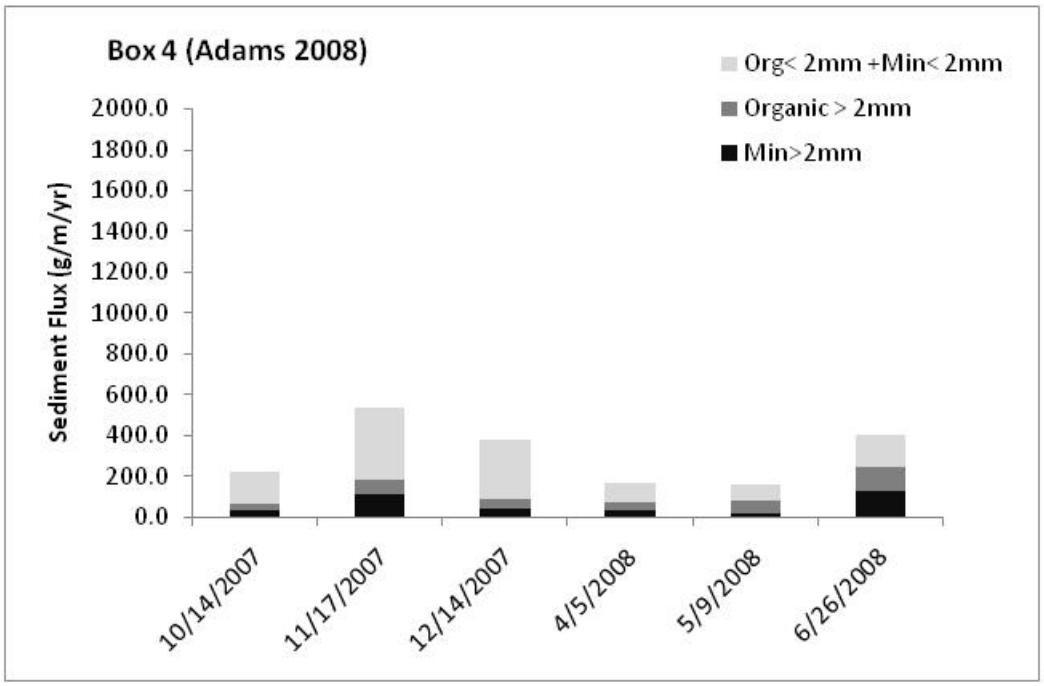



Box 2 (Adams 2008)
Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008


Box 2 (McFadden 2010)
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010


Box 3 (Adams 2008)
Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008


Box 3 (McFadden 2010)
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
4000
3500
3000
2500
2000
1500
1000
500
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010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Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
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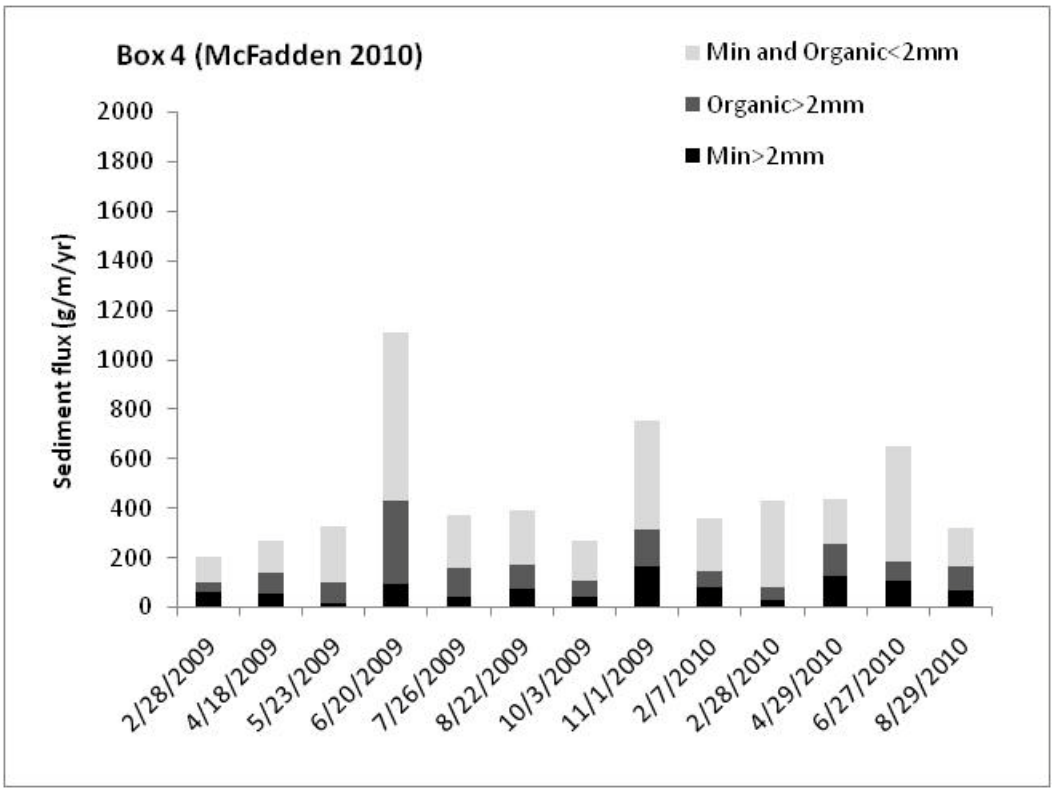
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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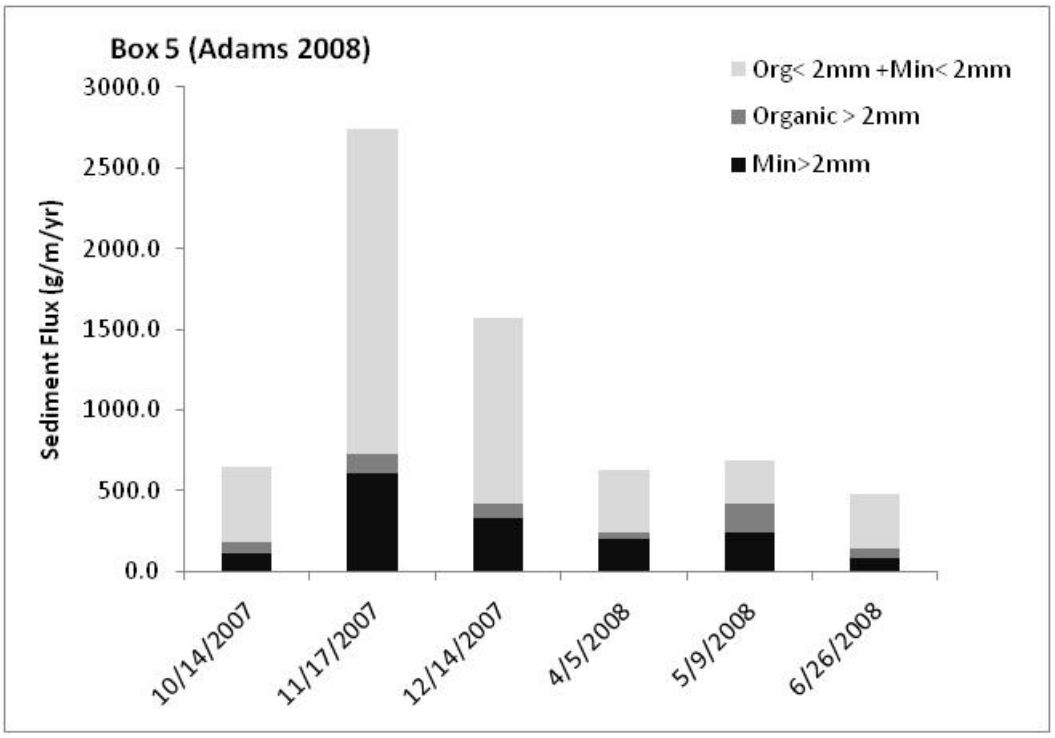
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010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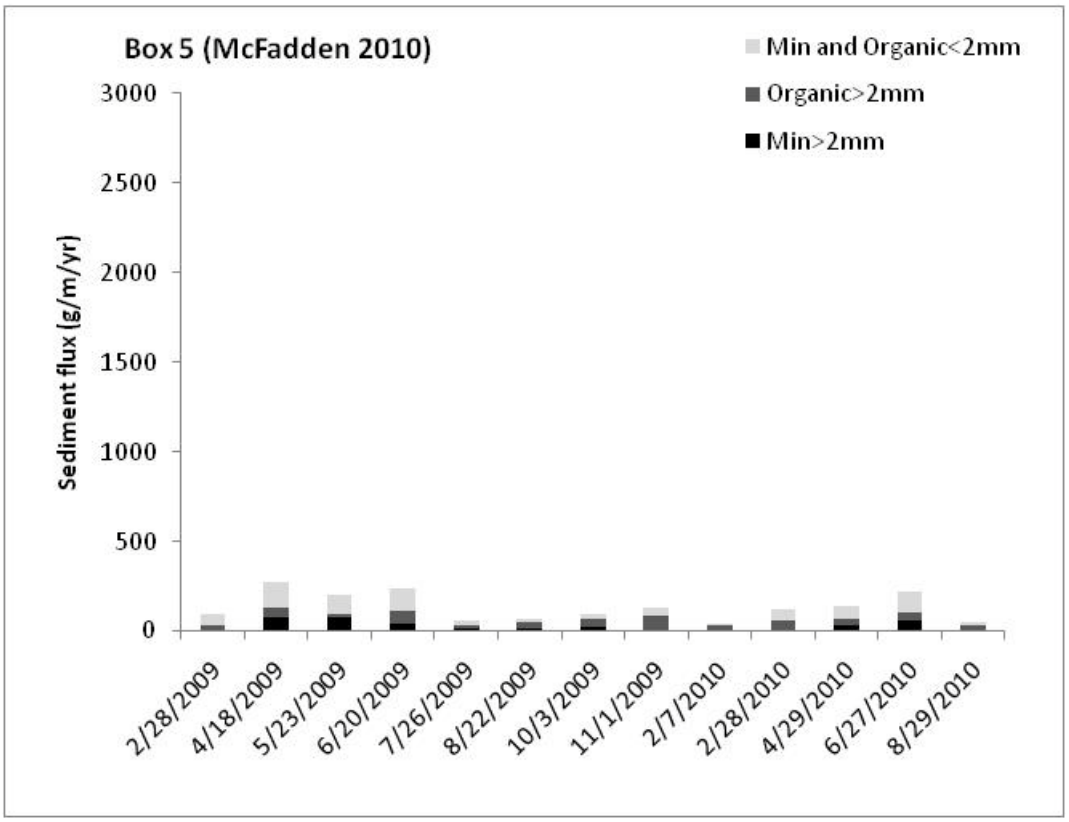
Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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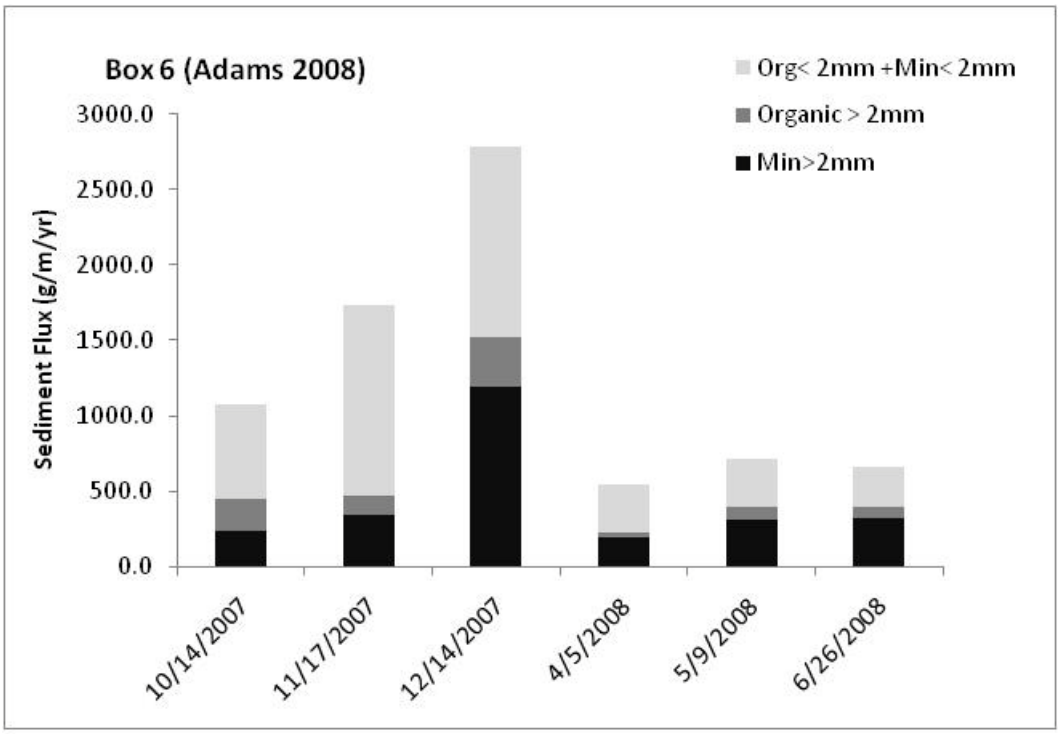
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
3000
2500
2000
1500
1000
500
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010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Min>2mm
Sediment Flux (g/m/yr)
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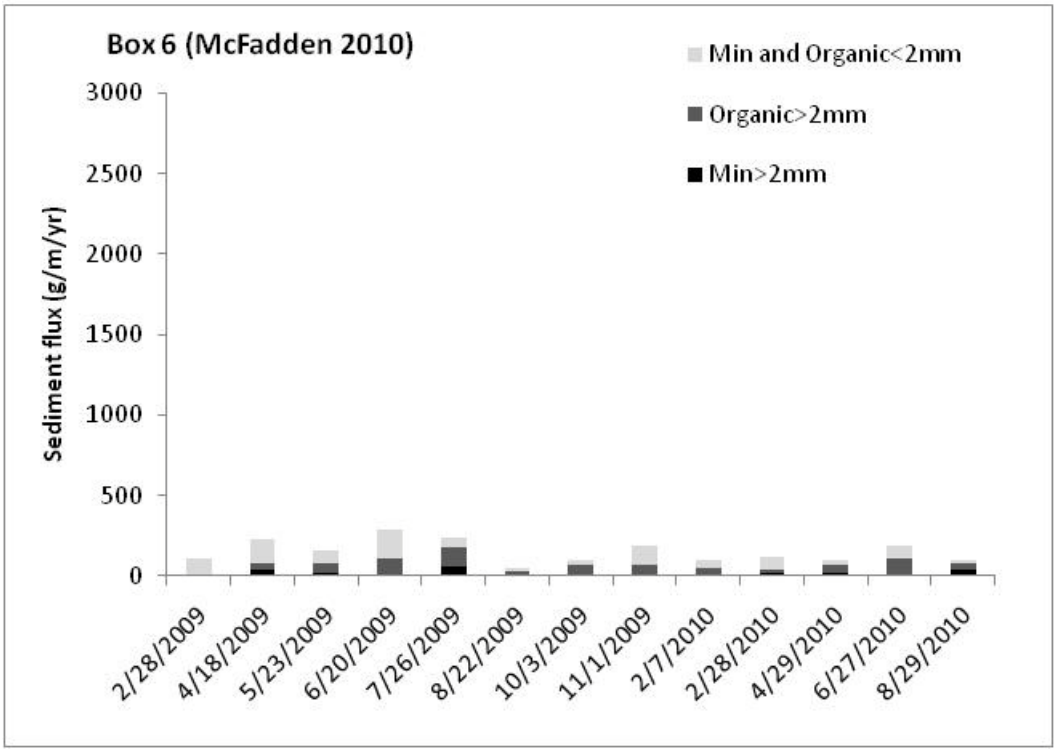
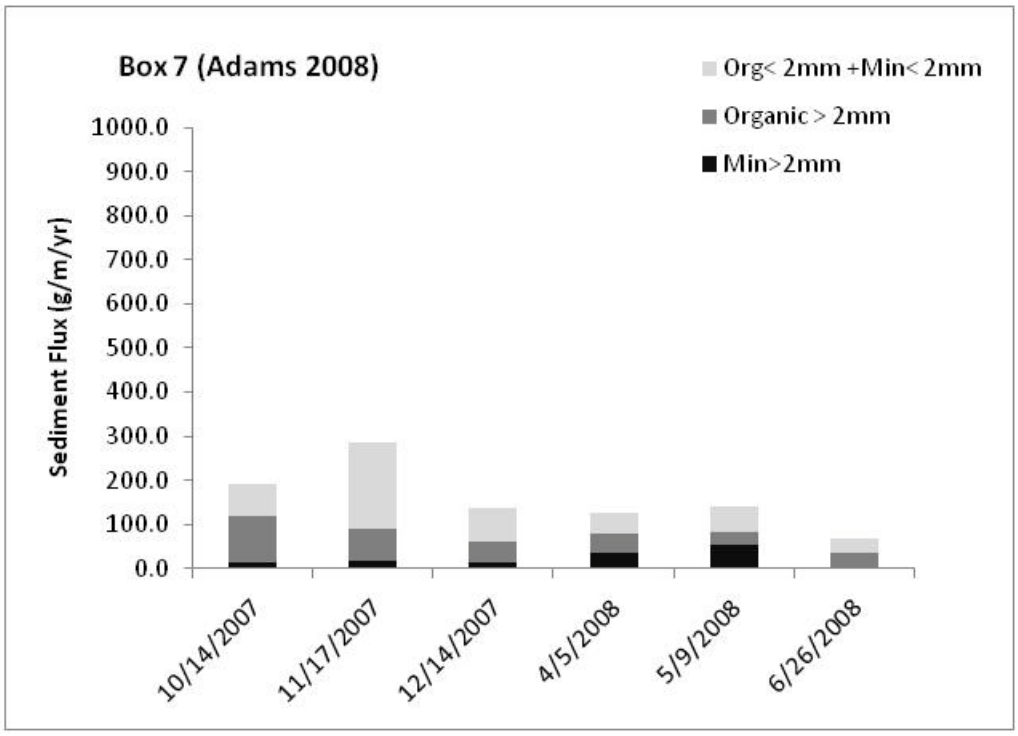
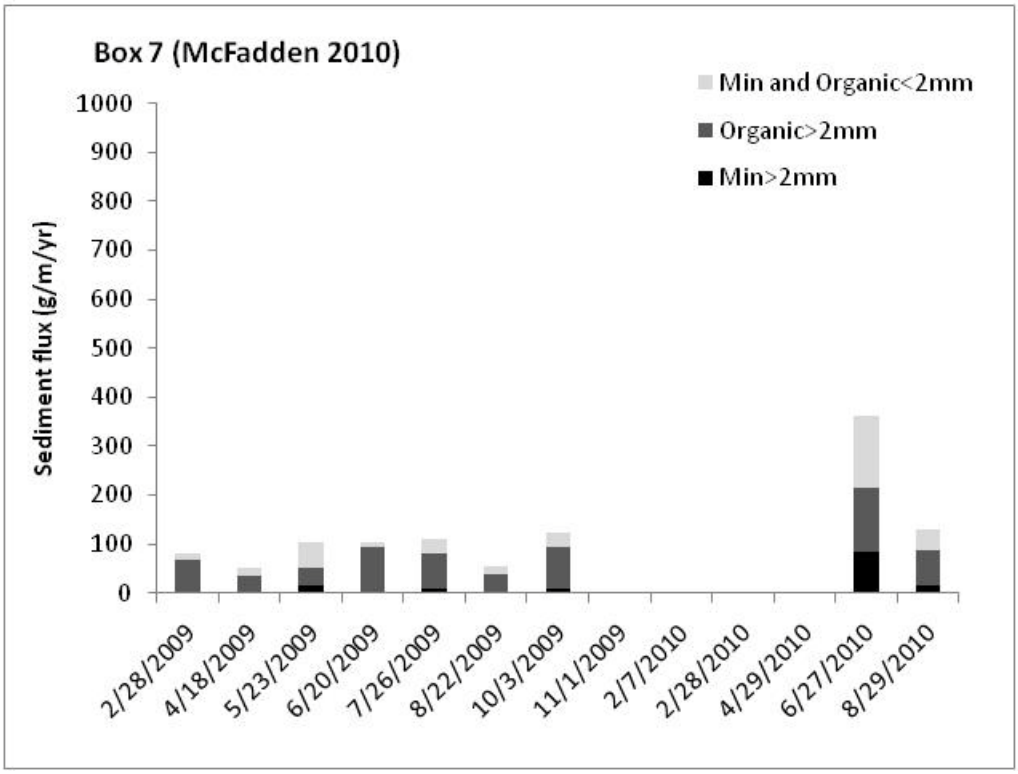
2500.0
2000.0
1500.0
1000.0
500.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008


