Low-grade Weirs as a Suspended Solid Mitigation Strategy for Aquaculture Effluent

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Mitigating suspended solids after discharge is a critical component of sustainable aquaculture practices. Total suspended solids and their volatile component were determined from water samples collected during and after pond discharge in a vegetated ditch system fitted with consecutive low-grade weirs. Concentrations and reduction efficiency were analyzed using repeated measures ANOVA for each reach of the system. Suspended solids increased over the residence time and returned to baseline within the 48 hour sampling period for each discharge. The highest concentration of suspended solids was in the initial effluent, while the smallest concentration was at weir 4. On average, concentrations were reduced between 0.009 mg/L – 0.021 mg/L across the system. Volatile suspended solids made 16% - 30% of the total suspended solids. Reduction efficiency of total suspended solids ranged from 14% - 54% over the system as a whole. Overall, the vegetated ditch fitted with low-grade weirs functioned as a mitigation tool for aquaculture effluent.

Introduction

The introduction of sustainable production system certifications is giving more incentive for commercial aquaculture farmers to introduce new practices to their production facility (Boyd, 2003; Bosma and Verdegem, 2011). Several organizations are developing standards for ecolabeled products as large-scale seafood buyers are seeking products produced using responsible methods to satisfy increasing demand (Seafood Choices Alliance, 2003; Boyd et al., 2007; Bosma and Verdegem, 2011). The adoption of easy to monitor indicators may stimulate the adoption of sustainable practices (Bosma and Verdegem, 2011). Mitigation of suspended solids after discharge would be easy to monitor and is a critical component of sustainable practices that should be monitored.

Suspended solids is the largest category, by volume, of pollutants in the United States (Fowler and Heady, 1981). Sediments degrade downstream water quality and carry nutrients that adversely influence aquatic life (Ritchie, 1972). Cooper et al. (1991) found as suspended sediment load decreased, water quality improved rapidly. Therefore, the first principle of sediment reduction centers on sound policy and management (Cooper and Lipe, 1992). There are several best management practices that can be utilized to mitigate suspended solid concentrations and loads from effluent. Settling basins and constructed wetlands allow time for suspended solids to fall out of the water column; however, these practices are not always practical for farmers (Boyd, 2003). Ghate et al. (1997) showed 18 – 82% of suspended solids were removed over a 24 m distance using grass strips to filter catfish effluent. Tucker and Hargreaves (2003) noted that a vegetated ditch has the potential to act as a long settling pond. A ditch with a low gradient and area comparable to that of a settling basin is sufficient for solids removal. Shireman and Cichra (1994) found a 93 m long ditch initially added suspended solids, but later acted as a sink and an potential management practice to reduce TSS.

Most commercial aquaculture ponds already drain into vegetated ditches. The introduction of low-grade weirs may serve as an innovative alternative to reduce suspended solids and organic material entering receiving waters. This controlled drainage structure increases residence time within the ditch system allowing time for natural processes to occur (Kröger et al., 2008; Kröger et al., 2012). This study analyzed the efficiency of a vegetated ditch system fitted with consecutive low-grade weirs in mitigating aquaculture effluent by reducing suspended material concentrations reaching receiving waters. Reduction efficiency of weirs was compared across and within the system.

Materials & Methods

In fall 2011, three embankment ponds (0.05 ha) stocked with freshwater prawns were intentionally discharged at the Mississippi State University South Farm Aquaculture Facility (Mississippi State, MS) into a 292 m vegetated ditch fitted with four pre-cast concrete low-grade weirs. Weirs ranged from 0.3 m to 1.2 m in depth. Prior to each pond draining event; initial water samples (n=2) were taken from the pond and any ditch sampling sites (n=4) where water was present. Initial samples were used to establish baseline parameters for the system for each event.

