Assessing the Effects of Cattle Exclusion Practices on Water Quality in Headwater Streams in the Shenandoah Valley, Virginia

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ABSTRACT

Livestock best management practices (BMPs) such as streamside exclusion fencing are installed to reduce cattle impacts on stream water quality such as increases in bacteria through direct deposition and sediment through trampling. The main objective of this study is to assess the effects of different cattle management strategies on water quality.

The project site was located near Keezletown, VA encompassing Cub Run and Mountain Valley Road Tributary streams. During two, one-week studies, eight automatic water samplers took two-hour composites for three periods: baseline, cattle access, and recovery. During the cattle access period, livestock were able to enter the riparian zone normally fenced off. Water samples were analyzed for *E.coli*, sediment, and nutrients to understand the short-term, high-density, or flash grazing, impact on water quality. Additional weekly grab and storm samples were collected.

Results show that cattle do not have significant influence on pollutant concentrations except in stream locations where cattle gathered for an extensive period of time. Approximately three cattle in the stream created an increase in turbidity above baseline concentrations. *E.coli* and TSS concentrations of the impacted sites returned to baseline within approximately 6 to 20 hours of peak concentrations. Weekly samples show that flash grazing does not have a significant influence on pollutant concentrations over a two-year time frame. Sediment loads from storms and a flash grazing event showed similar patterns. Pollutant concentrations through the permanent exclusion fencing reach tended to decrease for weekly and flash grazing samples.

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1 Introduction

Under the Clean Water Act of 1972, the United States Environmental Protection Agency (USEPA) established goals to clean up the nation's water systems through programs such as total maximum daily loads (TMDLs). A TMDL is the calculation of the maximum amount of a pollutant allowed in a water body that meets water quality standards by allocating loads from point sources and nonpoint sources (NPS) (USEPA, 2008). Because point sources are easier to trace, they have been the primary focus in pollutant control efforts. NPS pollution does not have a clearly defined inlet point and comes from many sources, from runoff of urban parking lots to the impacts of roaming livestock in streams.

As livestock enter water bodies such as streams, they disturb the riparian habitat and introduce pollutants such as bacteria into the system. The first attempt in regulating the negative impacts of cattle was through the Taylor Grazing Act of 1934. This act limited the number of cattle per pasture area and promoted rangeland ecosystems through the installation of fencing and vegetation management (BLM, 2011).

The two primary ways in which cattle affect stream water quality are through direct cattle presence in the stream corridor and from overland flow during storm events carrying NPS pollutants to the stream. There are many different best management practices (BMPs) that help reduce direct deposition, overland flow, or both. One practice that is widely used is establishing cattle streamside exclusion fencing because approximately 80 percent of riparian damage is due to cattle presence (Agouridis et al., 2004a). Fencing protects the riparian habitat by restricting cattle presence while still allowing the farmer to utilize the land around the water. Although cattle streamside fencing has been proven to reduce pollutant concentrations in water systems, the impact is not well documented because it is often costly to quantify (Zeckoski et al., 2007).

Farmers find it desirable to have the option to use 'flash grazing' to utilize forage or to benefit from streamside shade at a limited number of times through the year. Flash grazing is defined as the short-term introduction of cattle into pastures areas at a higher than normal density to quickly harvest vegetation. Under the Conservation Reserve Enhancement Program (CREP), farmers are prohibited from allowing cattle into the riparian areas, thus restricting flash grazing (James et al., 2007). Through this study, the effects of flash grazing on stream water quality were analyzed to help determine if flash grazing could be considered as an accepted

management practice which could provide farmers with additional cattle and land management opportunities.

This research focuses on cattle exclusion practices in the Shenandoah Valley, Virginia in Rockingham County near Keezletown, Virginia. The stream systems are part of the Potomac River Basin which ultimately flows into the Chesapeake Bay.

The main objective of this project is to assess the impact of short-term grazing practices on water quality parameters in agricultural headwater streams. To define the objective further, the following sub-objectives were evaluated:

- Determine if short-term introduction of cattle significantly increases pollutant concentrations
- Quantify the number of cattle that increase turbidity above a baseline concentration
- Calculate time for peak concentrations to return to baseline
- Determine if pollutant loads from a flash grazing event are larger than loads from storm events
- Assess differences in stream water quality between reaches with no cattle, free access cattle, and flash-grazing access over a two-year sampling period
- Compare changes of water quality parameter concentrations through permanently excluded and flash grazing reaches

2 Literature Review

2.1 Best Management Practices

A best management practice is a generic term for a practice that is implemented or installed with the intent of reducing or mitigating pollution. According to the USEPA (2003), there are three types of livestock BMPs designed to improve water quality: structural (e.g. stream fencing), vegetative (e.g. riparian buffers), and management (e.g. rotational grazing). These three types of BMPs reduce NPS pollution in three ways: reducing carrier mass and direct pollutant concentrations, reducing overland flow concentrations to water bodies such as streams, and remediation (USEPA, 2003). Along with reducing NPS pollution, BMPs have other benefits such as improving long-term soil productivity and reducing production costs (Johengen et al., 1989).