Box 6 (McFadden 2010)
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
3000
2500
2000
1500
1000
500
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010


Box 7 (Adams 2008)
Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
1000
900
800
700
600
500
400
300
200
100
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
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2/7/2010
2/28/2010
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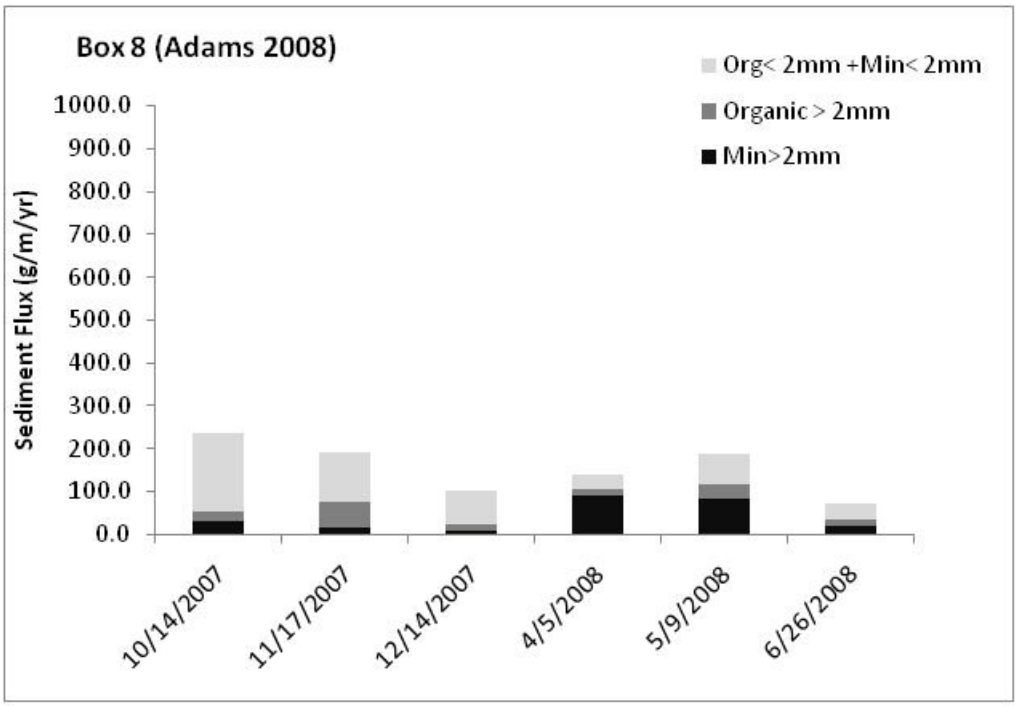
8/29/2010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Min>2mm
Sediment Flux (g/m/yr)
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900.0
800.0
700.0
600.0
500.0
400.0
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100.0
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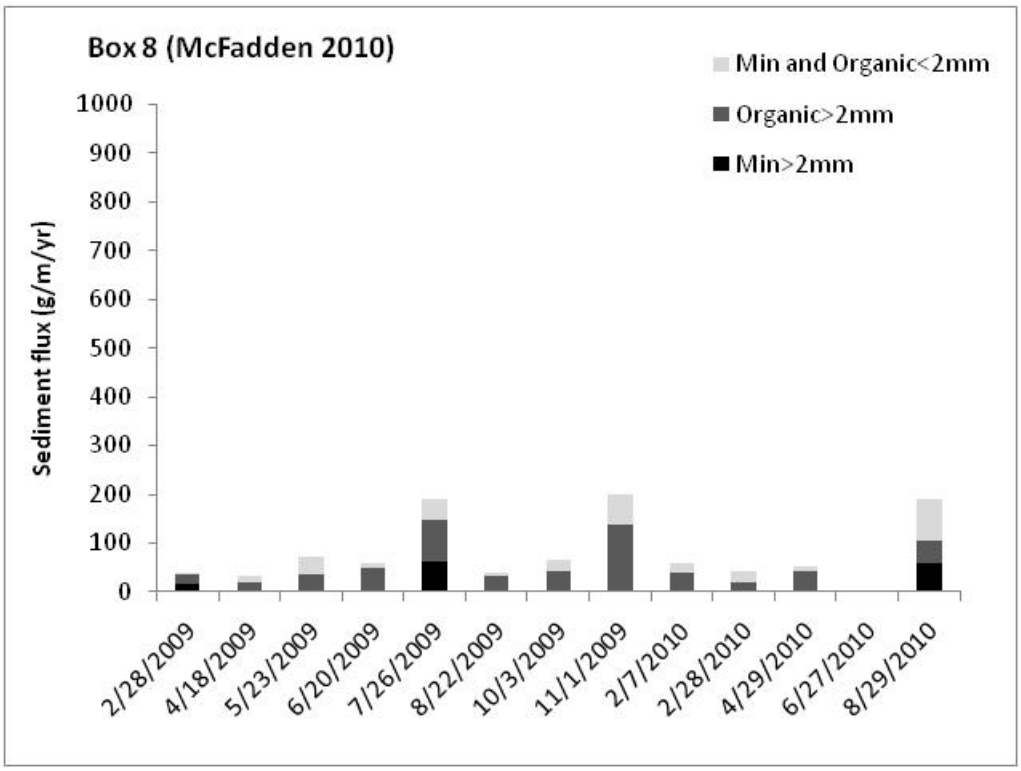
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
1000
900
800
700
600
500
400
300
200
100
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
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10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
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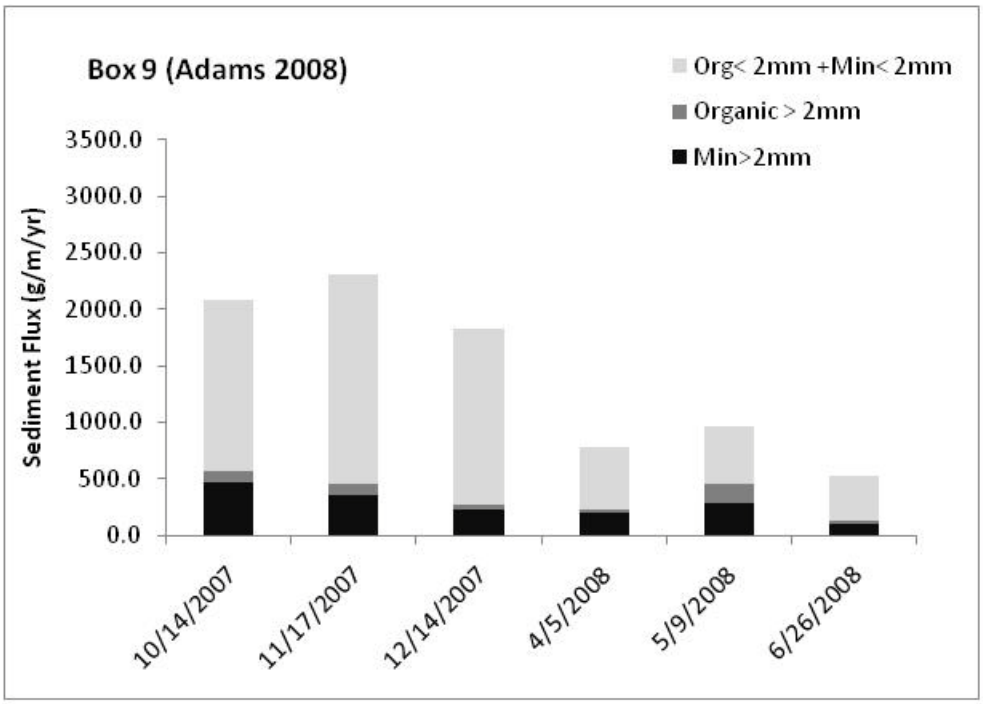
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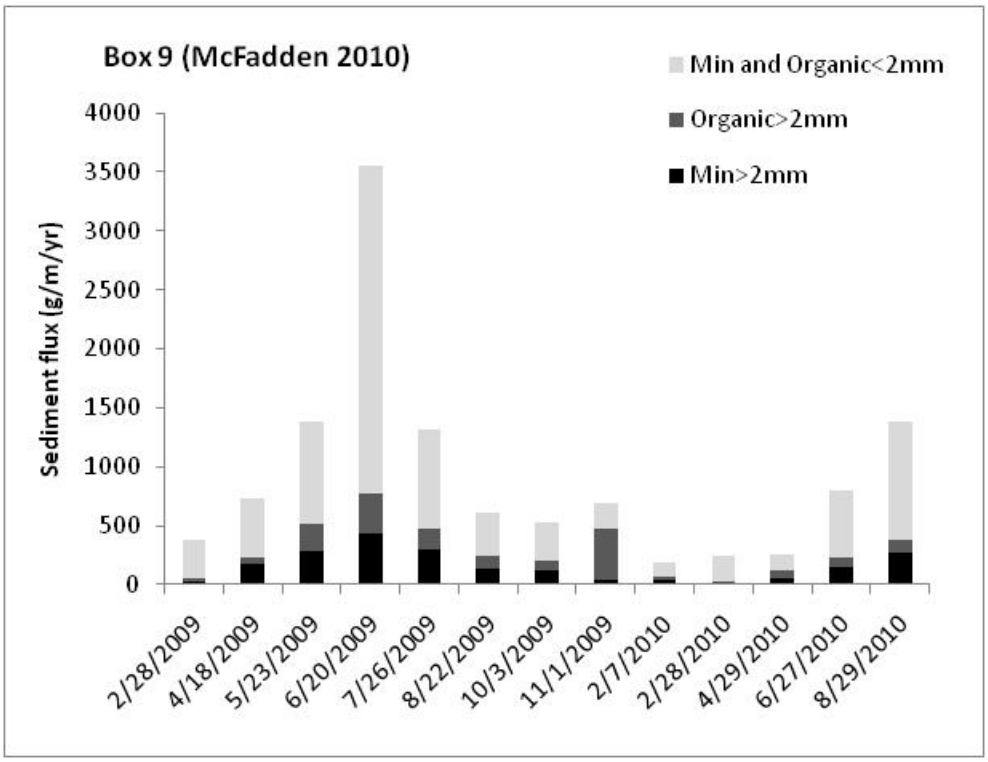
Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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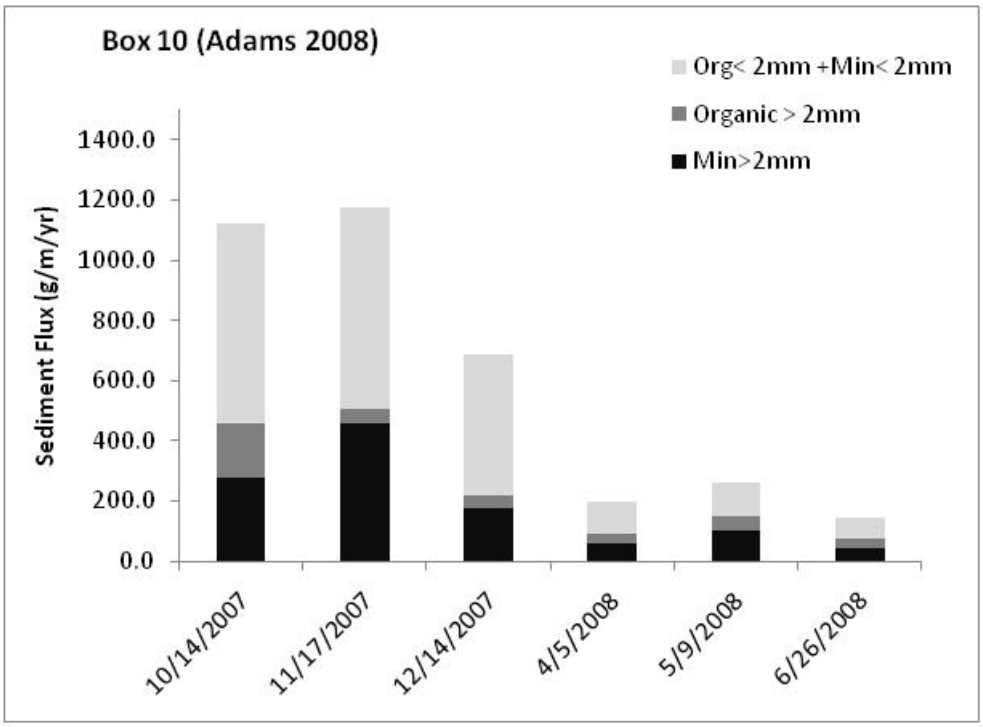
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
4000
3500
3000
2500
2000
1500
1000
500
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010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Org< 2mm +Min< 2mm
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Min>2mm
Sediment Flux (g/m/yr)
1400.0
1200.0
1000.0
800.0
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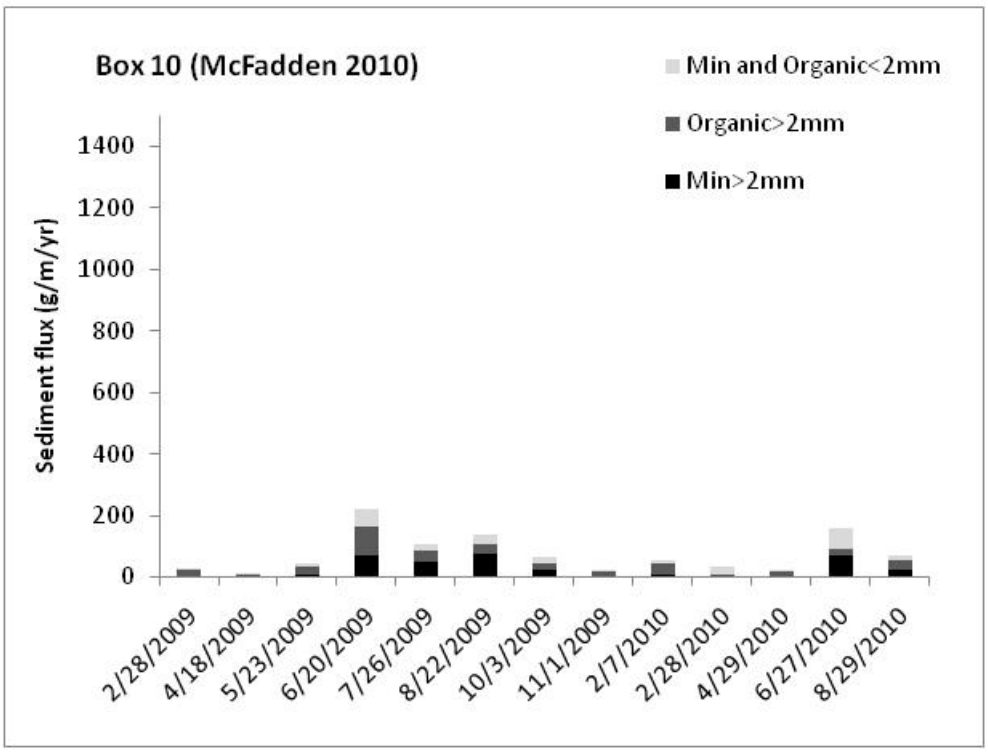
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
1400
1200
1000
800
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2/28/2009
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6/20/2009
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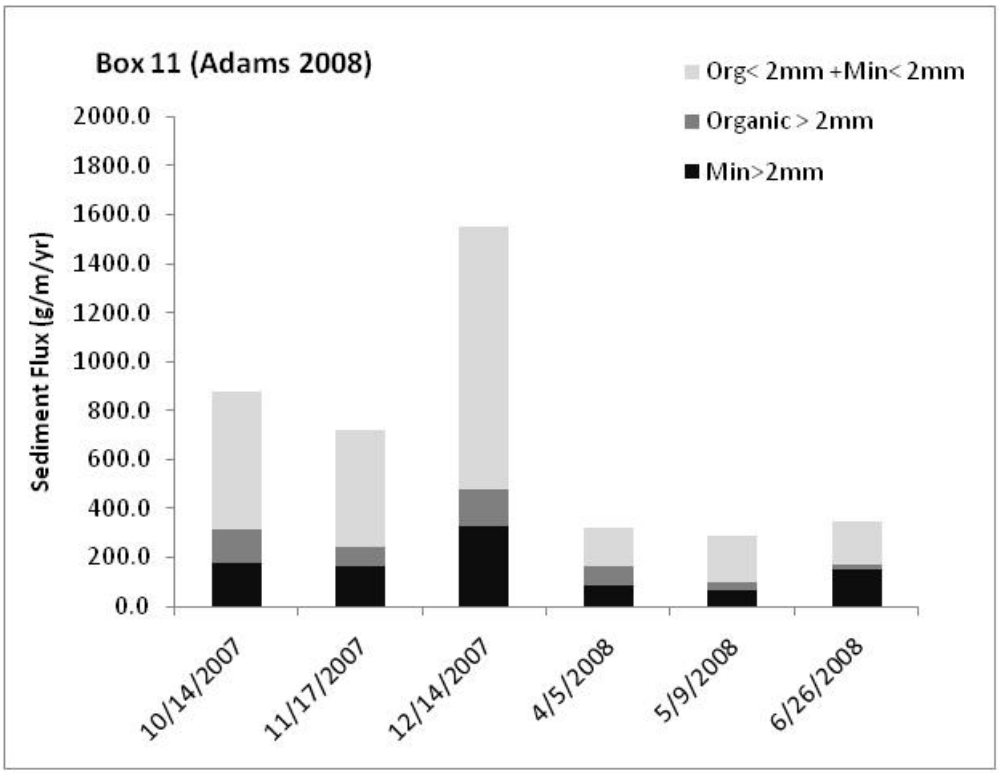
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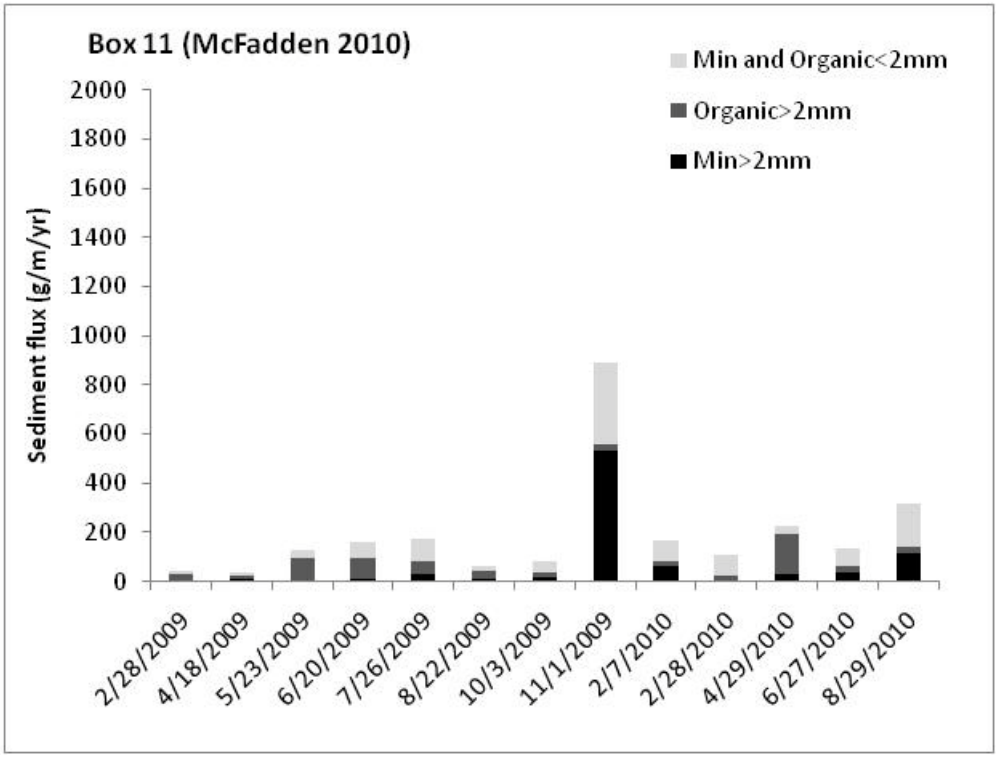
Org< 2mm +Min< 2mm
Organic > 2mm
Min>2mm
Sediment Flux (g/m/yr)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008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Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
2000
1800
1600
1400
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600
400
200
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2/28/2009
4/18/2009
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6/20/2009
7/26/2009
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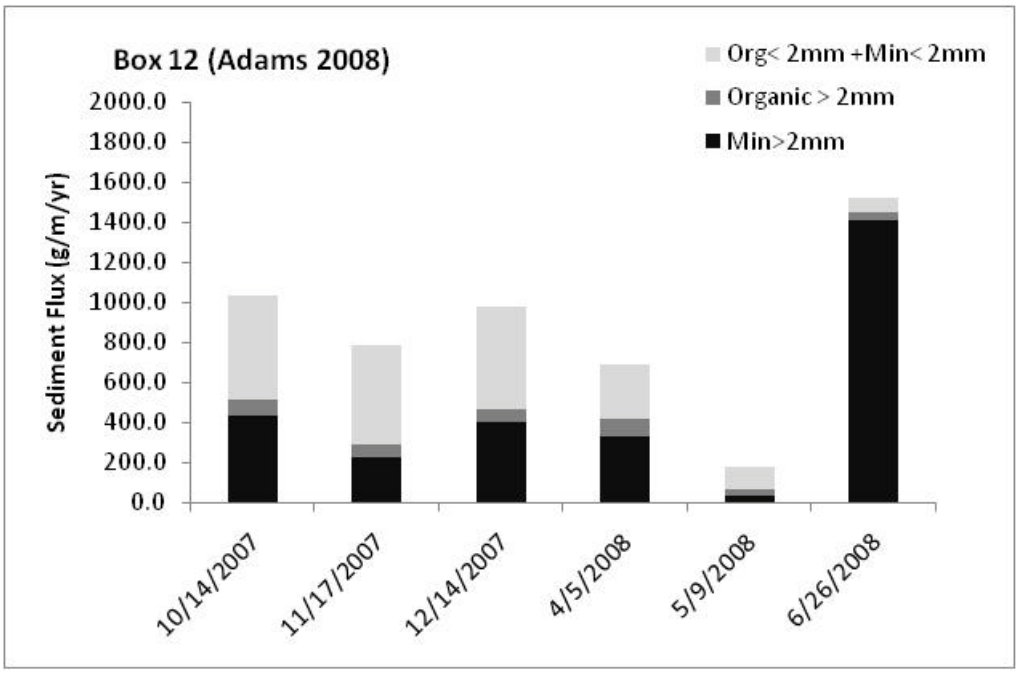
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Min>2mm
Sediment Flux (g/m/yr)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
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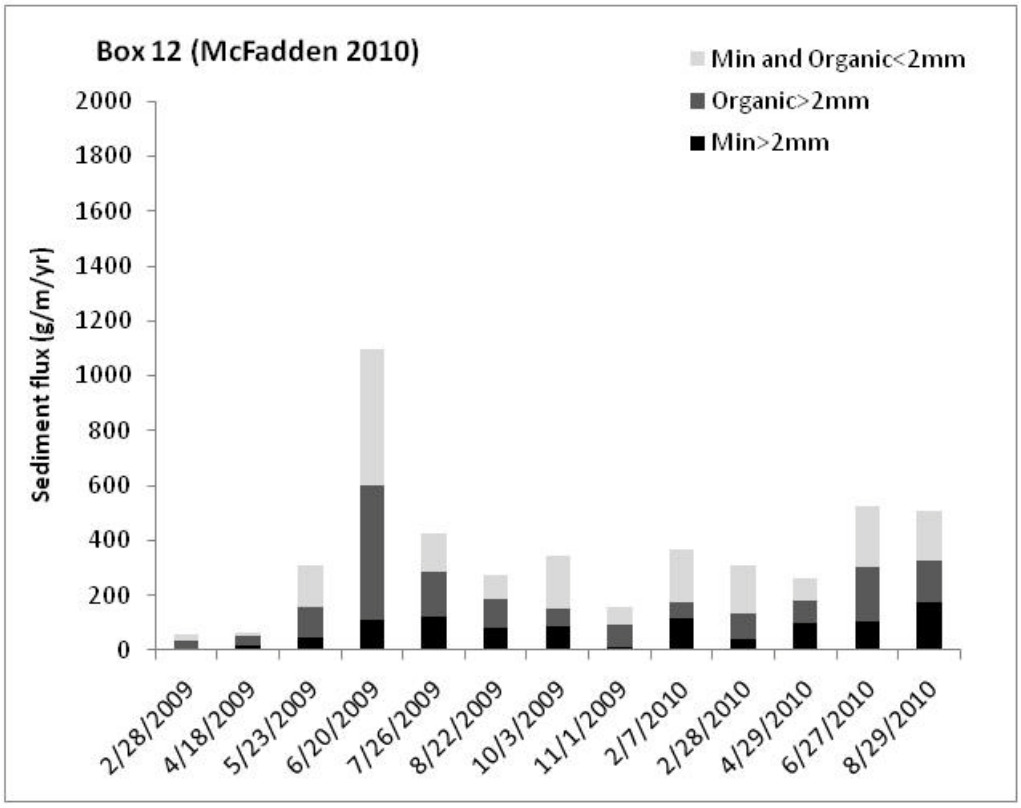
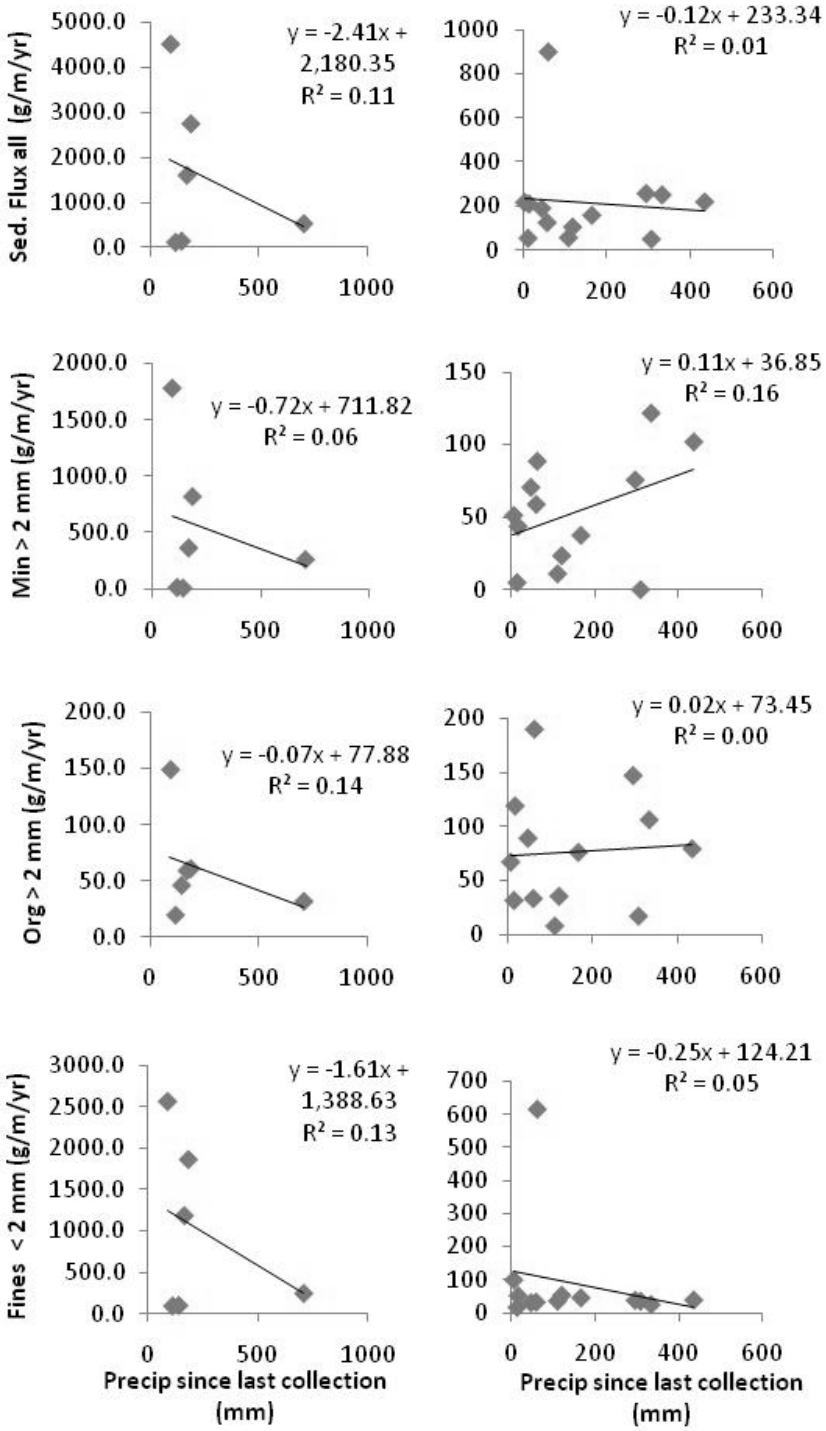
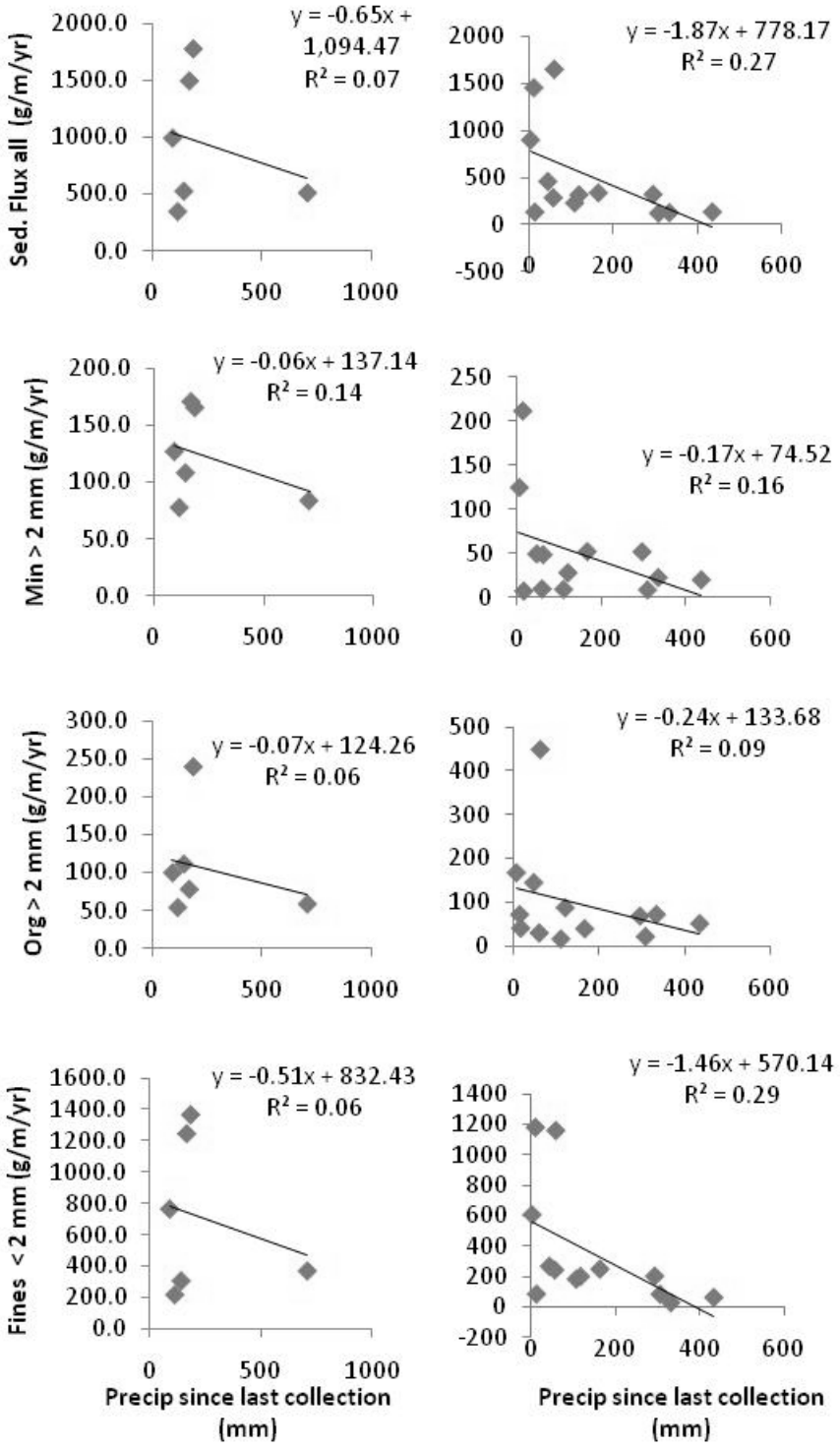
400.0
200.0
0.0
10/14/2007
11/17/2007
12/14/2007
4/5/2008
5/9/2008
6/26/2008