Ponds were drained using a hydraulic PTO tractor pump (custom fabrication, Starkville, MS) or a 15 cm stand pipe depending on proximity of the pond to the ditch. To monitor the flow of effluent and calculate residence time, a salt slug was delivered to the system. This solution was created in a mixing chamber using 99% pure NaCl as the tracer. Diamond Crystal® pool salt (Cargill, Inc., Wayzata, MN) was dissolved in pond water and delivered immediately into the ditch when pumping began.

Effluent samples were collected over two periods; while water was flowing over weirs and after water flow over weirs stopped. Water samples were collected in 275 mL polyethylene cups (Fisher Scientific, Pittsburgh, PA). Samples were collected between 0.1 – 0.3 m below the water surface. Initial effluent was sampled at 5 min intervals during the first hour. After the first hour, the initial effluent was sampled every 30 min until pumping stopped. When water began to flow over each weir, water samples were taken below each weir every 30 min. Once water stopped flowing over the weirs, samples were collected above each weir every 6 hr until the experiment ran for 48 hours. Samples were kept on ice and transported to the Mississippi State University Water Quality Lab for analysis.

Water samples were analyzed for TSS and volatile suspended solids (VSS). One hundred mL of each sample was filtered through pre-ashed, pre-weighed 0.45μm Whatman glass fiber filters (APHA, 1998). Filters were dried at 105°C for 24 hours and then weighed to the nearest mg using a Scientech SA210 scale (Scientech Inc., Boulder, CO). TSS was calculated as:

TSS = Dried filter weight (g)– Initial filter weight (g)

Initial effluent and above weir samples were additionally ignited in a muffle furnace ( ) at 550°C over 20 minute intervals. VSS was calculated as:

VSS = TSS (g)– Ignited filter weight (g)

An ANOVA using general linear model procedure (PROC GLM) with repeated measures of SAS (SAS Institute 1988) was used to determine any significance among drainage events related to TSS and VSS. Reduction efficiency was calculated as:

*% efficiency=(peak concentration (mg⁄L)-concentration(mg⁄L))*100*

Efficiency was calculated at each weir for each sampling period.

Results

Total suspended solid concentrations were reduced, on average, between 0.0088 mg/L – 0.0212 mg/L across the system (Figure 1). The highest concentration (0.0908 mg/L) of TSS was in the initial effluent. A significantly ($F= 31.91$, $P < 0.001$) smaller concentration (0.0005 mg/L) was measured at weir 4. Individual weirs showed significant reductions, as did the system as a whole ($F=5.05$, $P=0.025$). Volatile suspended solids comprised 15% - 30% of TSS. The second discharge, through a standpipe, showed significantly ($F=27.26$, $P < 0.001$) higher concentrations of TSS than the tractor pump discharges. Overall, higher concentrations of initial effluent significantly ($F=68.78$, $P < 0.001$) increased the reduction efficiency across the system.

Positive reduction efficiency of TSS was observed across the system. Efficiency of reduction ranged from 0.7% - 98%. Reduction efficiency of weir 1 increased with time in each drainage event (Figure 2). However, efficiency decreased from the first to the second drainage. Weir 2 functioned similarly to weir 1 in the first two drainage events and then weir 2 efficiency increased from the second to the third drainage event. Weir 3 efficiency decreased over consecutive drainage events. When effluent was analyzed at weir 4, for the first time a negative efficiency over time was observed during the final drainage event.

Discussion

The goal of best management practices is to make aquaculture environmentally responsible, while also considering the economic sustainability (Bosma and Verdegem, 2011). The use of a vegetated ditch fitted with low-grade weirs shows the potential to fill these considerations. Over the course of this study, the vegetated ditch fitted with consecutive weirs was a tool for suspended solid reduction. Suspended solids initially increased over the residence time, or dilution period, of the system, returning to baseline levels within 48 hours of each event. Suspended solid concentrations were highest when a standpipe was used. This is consistent with findings by Hargreaves et al. (2005a) which found the TSS to be high during the first 10 - 30 min of discharge when a standpipe was used. The increase in concentration in our study, however, did not affect the efficiency of reducing TSS at each weir. Samocha et al. (2004) reported the major fraction in TSS was low density and likely composed of fine organic particles (uneaten feed and plankton). Results from our study found VSS comprised on average 16% - 30% of TSS in effluent. New et al. (2009) found that one of the areas of concern in freshwater prawn aquaculture is potential pollution released at discharge. It was suggested that effluent could be treated prior to discharge, but there is no mention of utilizing adjacent landscape features such as drainage ditches, nor were management strategies to treat effluent post-discharge suggested. Kröger et al. (2008) found the presence of both vegetation and weirs affected agricultural ditches.