Some best management practices such as cattle exclusion fencing also promote the use of other BMPs. Such BMPs are called indicator best management practices because fencing implies that other BMPs such as off-stream waters may also need to be implemented in a given production system (Benham et al., 2005).

BMPs must be implemented and maintained properly to be effective. In order to determine BMP effectiveness, extensive and costly monitoring programs are often used. Therefore, there is a need to establish a systematic approach to evaluating such BMPs in order to improve quality. Understanding the effectiveness of BMPs includes knowing inputs into the system from non-agricultural sources such as urban straight pipes that may mask the inputs from agricultural lands. It is also important to understand the variability among each site. Since no two sites are the same, it is crucial to research how each site behaves individually in order to implement the best BMP (Robillard et al., 1992).

2.2 Buffers

A buffer is the area between a water body and a pollutant source. In agricultural settings, a buffer is designed to reduce the amount of pollutants entering a stream and is often vegetated with a variety of grasses, shrubs, and trees. Streamside cattle fencing creates a buffer which prevents cattle trampling, allowing for riparian vegetation to thrive.

To help promote the installation of buffers, in 1985 the United States Department of Agriculture established the Conservation Reserve Enhancement Program (CREP) which provides land

owners a cost-share for renting their land for conservation practices (Sweeney and Blaine, 2007). Through this program, the government rented approximately 45 million acres of highly erodible land to establish a natural ecosystem to reduce transport of sediment and excess nutrients from 10 to 85 percent depending on width and type of vegetation (Sweeney and Blaine, 2007).

When installing streamside fencing or growing a vegetative buffer, a major concern is often how wide or long should it be to be most effective. Research is being done to quantify the effectiveness of different types of buffers at specified widths to prevent certain pollutants from entering a water body (examples found below). The most effective width optimizes the buffer area as well as the percent reduction of pollutant loads. It is also important that the buffer is cost-effective for famers in order to optimize land and cattle management. A large distance between the stream and pasture reduces the amount of useable land for the cattle which may create a need for additional, costly feed.

Studies try to optimize the effectiveness of BMPs and provide varying results and suggestions since every site is different. For example, Vidon et al. (2008) found that when monitoring two – 130 meter reaches, one buffered and one not buffered, there were concentration reductions in nitrate, suspended solids, and fecal coliform. Scrimgeour and Kendall (2002) found that even buffer widths of 5 to 12 feet can improve stream water quality, benthic macroinvertebrates, and groundwater quality. Another study discovered that buffers should be the same width as the width of the cattle area in the uplands; however, the same study found that with high infiltration rates represented by a sand surface, a 1.37 meter buffer can reduce bacteria by 95 percent (Larsen et al., 1994).

With cattle exclusion fencing, a riparian buffer is naturally established as native vegetation thrives. Although the widths, lengths, and vegetation may vary, buffers are still a very effective way of reducing pollutant concentrations of overland flow into streams (Hughes, 2008).

2.3 Animal Stocking Density

Proper cattle-stocking density is critical to ensure forage and nutrients availability. Increasing cattle density (# of animals per unit area) puts more strain on the food and water supply of the landscape. Along with a decrease in forage availability, higher cattle densities increase fecal matter in the pasture.

One study in New York, which reviewed phosphorus concentrations for free-range cattle, found that the number of cattle in each pasture was proportional to the number of cowpies that were found near streams. Similarly, the largest herd produced more cowpies than the smaller herd (James et al., 2007). Although this is expected, it shows that managing the proper number of cattle may be important to water quality issues as well.

Densities also help define the influence livestock will have on water habitats. A large number of cattle in a small, confined area have the potential to be more detrimental to water quality versus a small number of cattle in a large area. Buckhouse and Gifford (1976) found that at a density of 2 ha/aum (hectares/animal unit per month), there were no significant public health hazards due to fecal coliform in runoff.