Box 12 (McFadden 2010)
Min and Organic<2mm
Organic>2mm
Min>2mm
Sediment flux (g/m/yr)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2/28/2009
4/18/2009
5/23/2009
6/20/2009
7/26/2009
8/22/2009
10/3/2009
11/1/2009
2/7/2010
2/28/2010
4/29/2010
6/27/2010
8/29/2010

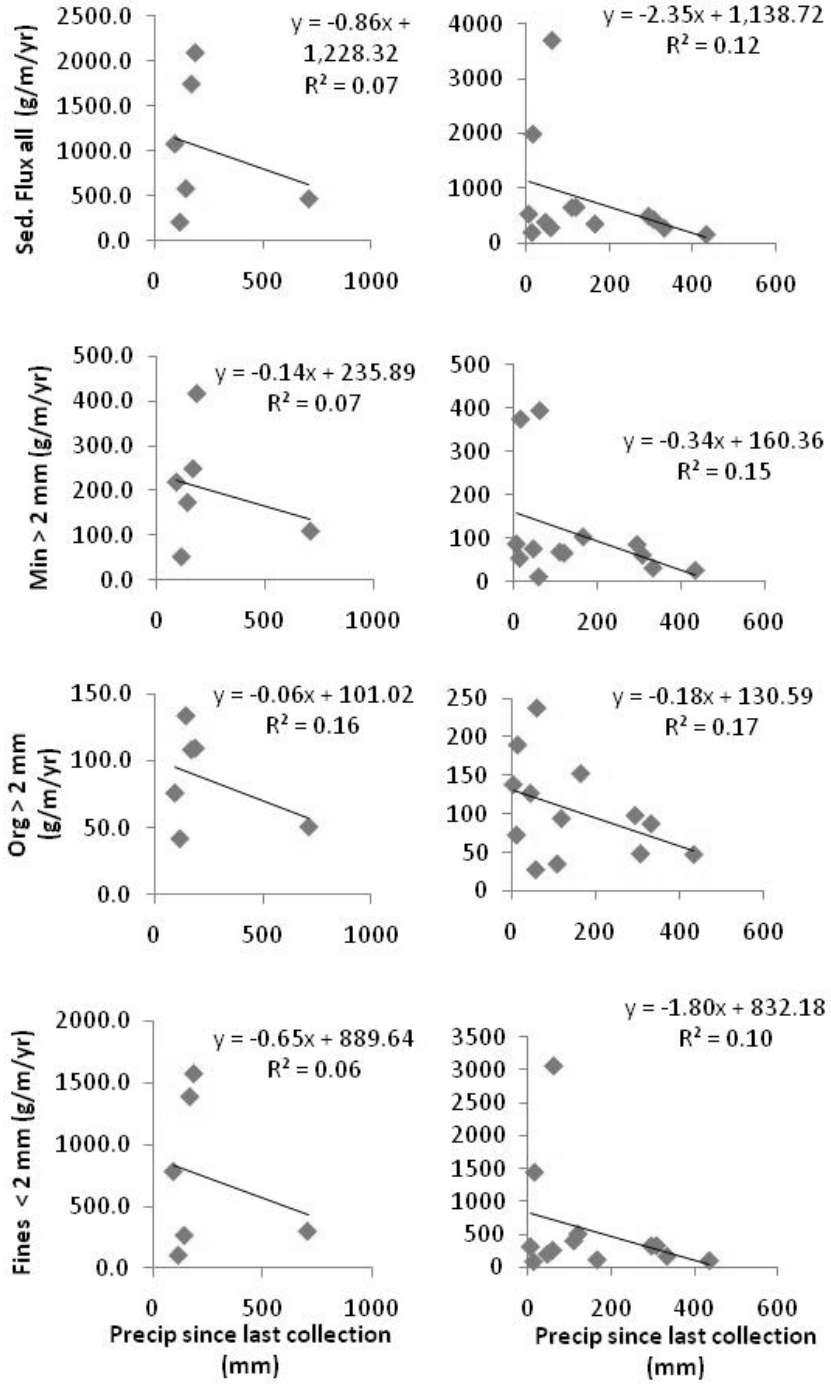
Appendix B. Non-Normalized Precipitation and Sediment Transport Plots at each trap location for pre-and-post treatment sediment transport rates. Normalized Plot can be found following plots of non-normalized data.