Drainage ditches are features of the aquaculture landscape that have not received much attention for nutrient reduction potential. It is known that in-stream vegetation will increase friction and roughness in a stream channel, thus decreasing water velocity, increasing sedimentation and decreasing suspended sediments from the overlying water column (Dieter, 1990; Abt et al., 1994; Braskerd, 2002; Schoonover et al., 2006). The study of Hargreaves et al. (2005b) represents the sole investigation that evaluated drainage ditch effectiveness in reducing aquaculture effluent loads. Their study found a substantial decrease in TSS concentrations . Moore et al. (2010) found a significant difference in total solid loads between vegetated and non-vegetated ditches. Their study reported < 28% of total solids were comprised of suspended solids in vegetated ditch effluent as opposed to >95% in non-vegetated ditch effluent. This highlights the potential of vegetated ditches to remove suspended solids from effluent. Furthermore the installation of low-grade weirs increases the hydraulic residence time and capacity of a ditch system (Kröger et al., 2008). Our study shows the ability of weirs to reduce suspended solids from aquaculture effluent. Overall, weir effectiveness was variable. Efficiency of reducing TSS ranged from 14% - 54%. This may be explained by ecosystem services being heterogeneous in space and evolving through time (Fisher et al., 2009). Previous research on constructed wetlands found suspended solids retention varied from 61% - 98%. Variability in the system may be due to interrelationships that are spatially explicit (Boyd and Banzhaf, 2007).Further research is required to calculate loads in and out of the ditch system and analyzing interrelationships affecting the system. Temporal effectiveness based on effluent discharge at different times of the year also needs to be investigated.