2.4 Pasture Characteristics

There are many factors that affect how much time cattle spend in the stream such as shade, water availability, or pasture size and shape. A smaller pasture with stream access will increase the time cattle are in-stream then when compared to a larger, similar pasture (Russell, 2010). Even if the pasture is the same size, the shape of the pasture can also affect cattle behavior and movement within water habitats (Russell, 2010). A third factor can be the length of stream within the pasture and the spatial reference of the stream. For example, a stream at the edge of the pasture may have less cattle impact than a stream that cuts a pasture in half because cattle will have to cross it to get to the other half of the pasture for forage. The greater the length of stream in the pasture, the more area the cattle have to enter.

In livestock pastures, riparian areas tend to host the majority of the trees because pastures are often excavated for crop production and easy cattle management. Livestock are likely to congregate for longer time periods in areas with trees for shade during the hot summer season or shelter during storm events. Because the density and time of cattle in the stream increases, streams are particularly vulnerable, especially when streamside exclusion fencing is not present. Providing trees for shade and shelter outside of riparian areas may reduce the time cattle spend in the stream and the number of cattle in the stream without the need for exclusion fencing (Zeckoski et al., 2007).

2.5 Alternative Water

If streams are the sole source of water for livestock, an alternative water source needs to be provided when streamside fencing is installed. Without fencing and an alternative drinking

source, livestock must enter the stream to drink. While in the stream, cattle are likely to defecate, which adversely impacts water quality (Gary et al., 1983). One study found that when troughs were available, total suspended solids (TSS) and *E. coli* bacteria were reduced by 95%, dissolved phosphorus by 85%, and total phosphorus by 57%(Franklin et al., 2009).

Providing off-stream water can be a very effective way for diverting cattle away from streams. A study in Virginia found that the time cattle spend in the stream zone decreased in-stream time from 13 minutes/day to 6 minutes/day when alternative water was provided (Bewsell et al., 2007). Other studies have found that off-stream water reduced the time cattle spend in streams by 99% after feeding and up to 80% for other times in the day (Miner et al., 1992).

Temperature can also be a key factor as to how much time cattle spend in streams versus their need for a water supply. One study found that when the outside temperature is between 62 and 72^{o}F, off-stream waterers reduced the time cattle spent in streams by 63% (Franklin et al., 2009). However, when the environment is considered stressful (> 72^{o}F) the availability of off-stream waterers had no effect on time cattle spent in-stream (Franklin et al., 2009). In stressful conditions, cattle use the stream for more than just drinking purposes. The water, as well as possible riparian trees, aid in cooling the animal.

When given two water sources, cattle tend to go with the source that is closest or the one they are the most habituated toward. However, when clean off-stream water is available, cattle will drink that water over other water of poor quality, so providing an alternative water supply may decrease the amount of time livestock spend in water bodies for drinking (Vallentine, 1989). One way to provide clean water to livestock is to pump groundwater into troughs in upland areas instead of taking water from the stream (Bewsell et al., 2007).

2.6 Specified Entrance Points

Instead of fencing cattle entirely out of the stream, planned entrance points may be a beneficial option when alternative water is not available or when cattle need to cross the stream to get to other pastures. Creating an alternative entrance point can reduce the amount of time cattle are in the stream and reduce cattle influences along the entire reach (Russell, 2010). Thus, the amount of feces and urine deposited directly into the stream is reduced as well as the potential for erosion and nutrients to be re-suspended (Russell, 2010).

Cattle are habitual animals: they tend to walk in areas they normally walk and enter streams in the same location each time. Agouridis et al. (2005) found that when cattle had free access to

an entire reach, they favored certain sections of a stream. These areas may represent places with shade, easy access, or even a favorable stream bed material that is easy to traverse. Stabilizing these favorable sections instead of fencing the entire reach may have a significant positive improvement on water quality.

Alternative entrance points are often lined with a man-made material to stabilize the stream banks and bed since there will be increased animal traffic in these areas. Stabilizing materials can be made from a variety of materials and should be selected based on site-specific characteristics (Russell, 2010).

2.7 Cattle Impacts on the Stream Environment

Cattle are a major source of non-point pollution in agricultural watersheds (Vesterby and Krupa, 1997). Livestock can introduce many pollutants into the aquatic ecosystem including bacteria, nutrients, and sediment (from trampling stream banks and disturbing the stream-bed). Bacteria can enter the stream from cattle direct deposition of feces and in runoff during storm events. Cattle also tear away at the natural riparian habitat through trampling the ground and uprooting vegetation. Livestock streamside exclusion fencing has the potential to eliminate direct deposition and reduce pollutants in overland flow by providing the opportunity for vegetation in the fenced riparian corridor to thrive.