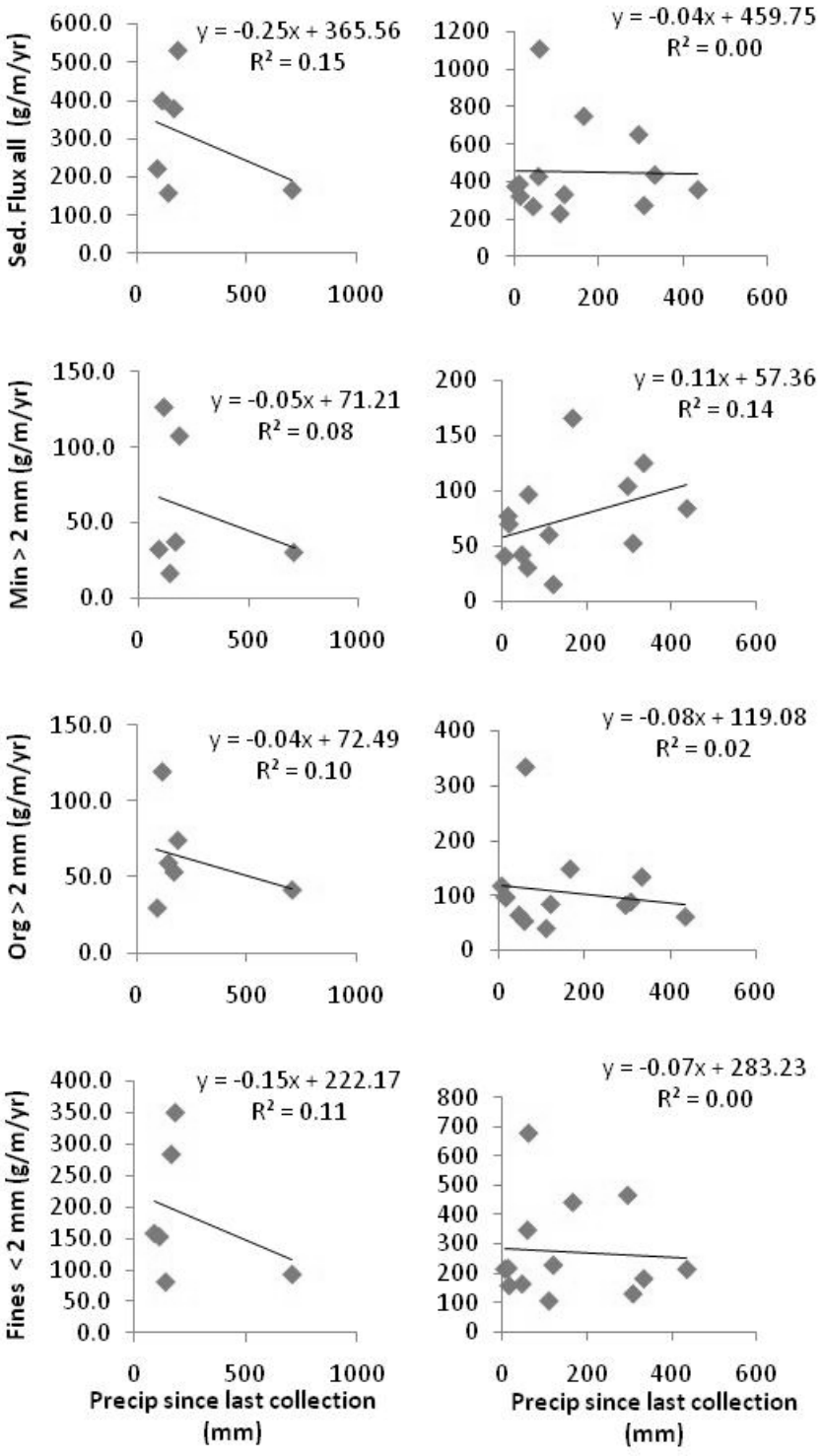
Box #1 Left Column: Adams (2008) data. Right Column: McFadden (2010)



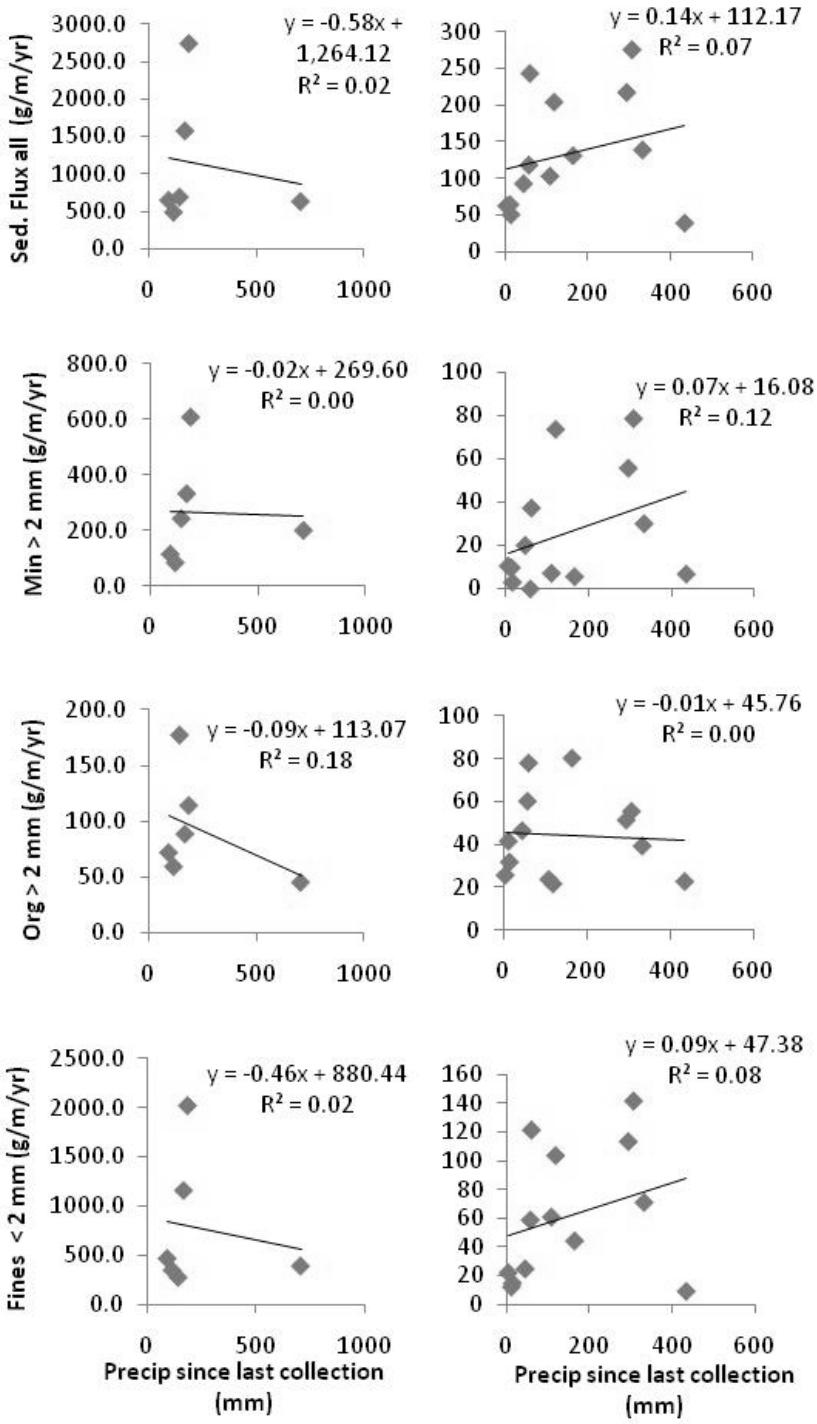
Box #2 Left Column: Adams (2008) data. Right Column: McFadden (2010)



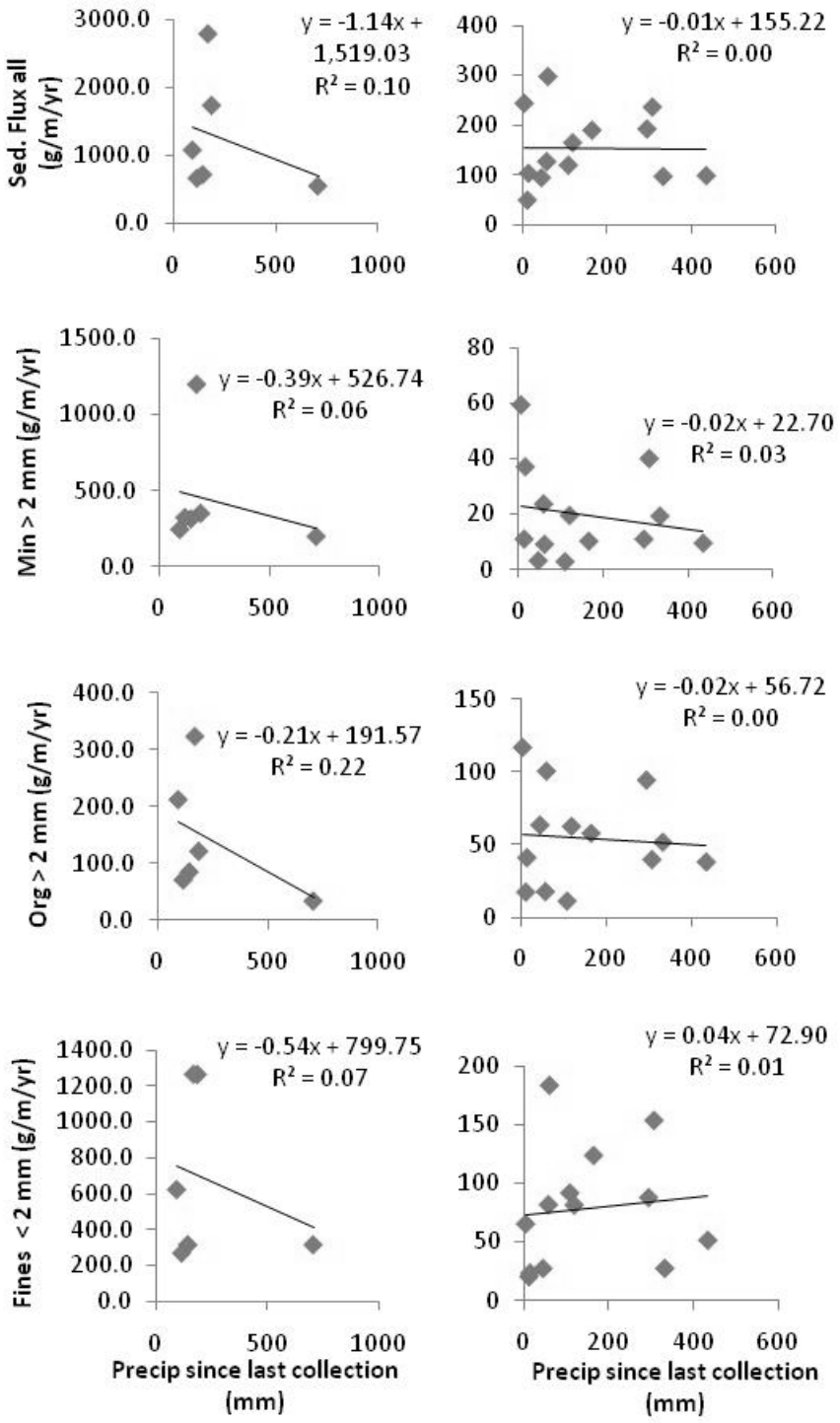
Box #3 Left Column: Adams (2008) data. Right Column: McFadden (2010)



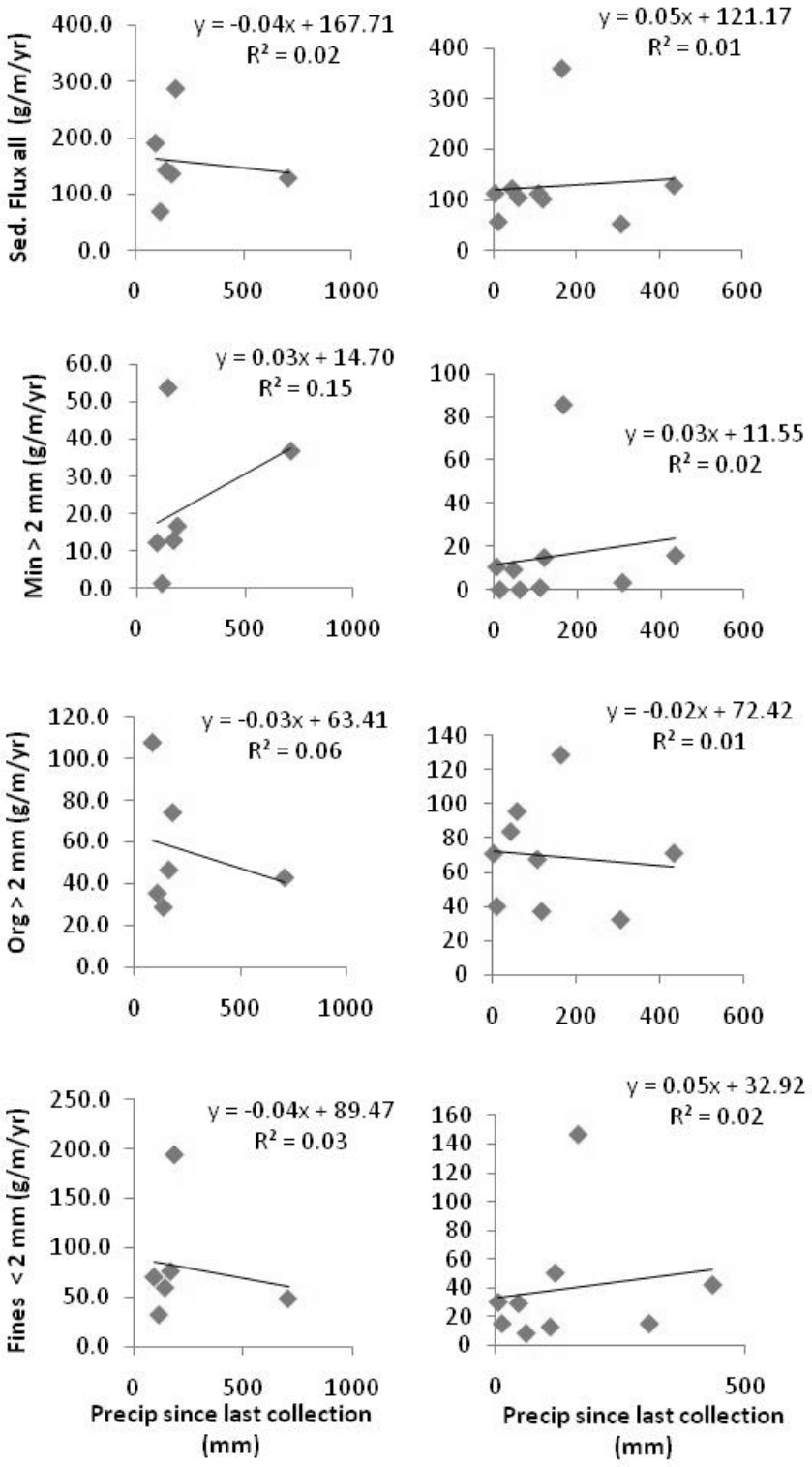
Box #4 Left Column: Adams (2008) data. Right Column: McFadden (2010)



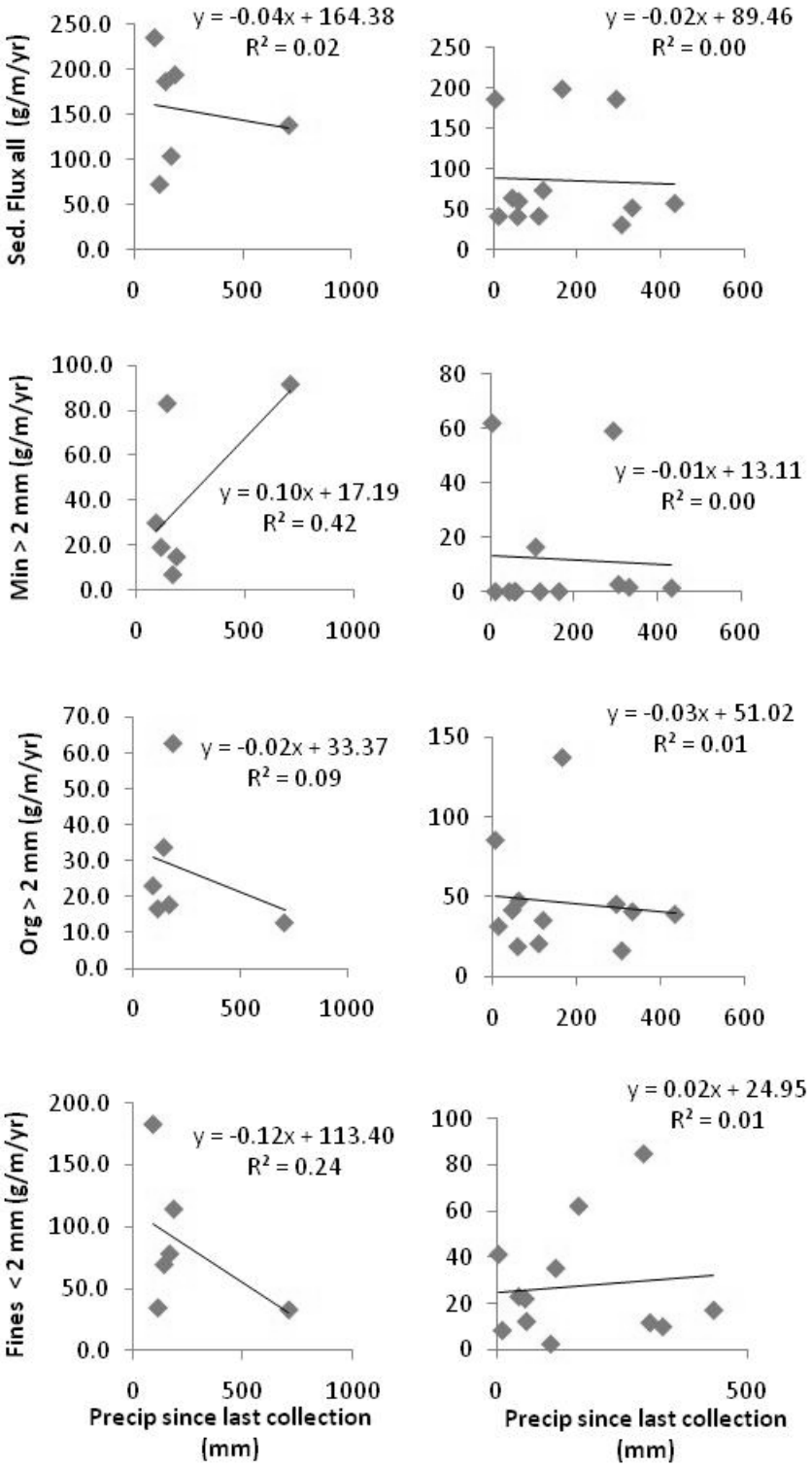
Box #5 Left Column: Adams (2008) data. Right Column: McFadden (2010)