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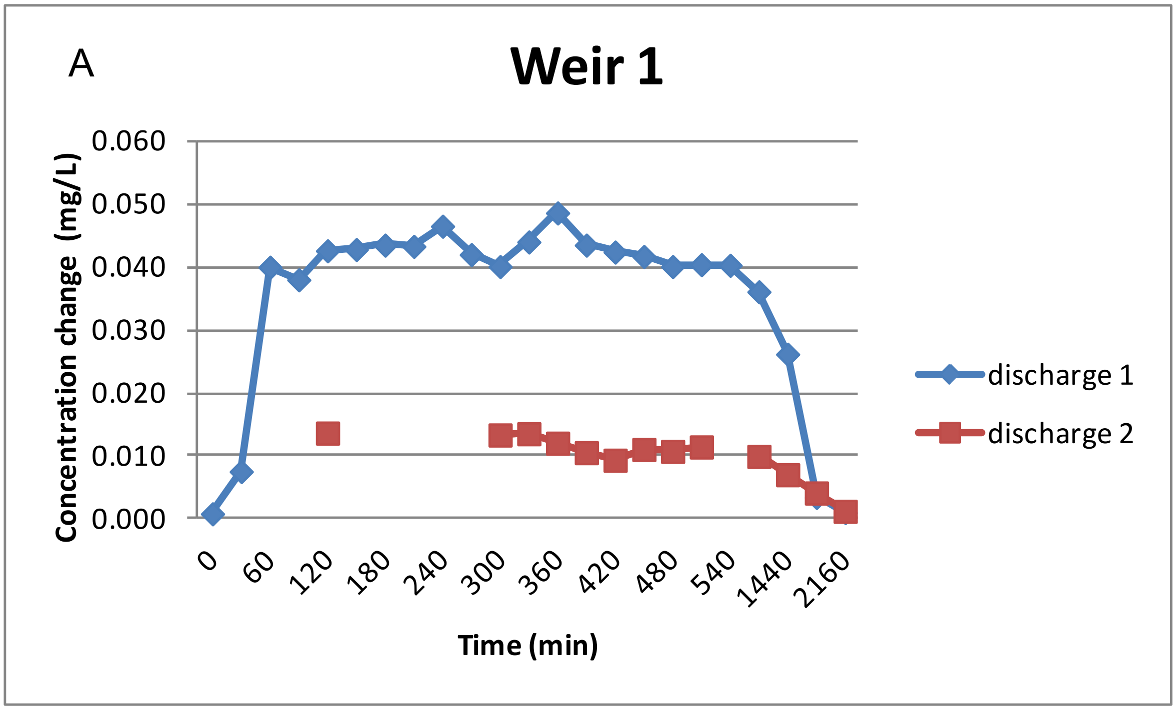
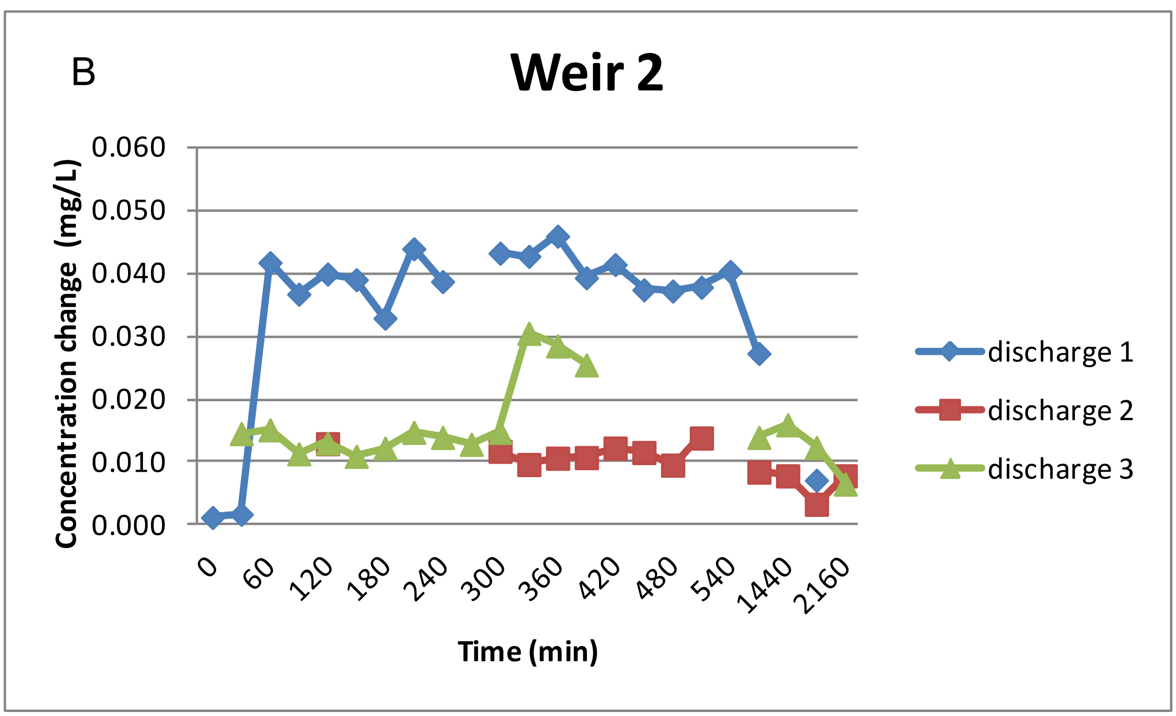
Figure 1. Change in total suspended solids concentrations (mg/L) with time (min) in three drainage events at individual weirs. A) Weir 1 B) Weir 2 C) Weir 3 D) Weir 4. Discharge 1 and 2 were discharged by tractor pump, while discharge 3 was discharged by standpipe. The standpipe was below weir 1, therefore weir 1 was not sampled for this event. Each discharge was sampled over a 48 hr period.