2.7.1 Stream Bed and Bank Impacts

When cattle have unrestricted stream access, they trample stream banks increasing the potential for erosion which in return degrades water quality. Streambank trampling can impact stream channel morphology, hydrology, in-stream and bank vegetation, and aquatic and riparian wildlife (Miller et al., 2010). Cattle can also degrade the banks by scratching their bodies against any protruding ground. Smoothed bare areas and eroding-terrace cuts can be explained by this scratching (Peppler and Fitzpatrick, 2006).

Streambank sediment loss increases erosion and re-suspends bacteria and other nutrients that were trapped in the soil (Franklin et al., 2009). When the soil erodes, unstable ground is left which provides a poor environment for riparian vegetation to thrive. Therefore, not only are the cattle re-suspending the sediment, but since the vegetation stabilizes the soil, even more sediment erodes away with a lack of vegetation. Banks get eroded when the forces of the flowing water are greater than the forces holding the soil in place, which is also known as being in a state of disequilibrium (Reynaud et al., 2003).

Vegetation reduces the force the water exerts on the soil as well as increases the forces holding the soil together. Banks become unstable under conditions of easily eroded soil with very little vegetation and smaller particle sizes (Miller et al., 2010). With the exclusion of livestock, native vegetation will have the chance to grow and thrive near the stream. Exclusion will also help introduce vegetation that needs a longer time to get established such as shrubs and trees (Miller et al., 2010).

In a study conducted in Lancaster County, Pennsylvania, Scrimgeour and Kendall (2002) found that the most prominent observation of eliminating cattle access to streams was increased vegetation along the stream channel with the stability of the assessed stream habitats increasing from 74 to 94% compared to stream habitats with cattle access. Scimgeour and Kendall (2002) also found that sediment yields decreased post-installation of cattle fencing during low-flows but significantly lowered sediment concentrations during storm flow. Post fencing, the overall yield reduction of suspended sediments was 46% at the outlet. When comparing yields to the control site, the outlet had an overall reduction of 37% while the further upstream point had a reduction of 44% of suspended sediments.

A study done in Kentucky used two bedrock streams to compare cross-sectional areas of cattle access and fenced stream sections. Along each stream were three different levels of cattle access - BMP system (alternative water) and exclusion fencing, BMP system only (just alternative water), and free access/control (Agouridis et al., 2005). Through this study, it was found that streambank erosion and soil loss is significant with treatment type, cattle in and near the stream, and flow. There was not much significant difference between the two cattle-restricted sites; however, there was a significant difference between those two treatments and the free cattle access site (Agouridis et al., 2005). It was also found that more damage to the stream was during wet periods which can influence cross-sections within a few hours to a few days after a wet period (Agouridis et al., 2005).

The suspension of sediment into the water column can also be transported downstream causing a more turbid stream. High turbidity decreases the amount of sunlight that reaches the stream bed where aquatic vegetation lives and grows. Without the vegetation, organisms such as macroinvertebrates and fish will decrease in numbers due to an unhealthier habitat.

Another reason it is important that livestock do not cut back the banks is that it changes the channel morphology of the stream. Streams naturally tend to meander through eroding banks;

however, when cattle degrade the banks, it disrupts this natural pattern and increases the erosion process (Peppler and Fitzpatrick, 2006).

When determining the sources of high sediment yields in the stream, the entire drainage area should be analyzed. Cattle can break up soils on the landscape that can be transported through overland flow to the water body. One study in Australia found that cattle exclusion on the watershed scale reduced sediment concentrations up to 90% (Vidon et al., 2008). Also, more total suspended solids can be found in areas of a long history of waste application due to the buildup of residual organic material on the surface of the soil (Soupir, 2003).

2.7.2 Nutrients

2.7.2.1 Nitrogen (N)

Because nitrate is very mobile in the water and soil system, it is often difficult to capture and quantify. Plants and animals take in and give off nitrogen in the aquatic system, which makes it hard to determine how much is increasing due to cattle influence in streams. According to Scrimgeour and Kendall (2002), cattle can cause an increase of in-stream nitrogen in five ways:

1. Increased in overland flow during storm events
2. Reduced denitrification in streams
3. Increased uptake in stream zone
4. Increased deposition of feces and urine
5. Increased contribution of nitrogen from eroded stream bank sediments

Nitrate concentrations have been found to decrease in pasture streams in the summer months due to biological uptake within the stream ecosystem (Jarvie et al., 2008). Vidon et al. (2008) also found that nitrate concentrations did not change in the summer and fall months where cattle had access to the stream. A study by Hughes (2008) found no significant difference of nitrate or ammonium concentrations in streams where cattle had unrestricted access versus streams without cattle.