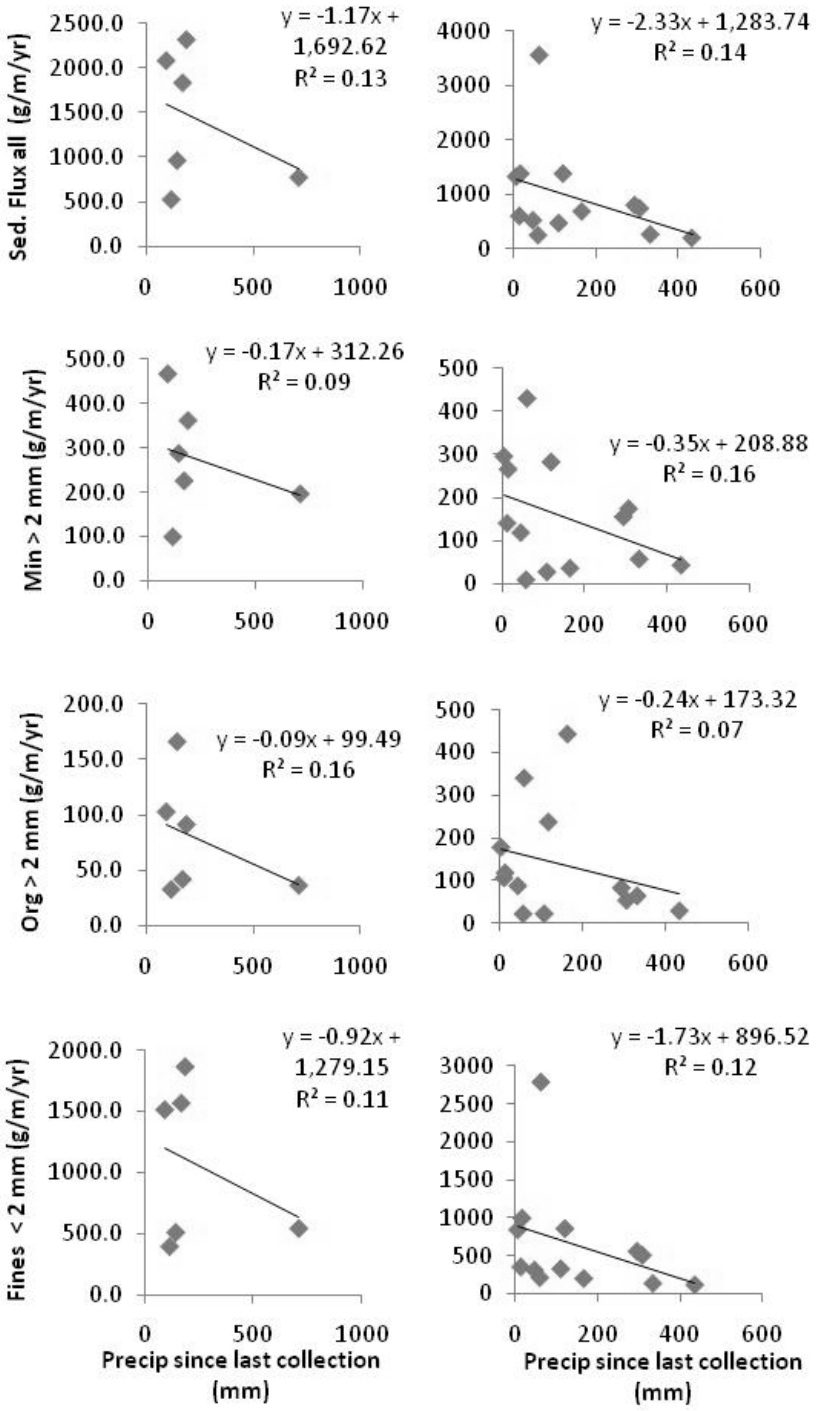
Box #6 Left Column: Adams (2008) data. Right Column: McFadden (2010)



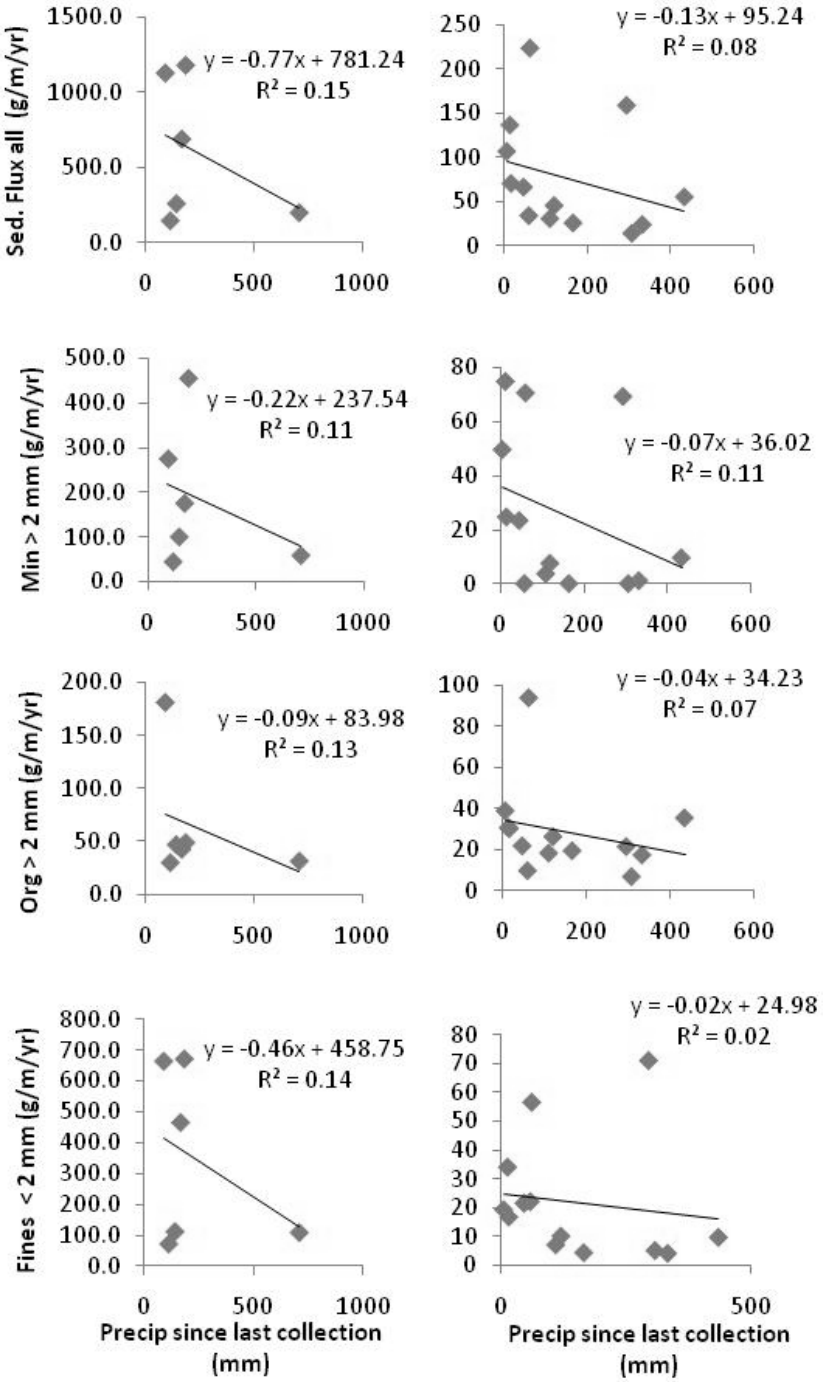
Box #7 Left Column: Adams (2008) data. Right Column: McFadden (2010)



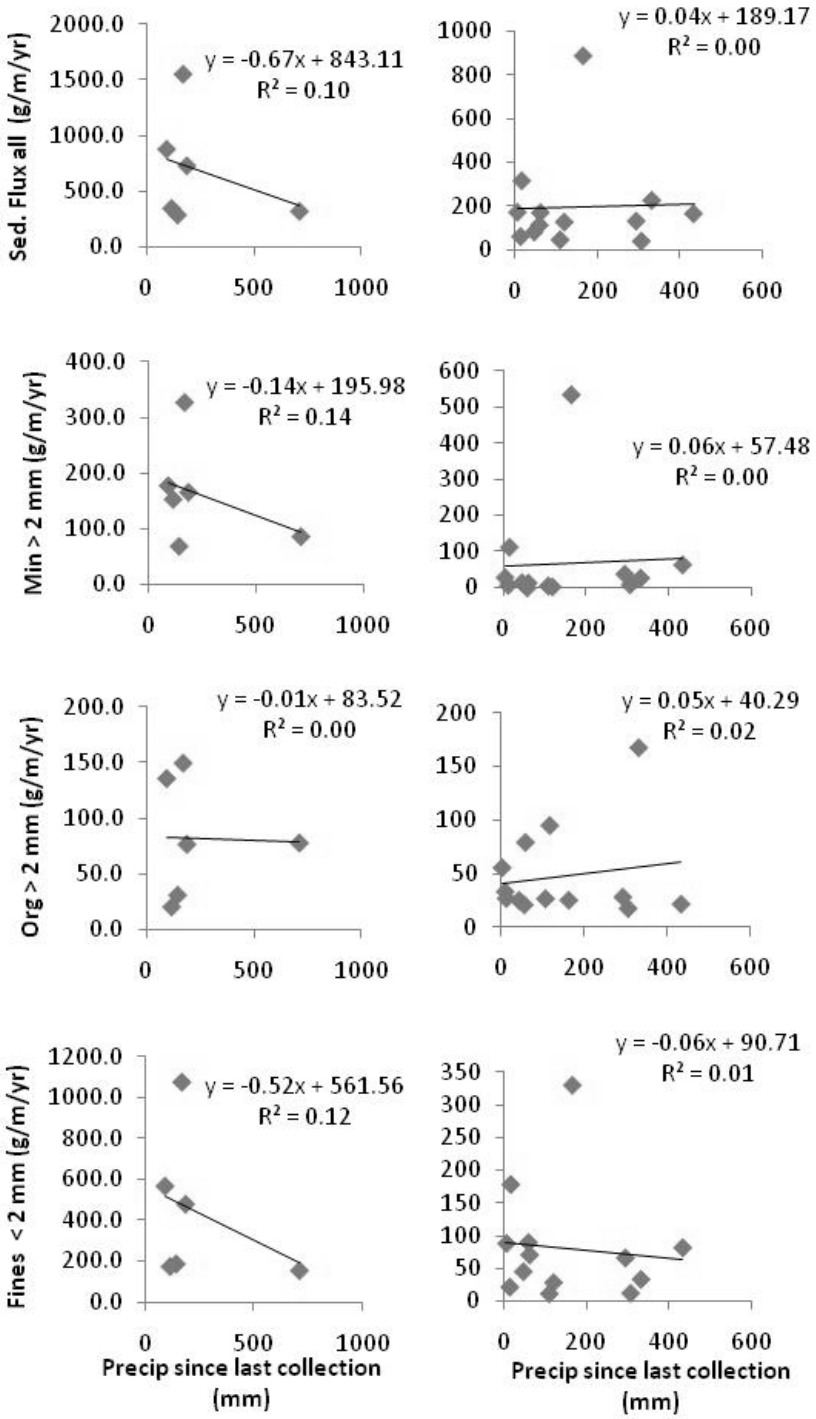
Box #8 Left Column: Adams (2008) data. Right Column: McFadden (2010)



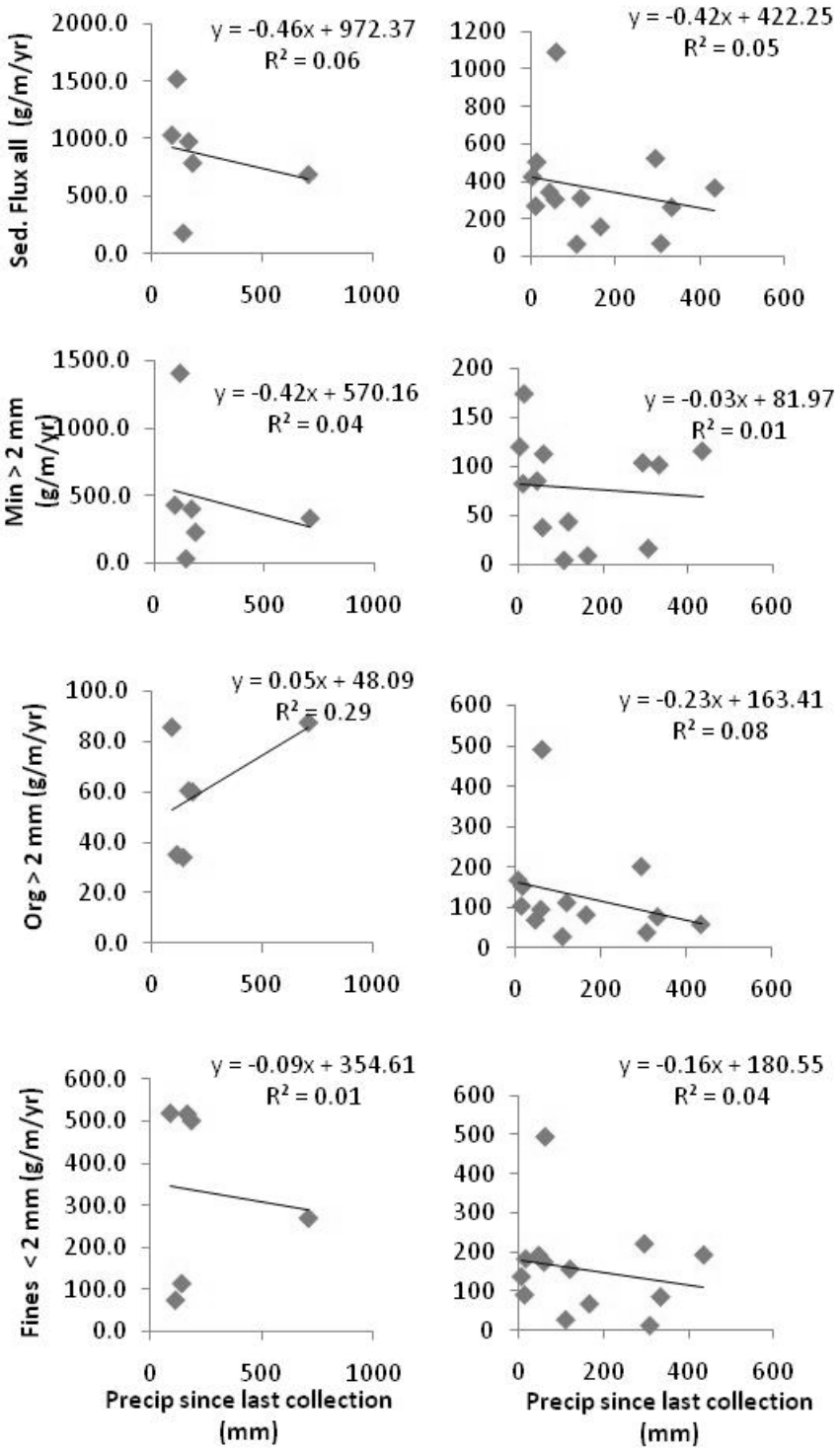
Box #9 Left Column: Adams (2008) data. Right Column: McFadden (2010)



Box #10 Left Column: Adams (2008) data. Right Column: McFadden (2010)