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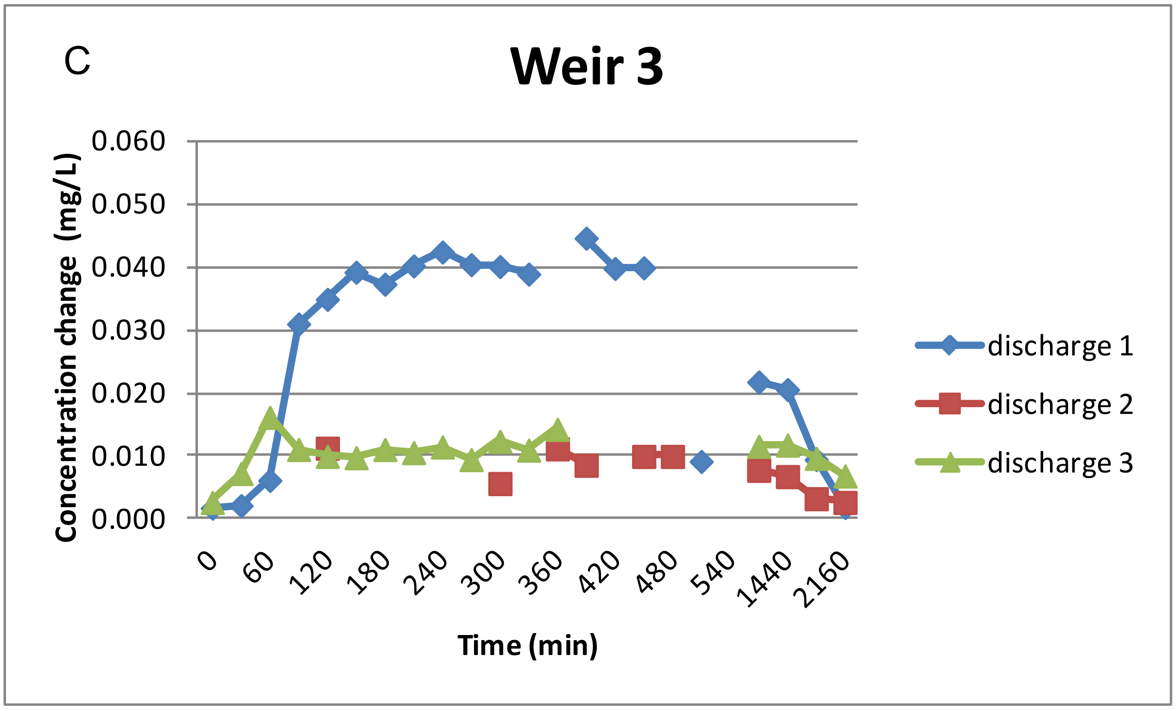