Agouridis et al, (2004a) also did an experiment comparing two different streams in Kentucky with three different treatments: 1) BMPs with cattle exclusion using a 9.1 m wide riparian buffer and a 3.7 m wide stream crossing, 2) BMPs with no fencing, and 3) complete stream access with limited BMPs (control). Within these three treatments, nitrogen as ammonia and nitrate were analyzed with bi-weekly grab samples. When cattle were noticed in the stream, samples

were taken. Ammonia-nitrogen concentrations were significantly greater in the control versus the two treatments. Nitrate-nitrogen also had a significantly different median concentration between the two BMPs treatments and the control treatment during times when cattle were present and absent. Because nitrate-nitrogen did not vary between when cattle were present or absent, there may be other factors in the landscape causing different concentrations between treatments. Nitrogen concentrations also appeared to vary seasonally (Agouridis et al., 2004a).

When reviewing baseflow data, it was found that nitrogen concentrations and yields decreased 9-17% after installing cattle fencing (Galeone et al., 2006). However, during storm events, fencing decreased nitrogen yields up to 19% with total nitrogen concentrations fluctuating at different sampling points post fencing. When comparing to the upstream, control site, total and dissolved nitrate decreased 19% and 18% respectively while a further upstream point had an increase of 21% and 15% respectively. This was contributed to the upstream agricultural conditions beyond cattle influence (Scrimgeour and Kendall, 2002).

Soupir (2003) compared runoff concentrations of three different natural fertilizers: cowpies, turkey litter, liquid diary manure, and a control with no fertilizer using a rainfall simulator. Among the treatments, cowpies placed on the landscape had the highest concentrations of total nitrogen (TN) at 9.8 mg/L, which was three times higher than the two other fertilizer types.

2.7.2.2 Phosphorus (P)

Cattle also have a great impact on phosphorus concentrations in the landscape. Because the phosphorus found in livestock deposition is more readily available than the phosphorus found in plant tissue, stored phosphorus in the soil and plants is reduced as cattle forage (Zeckoski et al., 2007). Not only do livestock change the state of phosphorus, but as cattle eat the vegetation, walk away, and then defecate somewhere else, they unevenly distribute the nutrients throughout the pasture (Brannan et al., 2001).

Summer and fall time generally have a higher concentration of pollutants such as phosphorus due to the increase time of cattle in streams and lower base flows (Vidon et al., 2008). A study done by Hughes (2008) found that phosphorus concentrations were highest in areas of excluded cattle versus the rotationally grazed and meadow lands. According Jarvie et al. (2008), there are three main ways particulate phosphorus can have high concentrations in livestock pastures:

1. Sorption of phosphate and stream precipitation of ferric oxyhydroxides

2. Cattle presence through trampling that reduces bank stabilization and disrupts channel mechanics
3. Through runoff during storm events that is often underestimated through sampling due to the flashy nature of headwater streams

Agouridis et al. (2004a) also tested for total phosphorus (TP) concentrations in the bi-weekly grab samples. When cattle were present in the streams, TP concentrations varied statistically between the BMP treatments and control; however, there was no significant change when cattle were absent. Control treatment median TP concentrations were significantly higher than those of the BMP treatments. Within the same study, orthophosphate was related more to high flow events than with cattle presence or treatment. When Soupir (2003) studied overland flow concentrations of different natural fertilizers, cowpies had the highest concentration of sediment bound phosphorus (SBP) at 0.73 mg/L.

During low flow, Galeone et al. (2006) found that total phosphorous concentrations increased from pre- to post-fencing installation; however, this was contributed to dissolved P from upstream alternative agricultural influences. The increase is also represented through storm flow with increase concentrations of TP concentrations. In contrast, the TP yield decreased post-fencing 22% for the outlet site and 46% for the upstream site (Scrimgeour and Kendall, 2002).

Another study in the Cannonsville Watershed in southeastern New York points out the amount of phosphorus load that was inputted into the stream system by livestock. With 5,100 milking cows in the free-access pasture for 6 hrs/day for 270 days and 4,500 heifers/dry cows in the pasture for 24 hr/day for 310 days, 2,800 kg of phosphorus was directly deposited into streams while 5,600 kg of phosphorus was within only 10m of the stream. It was also found that this contribution of phosphorus load represented approximately 10% of agriculture phosphorus loadings in the watershed (James et al., 2007).