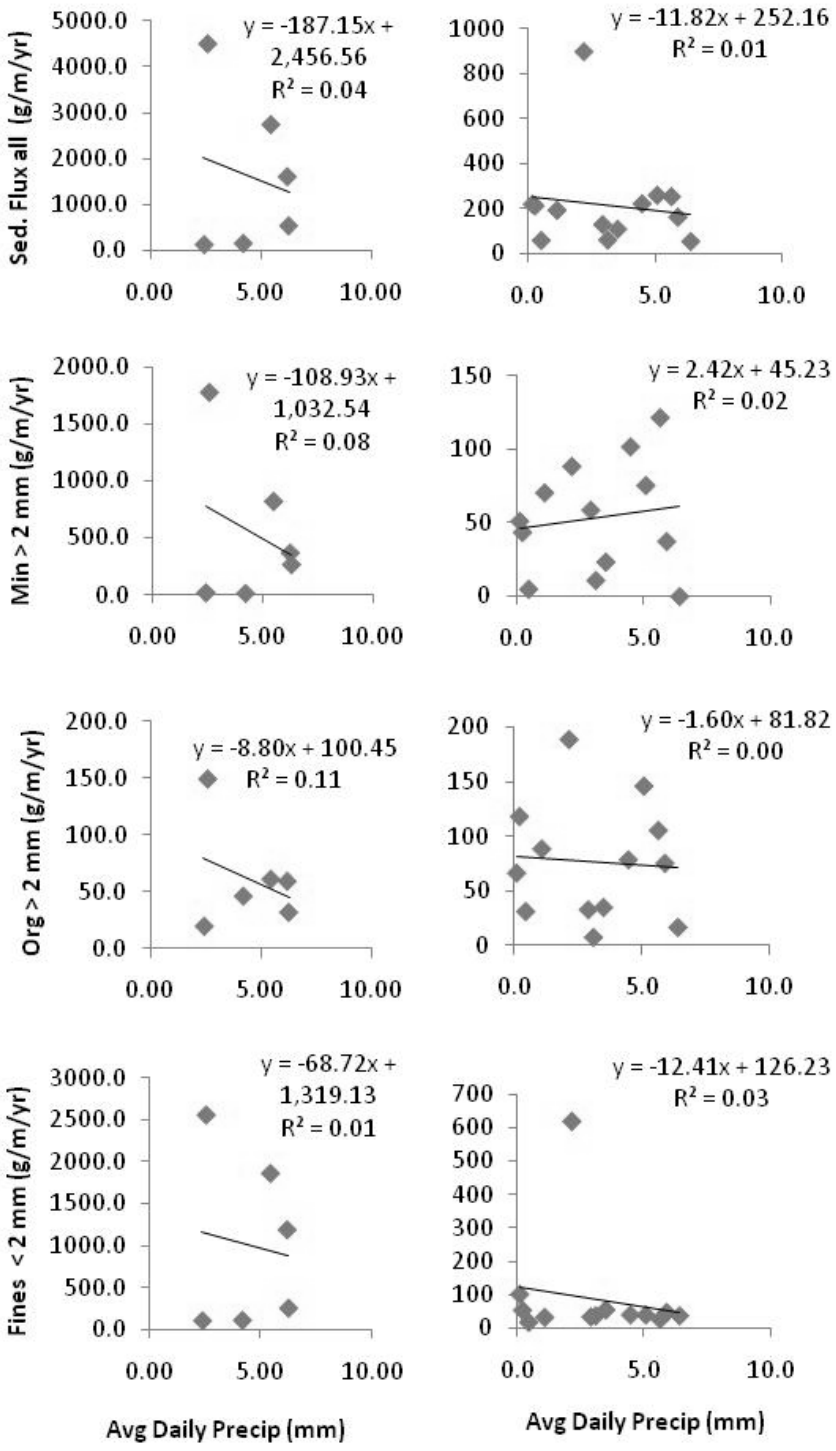


Box #11 Left Column: Adams (2008) data. Right Column: McFadden (2010)

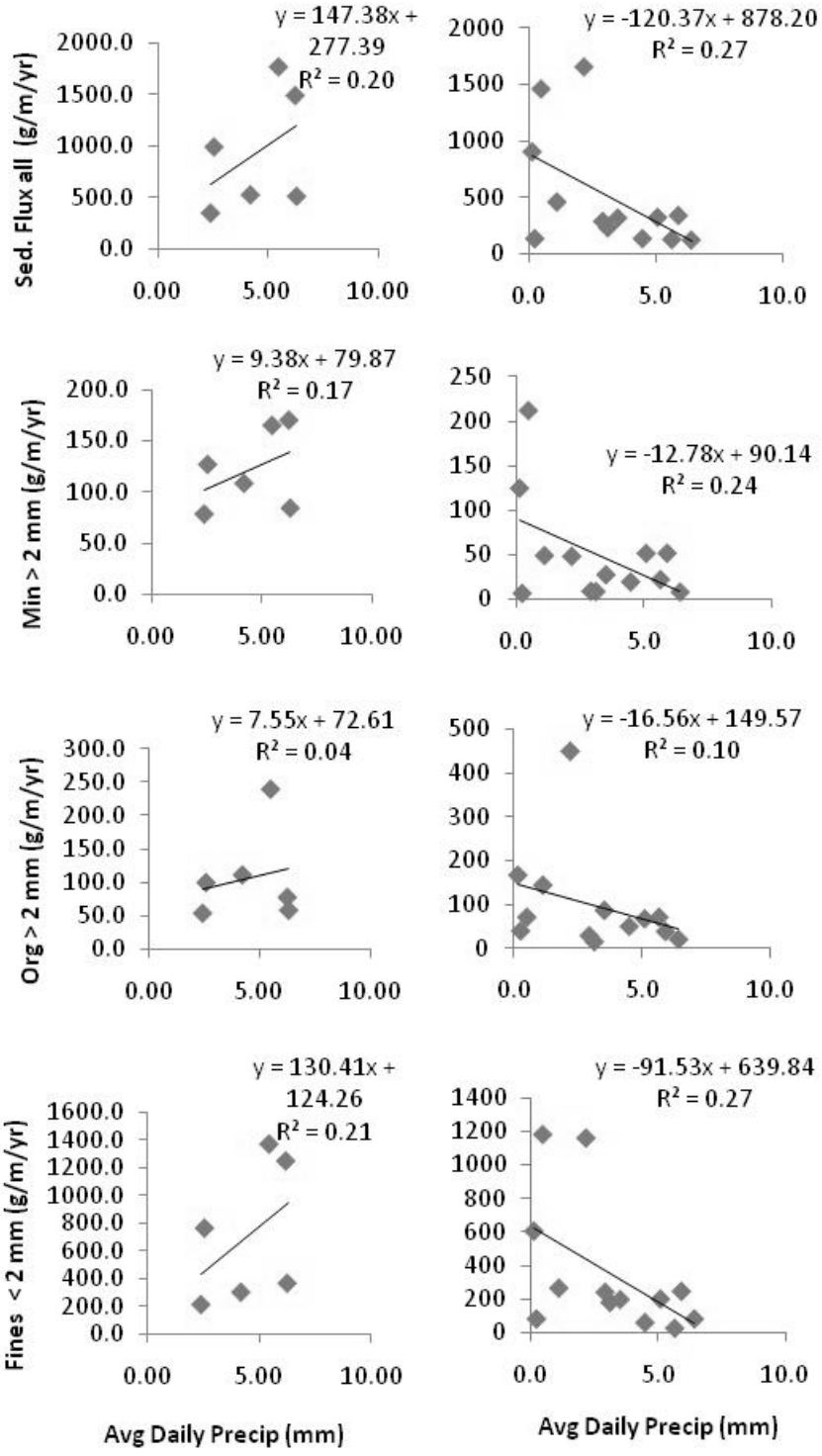


Box #12 Left Column: Adams (2008) data. Right Column: McFadden (2010)

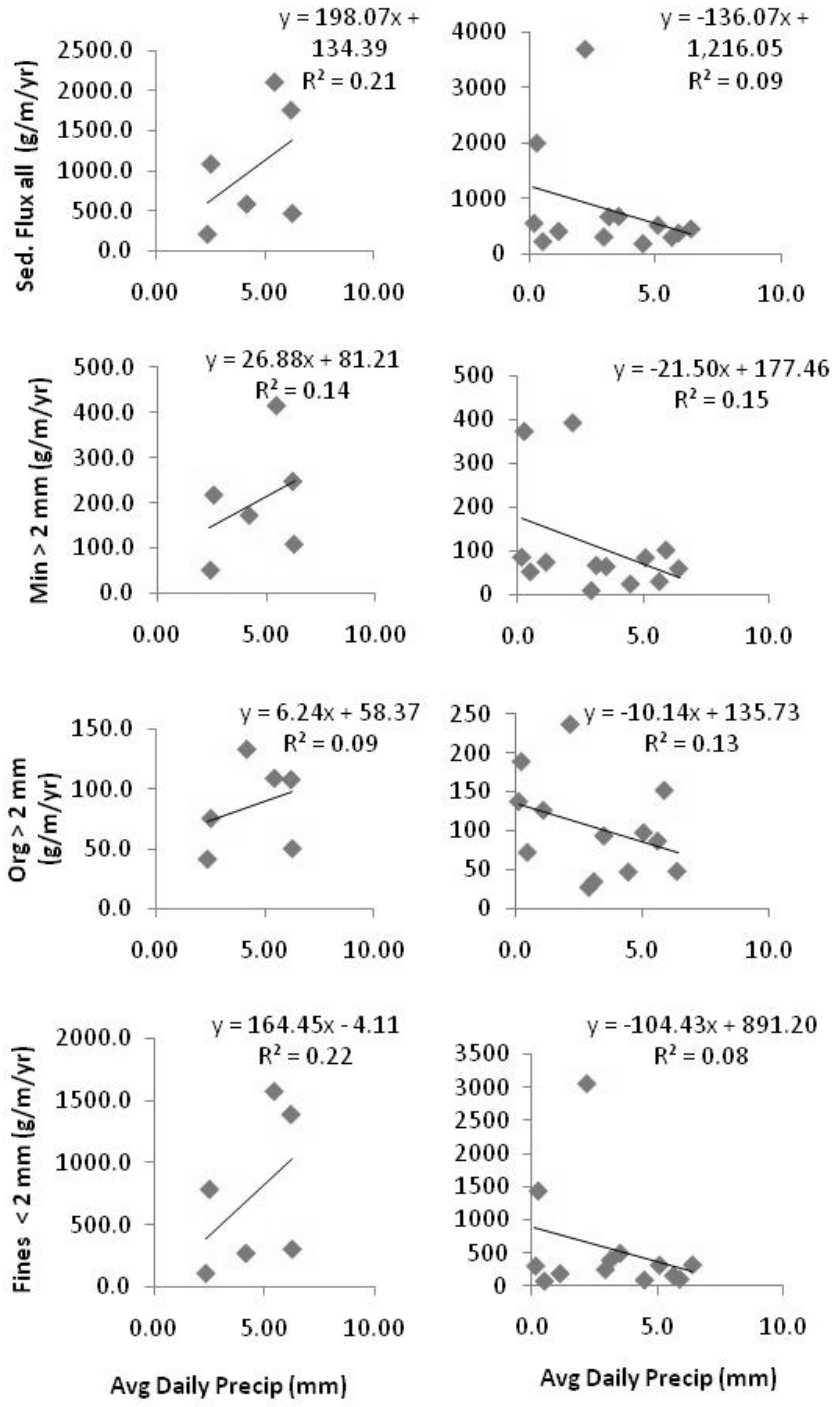
Appendix B continued. Normalized Precipitation and Sediment Transport Plots at each trap location for pre-and-post treatment sediment transport rates



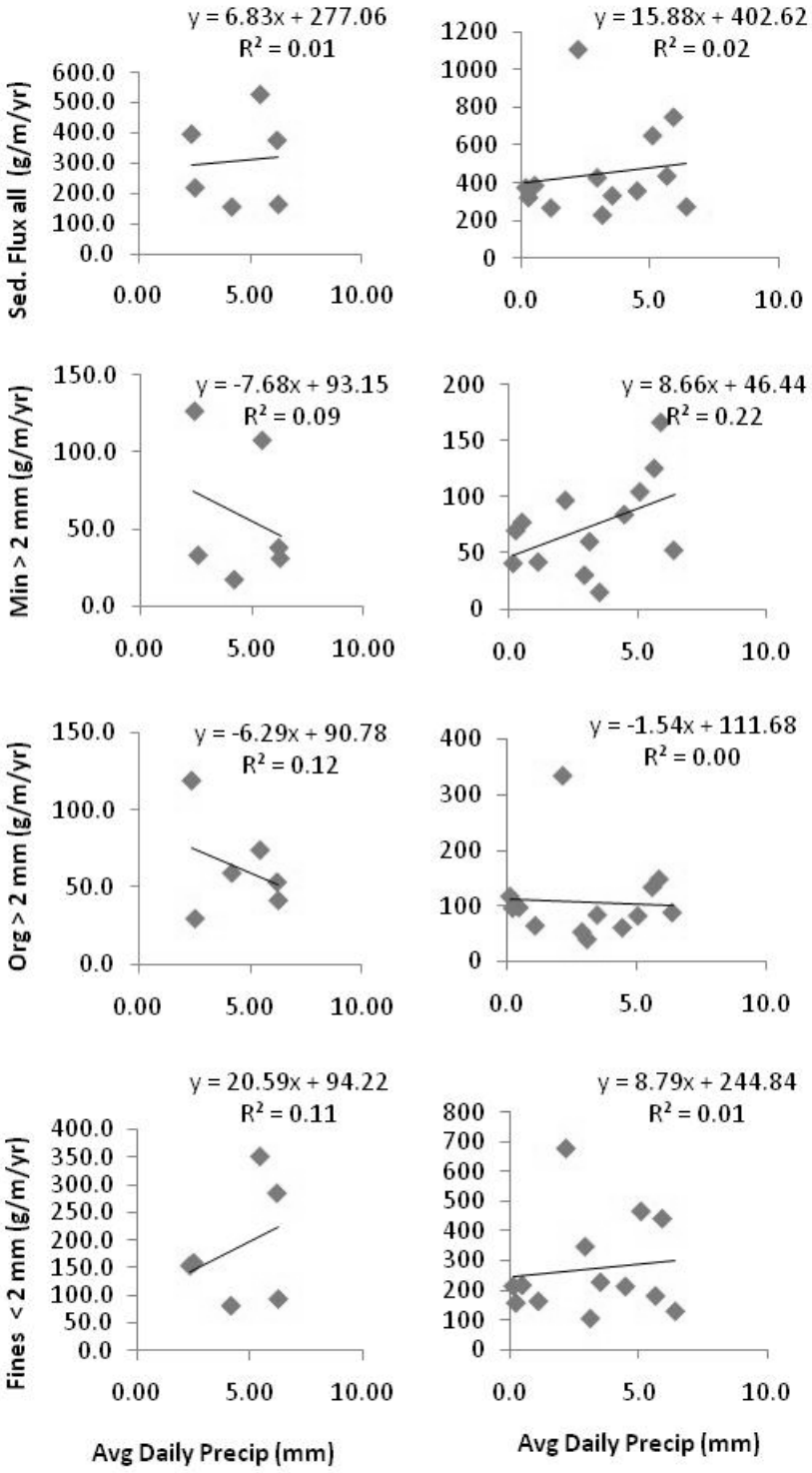
Box #1 Left Column: Adams (2008) data. Right Column: McFadden (2010)



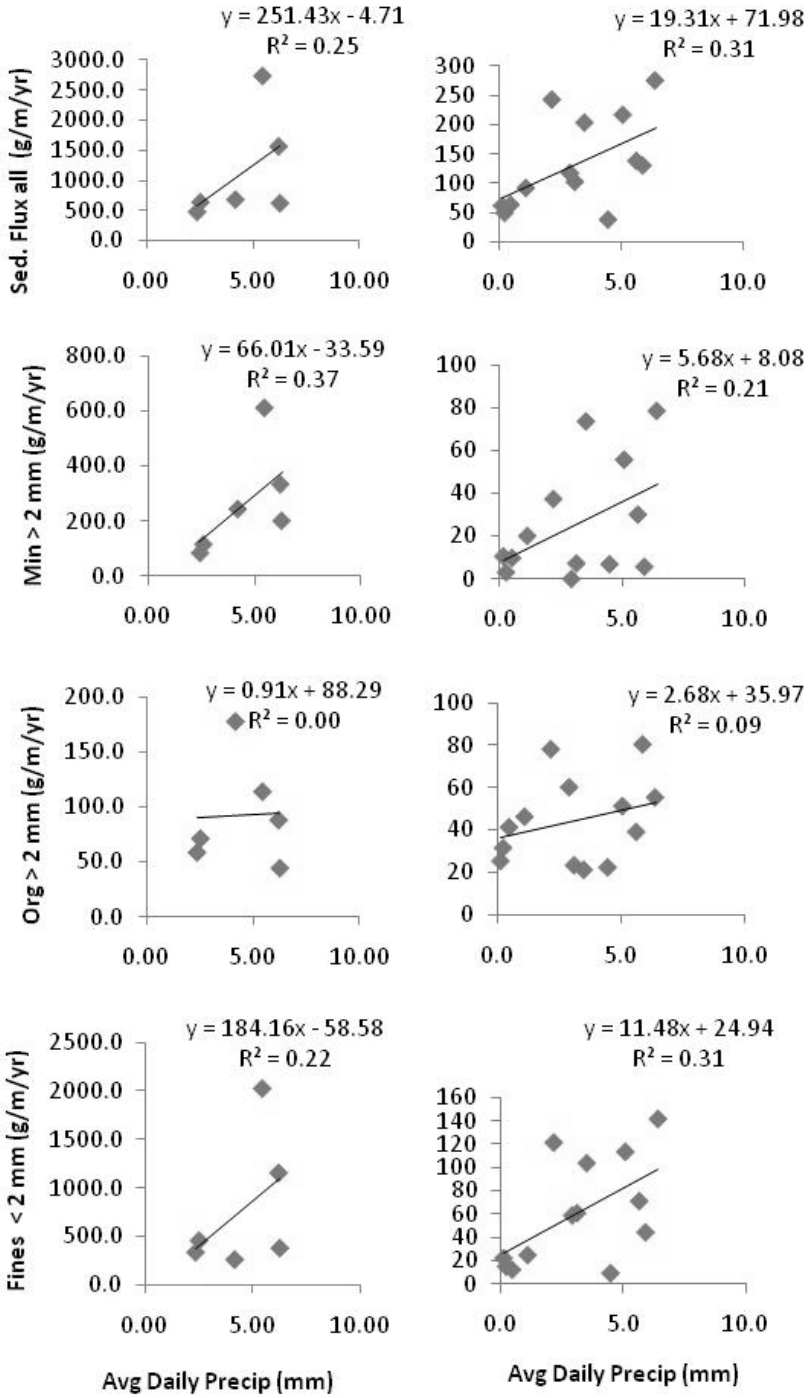
Box #2 Left Column: Adams (2008) data. Right Column: McFadden (2010)