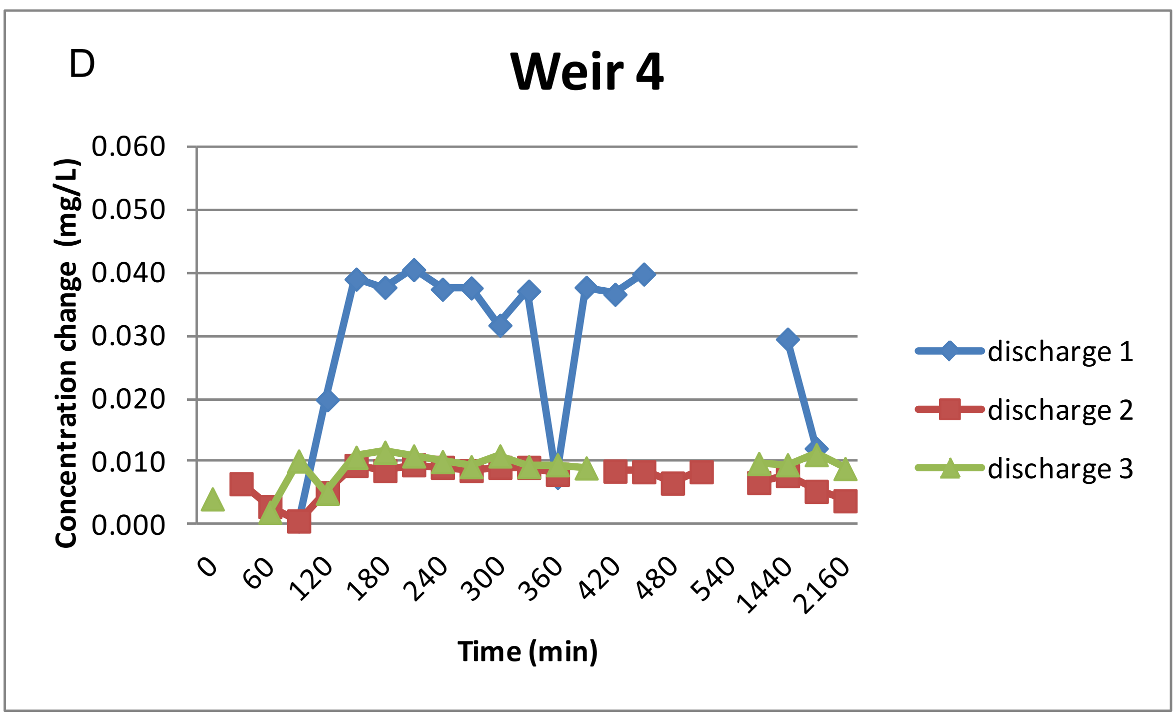
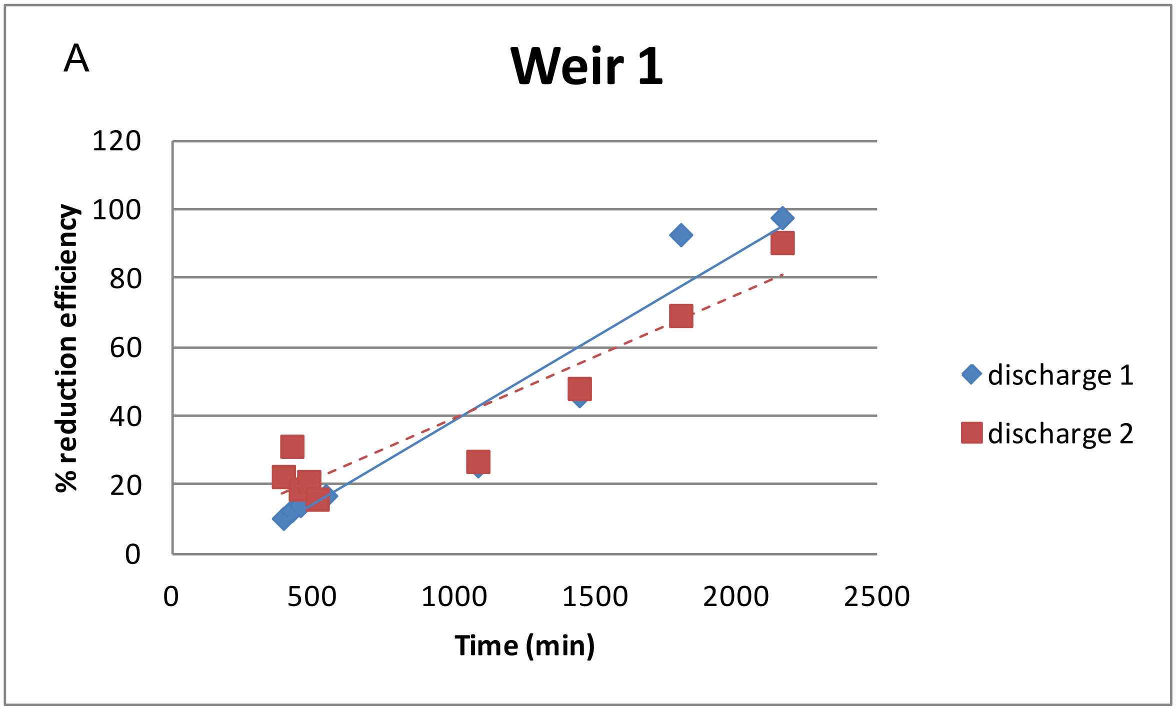
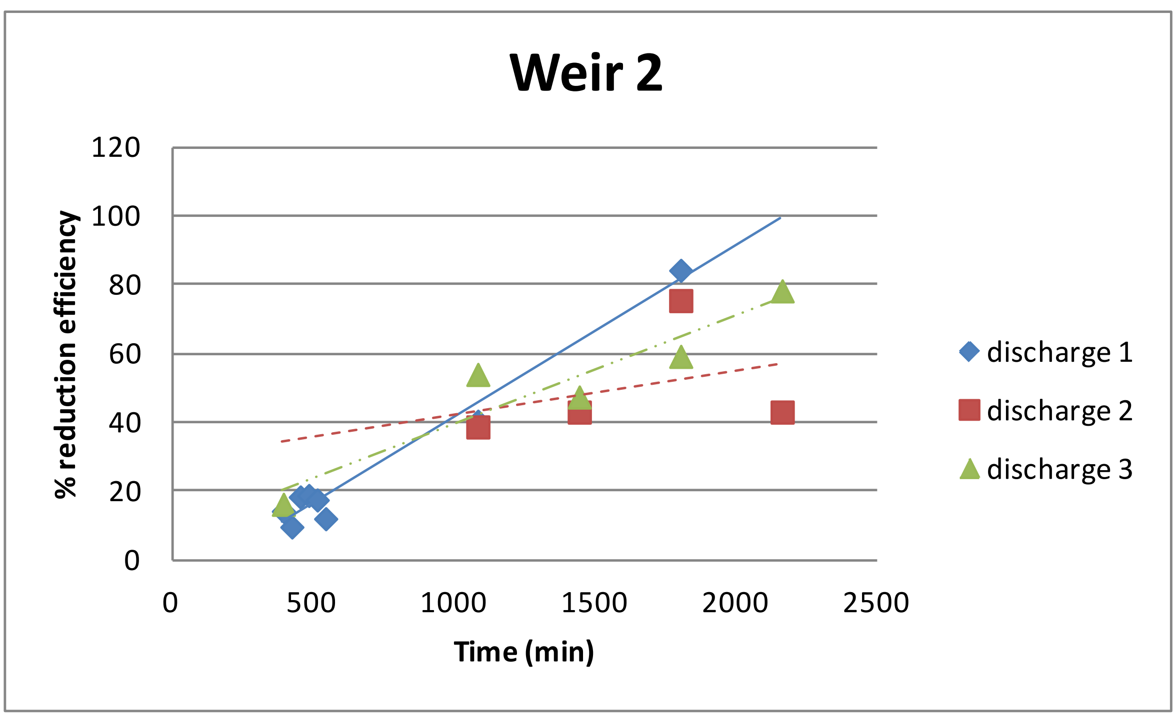


Figure 2. Changes in reduction efficiency of weirs in reducing total suspended solids concentrations with time (min) in three drainage events. A) Weir 1 B) Weir 2 C) Weir 3 D) Weir 4. Discharge 1 and 2 were discharged by tractor pump, while discharge 3 was discharged by standpipe. The standpipe was below weir 1, therefore weir 1 was not sampled for this event. Each discharge was sampled over a 48 hr period.





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