2.7.3 Bacteria

Fecal coliform concentrations are a major concern in many agricultural watersheds due to free-range access and concentrated livestock facilities. On average, a cow will defecate 12 times per day with a total of 18,144 g/AU of feces. A study on the Dry River in Virginia found that 36% of fecal coliform concentrations were from direct deposition (Masters, 2002).

When animal feces is deposited on land, bacteria has a much higher die-off rate than when deposited directly in the stream; therefore, direct deposition is more of a source of fecal coliform than that of over-land flow (Masters, 2002). However, bacteria can live within the soil column for 13-20 days, live for months attached to sediment and solids, and live up to a year in the livestock feces (Masters, 2002). Buckhouse and Gifford (1976) found that coliform bacteria can live for at least a summer season in low intensive sun. The dying rates of fecal coliform were also found to be much shorter in soils with a higher percentage of clay particles (Howell et al., 1996).

With resuspension of sediment through cattle trampling, bacteria can also be resuspended into the water column degrading water quality. In a square meter area, from 1-760 million fecal coliform organisms can get resuspended when cattle enter the stream (Larsen et al., 1994). However, Buckhouse and Gifford (1976) also found that the radial area of one meter around a fecal deposition on land is at risk of fecal contamination and not beyond that distance; therefore, only piles near or in stream may contribute to water quality contamination of fecal coliform.

One study found that cattle in-stream produced 12.5 times greater fecal coliform than a stream with where no cattle are present with concentrations varying from 380-20,000 FC/100 mL with cattle present and less than 250 FC/100 mL with no cattle present (Masters, 2002). When cattle were introduced, concentrations increased to greater than 10,000 FC/100 mL, which is 40 times higher prior to cattle inclusion (Masters, 2002). It takes a maximum of several months for the bacteria to go back down to base level concentrations after cattle are removed (Larsen et al., 1994).

Soupir (2008) found that plots with cowpies had the highest flow-weighted concentrations of *E. coli* at 200,000 cfu/100ml and fecal coliform at 234,000 cfu/100ml at baseflow conditions. Similarly, during rainfall events, the cowpie treatment had the highest concentration of bacteria with *E. coli* ranging from 37,000-300,000 cfu/100ml and fecal coliform ranging from 65,000-300,000 cfu/100ml.

Bacteria are also a water quality issue for TMDLs. In order to understand why a stream is impaired, a watershed evaluation of different sources is assessed. The Big Otter River in Virginia had a TMDL for fecal coliform in 2001. The 30-day geometric mean Virginia State standard for fecal coliform was 200 cfu/100ml with an instantaneous standard of 1000 cfu/100ml (Brannan et al., 2001). With a 5% margin of safety (MOS) of 10 cfu/100ml, the 30-day geometric mean standard becomes 190 cfu/100ml (Follett and Hatfield, 2001, pp. 17-43).

However, when the watershed is modeled for a 100% reduction of anthropogenic straight pipes and direct defecation from cattle, the 30-day geometric mean will still not decrease to 190 cfu/100ml (Brannan et al., 2001).

2.7.4 pH and Salinity

The pH can also be considered an important water quality indicator but is not often mentioned in studies because it generally does not fluctuate significantly. The pH in both BMP treatments in Agouridis (2004a) study was significantly lower than the pH in the control treatment when cattle were both absent and present. Because pH did not change significantly from cattle being present or absent, other external factors can be attributed for changes in pH other than cattle activity.

Although salinity is typically not affected by cattle exclusion, it affects cattle behavior, which in turn could affect cattle presence in the stream as well as health of the animal. Concentrations of 7,000 ppm of soluble salts is not harmful to an animal but caused them to drink less and potentially spend less time in the stream channel (Embry et al., 1959). Conversely, a concentration of 10,000 ppm could be toxic to livestock (Shukla, 2000).

2.7.5 Benthic Macroinvertebrates

Benthic macroinvertebrates (macros) are the larva stage of many insects that live on the stream bed. They are often used as a sign of water quality such as the Virginia Save Our Streams Program (VA SOS) because certain insects are very intolerant to certain water conditions. A healthier stream is comprised of a variety of tolerant and intolerant insects. Macroinvertebrates are often studied because collection and identification of the bugs are easy and require few equipment and people (Frondorf, 2001).