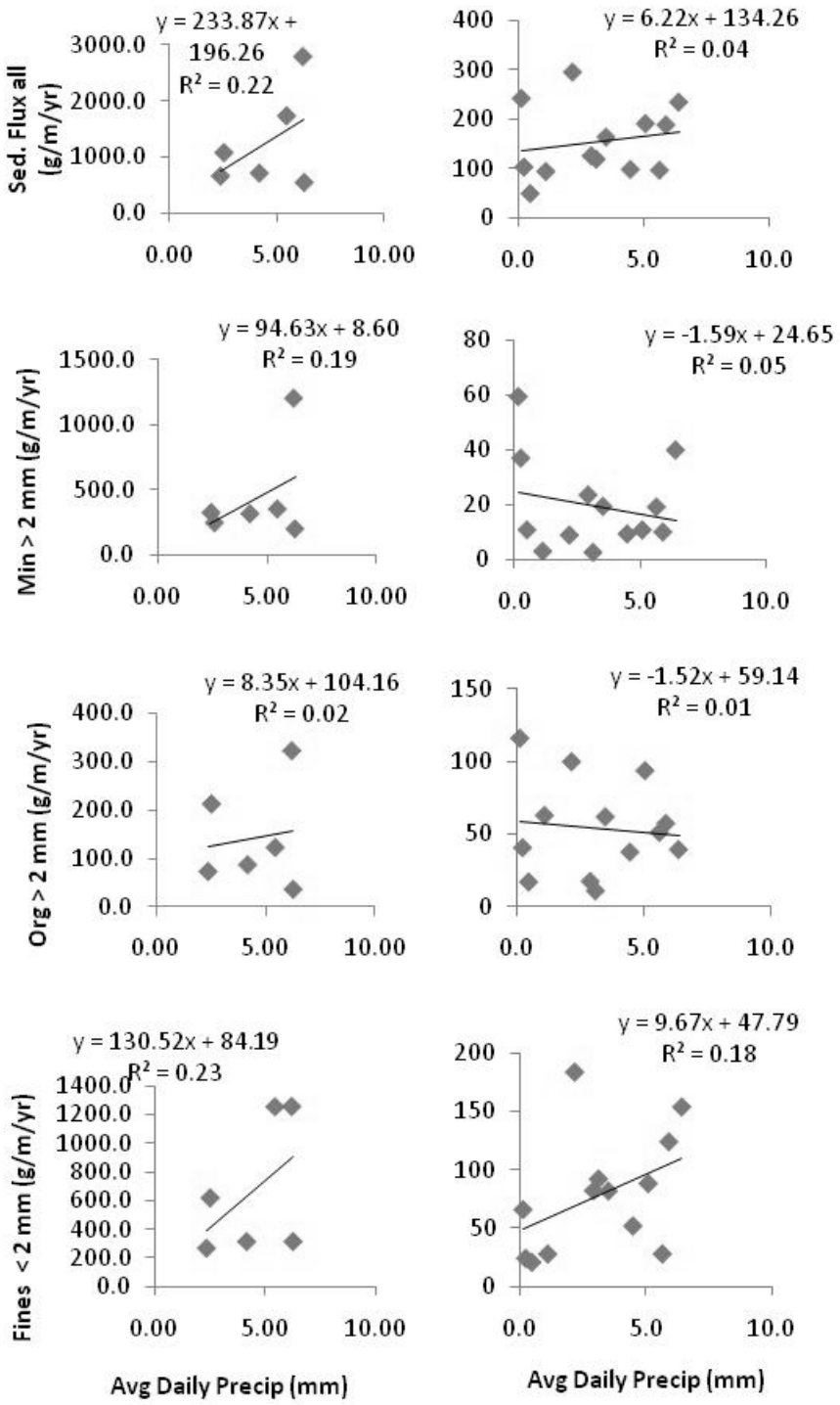
Box #3 Left Column: Adams (2008) data. Right Column: McFadden (2010)



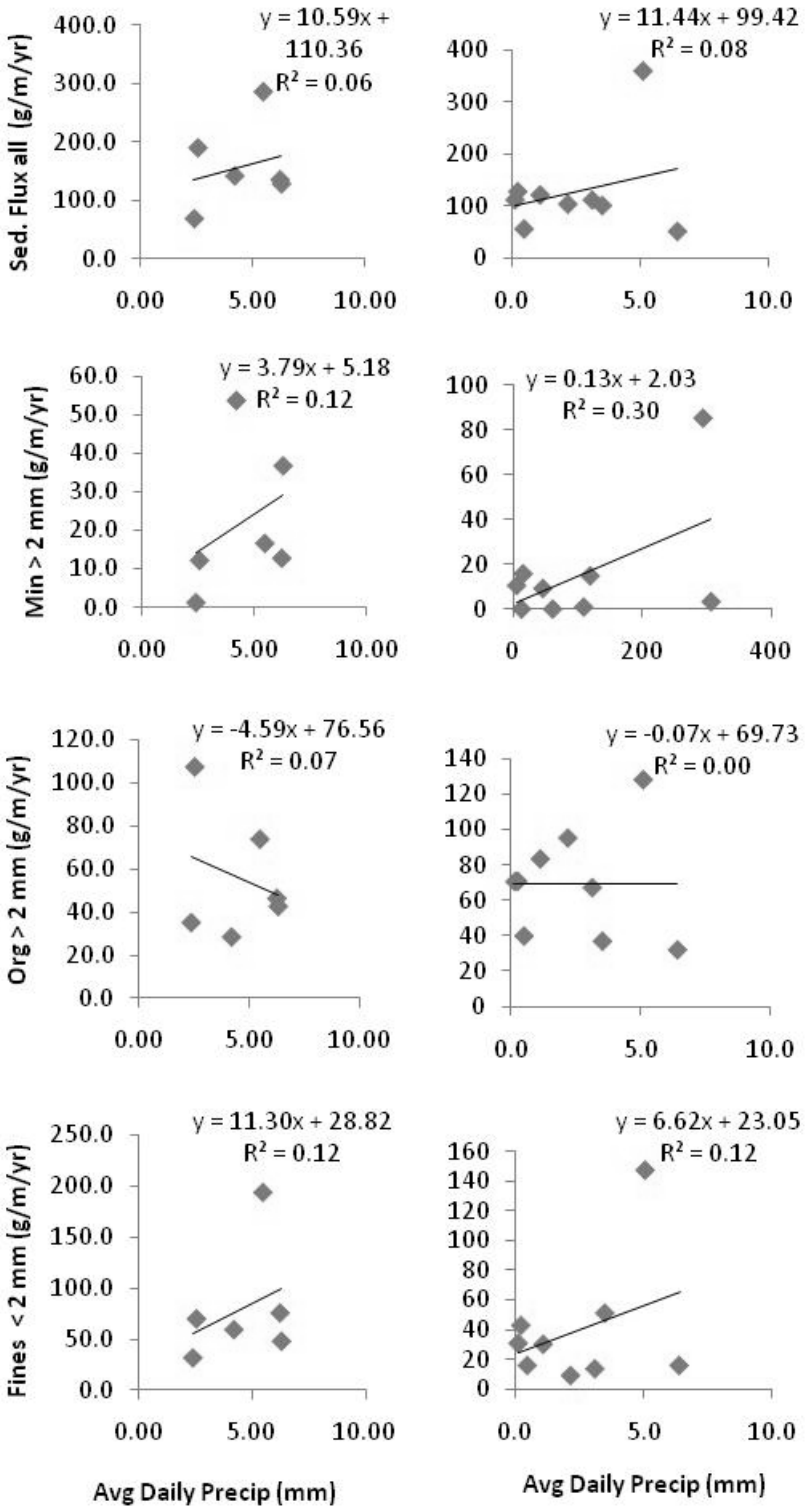
Box #4 Left Column: Adams (2008) data. Right Column: McFadden (2010)



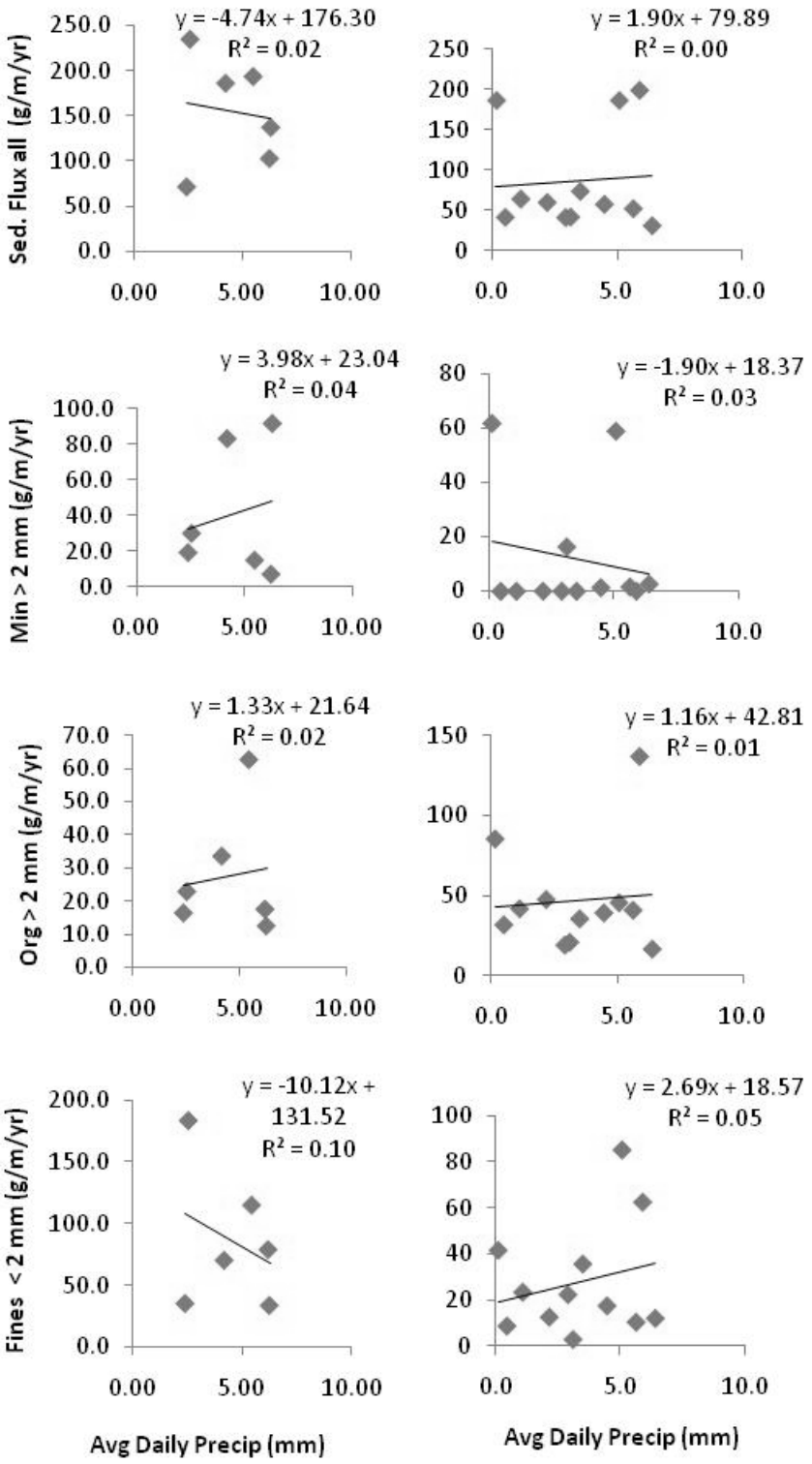
Box #5 Left Column: Adams (2008) data. Right Column: McFadden (2010)



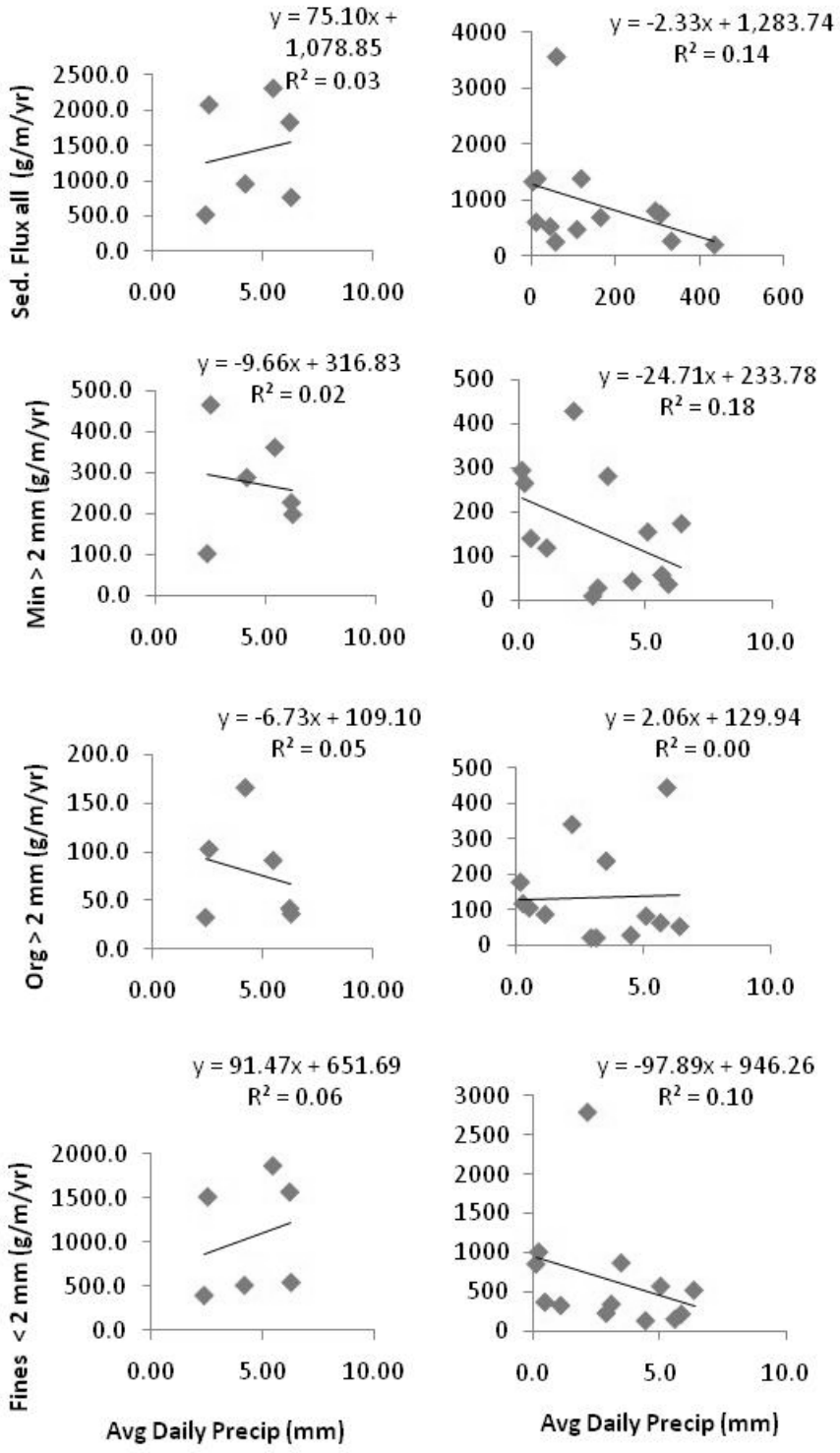
Box #6 Left Column: Adams (2008) data. Right Column: McFadden (2010)



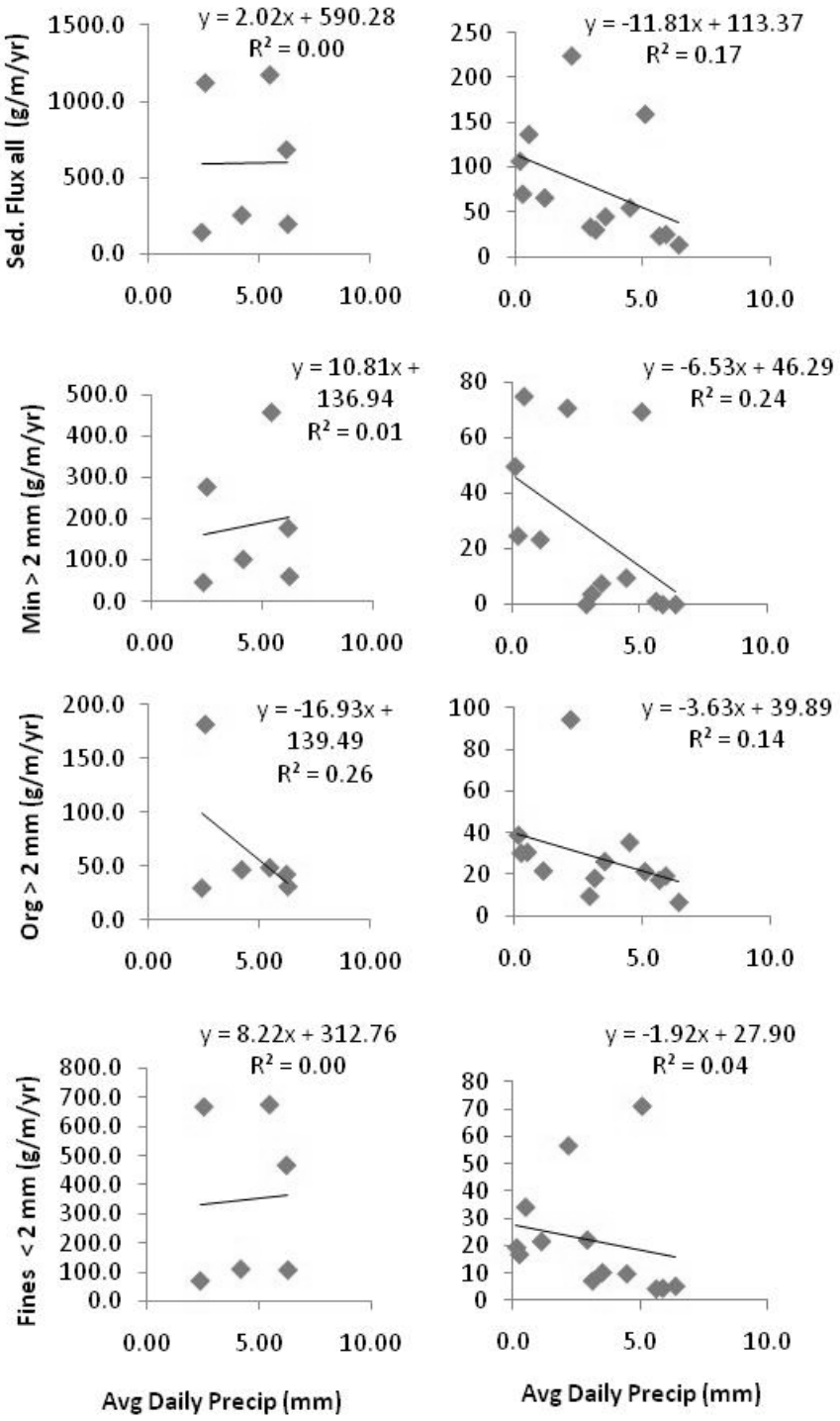
Box #7 Left Column: Adams (2008) data. Right Column: McFadden (2010)