Macroinvertebrates are generally very abundant in streams and rivers, much more so than other biological indicators such as fish (Frondorf, 2001). They also are good indicators of stress on the aquatic environment because they are not very mobile as opposed to fish which can swim around to various parts of the stream or river (MDDNR, 2004). Because of the short life span of macroinvertebrates, they quickly respond to pollutants and their stressors, which give scientists a snapshot of the water's quality (Frondorf, 2001). Stressors include nutrients, sediment, and organic and inorganic toxicants (MDDNR, 2004). An excess amount of sediment in the aquatic ecosystem can put stress on the benthos by changing the water's movement and decreasing

food quality (Frondorf, 2001). Once evaluations are made based on the macroinvertebrates, best management practices can be recommended to improve water quality.

For these reasons, benthic macroinvertebrates are also used when evaluating water quality improvements pre- and post-cattle fencing. Galeone et al. (2006) found that post fencing, the quality of benthic macroinvertebrates improved overall. This improvement could be due to the increase of streamside vegetation that allows for more trapping of sedimentation, which can increase habitat for macroinvertebrates. When comparing the control sites to the downstream, outlet location, the benthic macroinvertebrates improved in all indices categories but only three out of the five biological indicator indices for the upstream sites.

2.8 Flash Grazing

There are many different ways to manage livestock such as mob grazing, controlled grazing, deferred grazing, rotational grazing, and flash grazing. Because it is not economically feasible or realistic to fence separate riparian pastures for rotational grazing, it is important to develop a plan for livestock management that includes cattle and forage distributions (Platts and Nelson, 1985). Agouridis (2004b) outlined three practices for acceptable grazing in riparian areas:

1. Limiting time of grazing
2. Limiting livestock density
3. Limiting livestock time in pastures when banks are most susceptible to damage

Understanding the impacts of flash grazing can provide additional management opportunities for farmers and land owners. Under the CREP program, managers are not allowed to let cattle graze within the cost-shared fencing. Providing the opportunity to allow cattle to feed on the riparian vegetation and/or to gain shade under certain conditions may make managers more amenable on installing exclusion fencing. As research continues, flash grazing has the opportunity to be considered a BMP with the installation of streamside exclusion fencing as compared to continuous free access cattle. Already in Minnesota, the United States Department of Agriculture (USDA) has declared rotational animal densities as a best management practice and helps farmers develop grazing and livestock management plans (Miller et al., 2010).

One study in Minnesota looked at the impacts of continuous grazing (CG), short-duration grazing (SDG), and no grazing (NG). Continuous grazing sites had free range cattle without any fencing. Short-duration grazing sites rotated cattle within pastures and paddocks to utilize

riparian vegetation. No grazing sites were defined as those with no cattle within 5 km of the sampling locations. Many different parameters were measured for each of the grazing practices. The parameters that were most influenced by cattle were the riparian management variables based on soil compaction, cattle impact, and vegetation type. Soil compaction had a significant difference among all three managements with CG as the highest compaction, NG having the lowest, and SDG being in-between. However, soil compaction is unavoidable with any density of animals. Although compacted soil reduces infiltration through the reduction of macropores, a higher soil compaction may also reduce bank erosion because the soil is more tightly packed. Vegetation characteristics such as density and height were based mostly on livestock management conditions such as cattle density, duration, and the type of vegetation (Miller et al., 2010).

Another parameter that was measured was benthic macroinvertebrate index of biological integrity (IBI) scores, and although all scores were generally low, CG, SDG, and NG were worst, better, best scores respectively. Again, the same pattern was found when measuring the stability of banks at each grazing practice (Miller et al., 2010).

In addition, NG and SDG sites were evolving to more of an unstable morphology while the CG sites degraded past Schumm's channel evolution model which illustrates the natural adjustment of the stream channel. There was more quality vegetation along reaches within the SDG versus CG. Miller et al. (2010) also found that unmanaged trees can prevent vegetation from growing underneath which could promote more bank erosion.

In conclusion of the Minnesota study, there were differences in testing parameters among all three management types. There were differences found between the short duration grazing and the other two. There was a noticeable impact comparing the short term and the non-grazed sites, but the impact is not as severe as the continuously grazed sites. Part of the problem of defining between SDG and CG impact on pollutant concentrations was the inability to control upstream row-crop conditions (Miller et al., 2010).

2.9 Alternatives to Fencing

Although fencing is a popular solution to keeping cattle out of streams, there are also alternatives that do not include a physical barrier. Solutions such as understanding animal behavior, cattle management, and even virtual fencing may be cheaper, easier, or even less time consuming. Fencing certain areas may be difficult or even impossible due to a difficult

landscape, so an alternative may be necessary for farm managers in order to protect riparian areas.