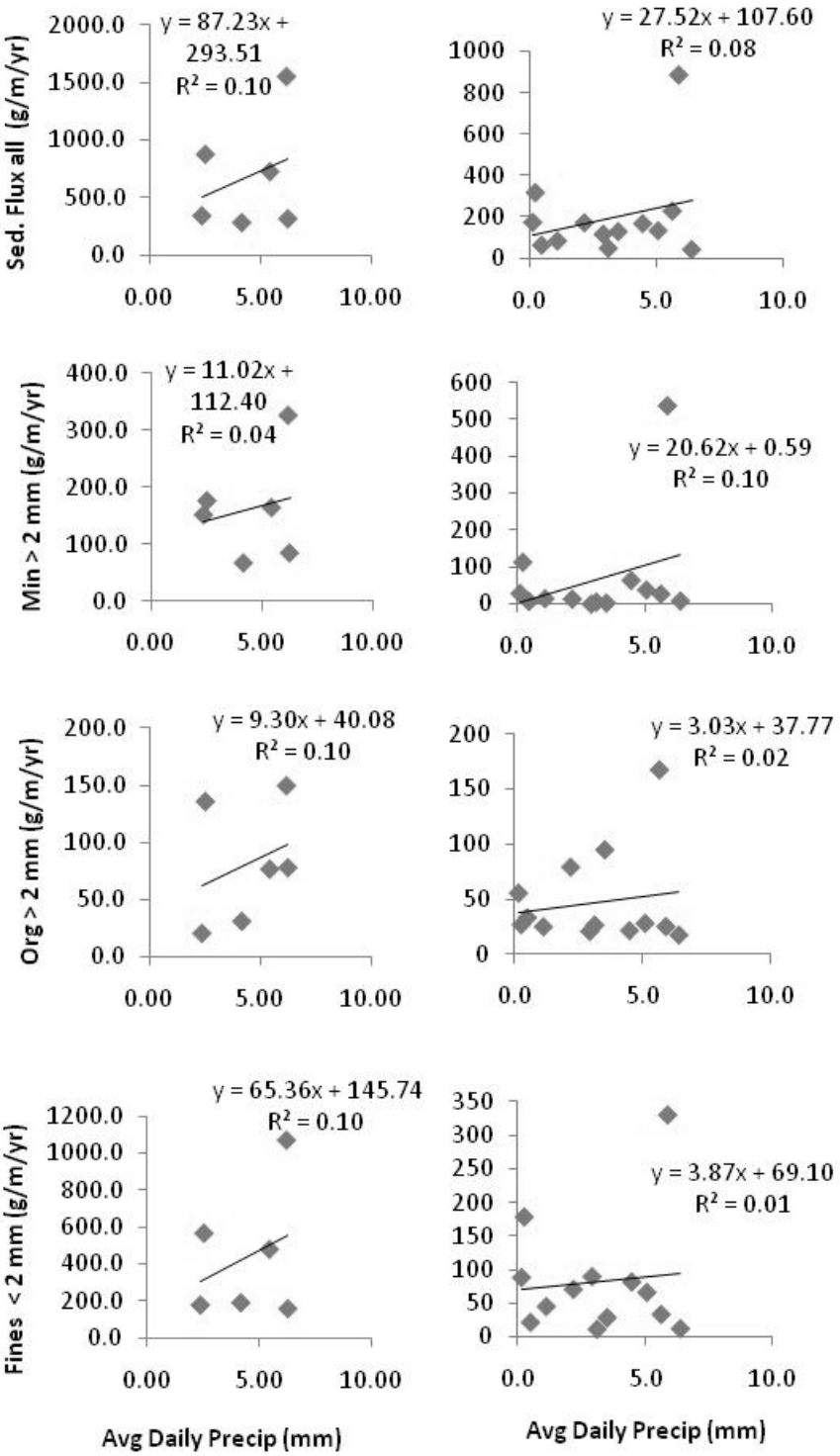
Box #8 Left Column: Adams (2008) data. Right Column: McFadden (2010)



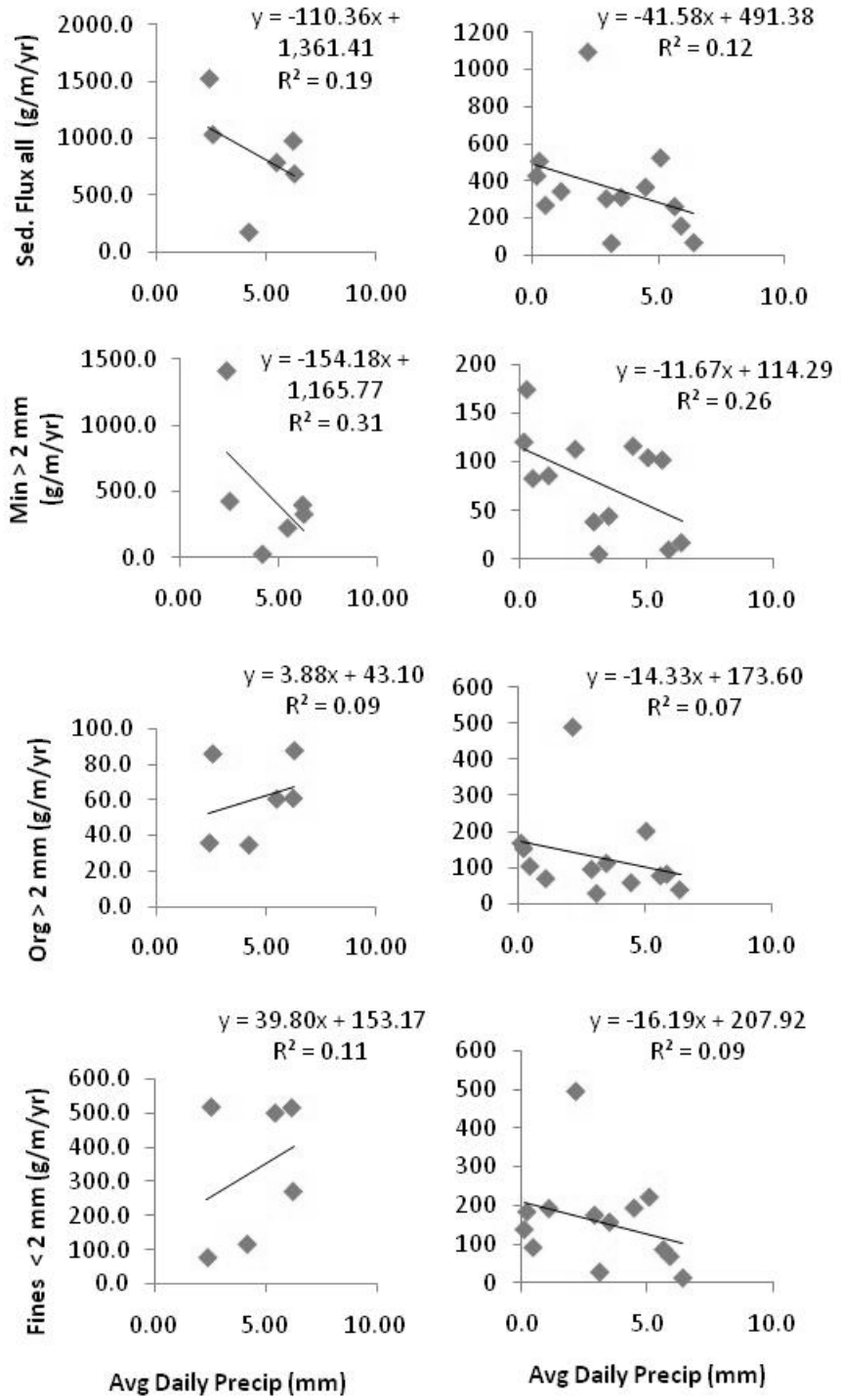
Box #9 Left Column: Adams (2008) data. Right Column: McFadden (2010)



Box #10 Left Column: Adams (2008) data. Right Column: McFadden (2010)



Box #11 Left Column: Adams (2008) data. Right Column: McFadden (2010)



Box #12 Left Column: Adams (2008) data. Right Column: McFadden (2010)

Appendix C. Table of soil erosion rates (g/m/yr) from both study periods. Precipitation values including total precipitation period as well as average daily precipitation values for the collection period are displayed

Adams 2008 Estimated Soil Erosion Rates (g/m/yr)
All Material

Box #	10/14/2007	11/17/2007	12/14/2007	4/5/2008	5/9/2008	6/26/2008
1	4500.8	2742.6	1610.5	540.4	155.9	128.9
2	992.7	1774.6	1495.3	512.3	526.5	347.8
3	1077.4	2099.5	1749.2	460.4	576.0	199.7
4	220.4	529.3	377.3	165.2	156.8	398.1
5	646.2	2746.4	1575.2	629.2	688.9	484.0
6	1073.3	1730.6	2784.1	543.8	711.7	657.5
7	189.7	286.0	135.2	127.8	141.6	68.2
8	235.4	194.2	103.4	137.9	186.7	72.1
9	2082.0	2315.5	1834.3	776.6	966.2	529.0
10	1125.0	1177.1	687.7	200.3	259.5	146.8
11	879.3	730.2	1553.5	321.3	287.8	347.4
12	1032.2	787.6	976.6	688.6	176.8	1522.8
Precip Total (mm)	91.4	185.4	167.6	708.7	142.2	114.3
Precip (Avg Daily mm/d)	2.5	5.5	6.2	6.3	4.2	2.4
Min> 2mm						
1	1781.8	819.6	364.4	261.8	8.4	13.9
2	127.0	165.2	170.5	84.0	108.3	78.0
3	217.8	415.4	248.0	108.7	172.7	51.6
4	32.6	107.4	37.6	30.6	16.8	126.3
5	114.6	609.6	332.7	200.3	242.7	83.3
6	241.2	347.0	1196.9	194.9	311.0	319.2
7	12.2	16.7	12.8	36.8	53.7	1.3
8	30.0	14.9	7.1	91.6	83.1	19.2
9	466.7	361.9	226.1	196.9	287.8	100.3
10	276.0	456.5	176.3	59.3	100.8	45.0
11	176.6	164.7	326.3	85.2	67.6	152.1
12	428.3	226.7	399.7	330.2	28.7	1412.0
Organic > 2mm						
1	149.0	60.7	58.8	31.5	45.7	19.2
2	99.6	239.9	77.6	58.1	111.1	53.6
3	75.8	109.2	108.1	50.6	133.5	41.7
4	29.1	73.7	52.9	41.0	58.8	119.0
5	71.4	113.9	88.2	44.7	177.4	58.8
6	212.4	122.2	322.8	35.1	86.1	72.1
7	107.5	74.0	46.6	42.9	28.7	35.4
8	22.9	62.5	17.6	12.6	33.6	16.5
9	103.1	91.6	42.0	36.5	166.6	32.8
10	180.7	48.5	42.3	31.2	46.7	29.8
11	135.5	76.8	149.2	78.0	31.5	21.0
12	85.7	60.2	60.6	87.4	34.2	35.4
Min and Organic < 2mm						
1	2563.8	1863.3	1186.1	246.9	100.8	95.9
2	765.3	1368.5	1247.2	369.1	305.3	216.2
3	783.8	1573.9	1388.3	301.4	267.9	106.5
4	158.7	351.0	284.5	93.3	81.2	153.4
5	461.1	2018.2	1154.4	384.5	267.9	341.9
6	619.7	1260.5	1262.1	313.0	312.8	266.1
7	69.9	194.3	75.8	47.9	59.2	31.5
8	183.4	114.8	78.8	33.4	70.0	35.0
9	1510.3	1861.1	1564.0	542.7	509.9	395.3
10	665.6	673.1	466.7	109.3	112.0	72.1
11	567.3	479.4	1073.3	156.5	188.8	176.3
12	518.3	500.7	516.3	269.8	114.8	75.4

McFadden 2010 Estimated Soil Erosion Rates (g/m/yr)
All Material

Box #	11/21/08	1/23/09	2/28/09	4/18/09	5/23/09	6/20/09	7/26/09	8/22/09	10/3/09	11/1/09	2/7/10	2/28/10	4/29/10	6/27/10	8/29/10
1	NA	NA	57.1	50.3	105.5	896.6	216.9	54.9	189.7	158.7	218.9	125.4	250.7	256.6	209.4
2	NA	NA	228.5	119.0	314.6	1651.6	900.2	1456.3	456.7	336.7	131.9	284.1	124.3	320.1	131.6
3	NA	NA	658.4	436.4	664.7	3703.3	538.7	206.3	391.7	360.5	168.2	290.4	283.5	501.8	1996.5
4	NA	NA	226.7	270.4	329.5	1108.6	372.1	384.5	264.8	748.1	355.0	425.3	434.1	650.1	319.4
5	NA	NA	102.5	275.1	203.5	242.6	61.7	63.5	92.1	130.4	38.3	117.4	138.3	216.7	49.7
6	NA	NA	118.7	235.3	163.8	296.7	243.0	48.4	93.6	188.8	97.6	125.9	96.0	191.5	102.5
7	NA	NA	112.4	52.4	101.8	104.5	112.8	56.9	122.0	NA	NA	NA	NA	358.6	128.4
8	NA	NA	41.7	31.1	73.7	60.1	186.9	41.5	64.3	199.5	57.6	41.3	52.2	NA	186.9
9	NA	NA	465.7	737.5	1375.2	3553.4	1318.9	596.6	515.7	681.0	192.4	243.9	257.6	796.9	1375.9
10	NA	NA	29.9	13.2	44.8	224.4	106.7	136.7	65.8	24.9	54.6	33.3	23.1	159.2	70.1
11	NA	NA	45.8	39.3	126.8	169.7	171.3	60.5	81.3	886.7	165.1	113.3	226.1	131.3	315.7
12	NA	NA	62.9	66.2	310.0	1092.3	424.8	267.5	341.5	156.2	364.6	302.1	260.3	522.4	503.4
Precip Total (mm)	NA	NA	109.2	307.3	119.4	61.0	5.1	12.7	45.7	165.1	434.3	58.4	332.7	294.6	15.2
Precip (Avg Daily mm/d)	NA	NA	3.1	6.4	3.5	2.2	0.1	0.5	1.1	5.9	4.5	2.9	5.6	5.1	0.2
Min>2mm															
1	NA	NA	10.9	0.0	23.3	88.4	51.1	4.9	70.4	37.4	101.8	58.7	121.6	75.5	43.5
2	NA	NA	9.1	8.6	28.0	48.7	125.2	212.4	49.5	52.1	20.0	9.5	22.6	52.0	7.2
3	NA	NA	67.1	59.5	64.4	393.3	85.5	52.5	74.3	102.0	24.5	9.5	30.1	84.3	373.7
4	NA	NA	59.9	52.2	14.9	96.4	40.6	76.9	41.8	165.5	83.8	30.2	124.8	104.0	69.6
5	NA	NA	7.3	78.7	73.7	37.4	10.6	9.8	20.1	5.7	6.9	0.0	30.1	55.8	3.1
6	NA	NA	2.7	40.0	19.4	9.0	59.4	10.9	3.1	10.1	9.4	23.6	19.2	10.9	37.0
7	NA	NA	0.9	3.3	14.8	0.0	10.5	0.0	9.2	NA	NA	NA	NA	85.2	15.7
8	NA	NA	16.3	2.6	0.0	0.0	61.7	0.0	0.0	0.0	1.3	0.0	1.6	NA	58.9
9	NA	NA	26.1	173.1	281.3	429.3	294.6	139.2	117.4	34.8	41.8	7.9	56.0	154.1	264.9
10	NA	NA	3.6	0.0	7.5	70.3	49.4	74.5	23.2	0.0	9.5	0.0	1.1	69.0	24.6
11	NA	NA	5.4	8.5	2.8	13.5	28.8	7.3	14.6	534.9	63.9	0.0	27.2	38.0	112.7
12	NA	NA	4.5	16.4	43.5	112.4	119.7	82.3	85.2	9.0	115.5	37.8	101.3	103.6	173.6

McFadden 2010 Estimated Soil Erosion Rates (g/m/yr)

Box #	11/21/08	1/23/09	2/28/09	4/18/09	5/23/09	6/20/09	7/26/09	8/22/09	10/3/09	11/1/09	2/7/10	2/28/10	4/29/10	6/27/10	8/29/10
Organic>2mm															
1	NA	NA	8.2	17.2	35.5	189.3	67.0	31.7	89.0	75.9	79.2	33.3	106.0	146.7	118.8
2	NA	NA	16.3	21.8	87.7	448.9	167.5	72.0	144.8	39.7	51.4	30.2	72.1	68.4	41.0
3	NA	NA	34.5	47.6	93.4	236.9	137.5	72.0	126.2	151.9	46.8	27.0	86.6	97.4	188.9
4	NA	NA	39.0	87.3	83.1	333.3	116.4	96.4	63.5	147.4	60.2	52.4	132.9	81.5	95.2
5	NA	NA	23.6	55.5	21.5	78.2	25.6	41.5	46.4	80.5	22.6	60.3	39.3	51.4	31.7
6	NA	NA	10.8	39.3	62.0	100.0	116.2	16.9	62.9	57.3	37.6	17.3	51.2	93.9	40.6
7	NA	NA	67.4	32.1	37.0	95.5	70.8	39.9	83.7	NA	NA	NA	NA	128.6	71.1
8	NA	NA	20.9	16.5	35.5	47.6	85.5	31.7	41.8	137.2	39.3	19.0	40.9	NA	45.6
9	NA	NA	20.7	52.4	236.9	340.5	177.4	105.3	86.7	443.9	27.9	20.5	62.9	81.9	117.2
10	NA	NA	18.1	6.6	26.1	94.1	38.8	30.5	21.7	19.3	35.3	9.5	17.2	21.3	30.2
11	NA	NA	26.1	17.0	94.4	78.7	55.1	32.7	24.6	24.7	21.1	20.5	166.9	27.7	26.4
12	NA	NA	27.0	37.4	111.1	491.1	166.9	102.9	68.3	80.9	57.1	94.4	76.3	200.7	152.3
Min and Organic<2mm															
1	NA	NA	36.3	36.4	54.1	616.6	100.5	17.1	31.7	46.5	39.6	33.3	25.8	38.9	52.7
2	NA	NA	182.3	84.0	199.8	1158.5	605.7	1179.2	267.1	248.2	62.5	242.8	28.5	202.5	84.5
3	NA	NA	399.9	326.6	504.1	3064.0	311.2	83.0	195.9	111.1	98.5	255.5	166.2	322.9	1442.6
4	NA	NA	105.2	129.6	227.8	679.0	214.2	217.3	163.3	442.1	213.3	347.5	181.3	466.8	157.7
5	NA	NA	60.8	141.5	103.6	121.3	22.0	12.2	24.8	44.2	9.2	58.7	71.0	113.3	14.8
6	NA	NA	91.7	153.4	81.4	183.2	65.6	20.6	27.6	123.6	51.6	81.8	27.7	87.9	23.9
7	NA	NA	13.5	15.7	50.9	9.0	30.6	15.7	29.9	NA	NA	NA	NA	147.0	42.6
8	NA	NA	2.7	11.9	35.5	12.5	41.4	8.5	23.2	62.3	17.3	22.2	10.2	NA	85.0
9	NA	NA	333.5	512.0	861.6	2784.7	846.1	359.4	317.0	206.8	123.3	218.7	141.9	563.1	998.8
10	NA	NA	7.3	5.3	10.3	56.7	19.4	34.2	21.7	4.5	9.8	22.2	4.3	71.1	16.9
11	NA	NA	11.7	12.5	28.7	70.8	88.3	21.8	45.3	329.3	81.7	89.7	33.6	66.2	178.1
12	NA	NA	27.0	11.8	156.4	495.6	137.2	90.8	191.9	67.4	193.0	174.6	85.3	221.3	183.2