2.9.1 Animal Behavior

Through the studies and teachings of Dr. Temple Grandin, options of training cattle versus forcing cattle are being understood. Most of the processes Dr. Grandin proposes involves handling cattle in shoots and facilities; however, the same ideals can be applied to pasture cattle as well (Grandin, 2011).

Cattle behavior is important to understand because it can give an insight as to how management can hone in and create the best management decisions for cattle health, productivity, and the environment. One behavioral adaptation noticed by Agouridis et al. (2004b) was that cattle often avoided trees even during rainfall events whereas the typical perception is that cattle use the trees as shelter from the rain. Agouridis et al., (2004b) also found that the amount of time cattle spent in streams was most related to the amount of daylight. The increase could be the result of more daylight for grazing or higher temperatures. As one study found, as air temperature got higher, the amount of time cattle spent near streams grew (Parsons et al., 2003).

2.9.2 Cattle Management

Understanding how to properly manage livestock numbers and eating habits may reduce the amount of time cattle spend in streams and therefore may eliminate the need for fencing. For example, a study done in the mountainous western United States found that cattle wandered further away from the stream during the early parts of summer versus late summer (Parsons et al., 2003). Grazing cattle in pastures with unfenced areas may be most beneficial in the early summer because vegetation throughout the pasture in the early summer is often most desirable. Therefore, cattle will roam more freely and not tend to favor the riparian areas that are luscious throughout the summer. Managing cattle away from the riparian zone in early spring allows for more growth of riparian during the summer season (Elmore and Kauffman, 1994). Platts and Nelson (1985) found that in 23 out of the 25 observations, cattle used streamside vegetation twice as much as vegetation in the uplands.

It was also found that the animals were the furthest from the stream in the early mornings and gradually became closer and closer as the day progressed until late afternoon where they moved further upland again. Because more cattle were found near the stream in early spring, it

was also found that there were more fecal piles that could contribute to poor water quality (Parsons et al., 2003).

2.9.3 Virtual Fencing

Another alternative to a physical fence is the new and upcoming technology of a virtual fence. A study in Australia researched the idea of creating boundaries using GPS technology. A virtual fence was made with GPS points representing the fencing, and through satellite technology, when cattle wearing the high-tech collar crossed the virtual fence, music started playing. If the animal continued to walk further past the fence, a shock was given encouraging the cattle to go back. Cattle were responsive to the method within an hour and remained stress free. Although each collar is costly at approximately $50 per collar, it may be a beneficial alternative when a physical fence is too challenging to install (Alison, 2007).

2.10 Stakeholders

Getting stakeholders involved in helping improve water quality is often difficult because of costs and time involved in installing BMPs. With cost-share programs, stakeholders are responsible for providing the upfront cost, full installation for BMPs, and any additional maintenance costs including parts and labor (VADCR, 2011). Benham et. al (2005) created a five point scoring system that measured BMPs based on quality, site selection, implementation, and maintenance. Results showed that cost-share and noncost-share BMPs had no significant statistical difference for indicator BMPs such as cattle exclusion fencing; however, the mean for the cost-share BMPs were higher, resulting in a better overall score.

Because it is ultimately the stakeholders' responsibility to install BMPs and keep it up to code, it is important to understand stakeholder perception. Stakeholders in four different watersheds were interviewed to determine their concerns with BMPs. The most important factor farmers mentioned when questioned about exclusion fencing is stock management (Bewsell et al., 2007). Cattle safety was designated the primary reason for fencing which might include fencing around a dangerous pipe, for example. Other reasons stakeholders would install fencing are to create farm boundaries, prevent cattle from getting trapped in a waterway, keeping cattle from parasites in the water, and pressure from the community (Bewsell et al., 2007).

In preparing the VA Cooperative Extension publication, Zeckoski et al. (2007) interviewed selected producers to understand their reason for either adopting or not adopting streamside exclusion fencing. The main reasons for adopting streamside exclusion fencing was for benefits

such as getting the cost-share for providing off-stream water troughs. The second most popular reason for installing fencing was because it is seen as the "right thing to do" for the environment. Another advantage to fencing was that it allows for easier movement of cattle for rotational grazing and to isolate individual cattle for veterinarian visits and other reasons (Zeckoski et al., 2007). The most prominent reason for not adopting streamside exclusion fencing was because it promotes the over-growth of vegetation between the stream and the fence (Zeckoski et al., 2007). Some landowners find the natural, overgrowth of vegetation unsightly and cause a nuisance to the fence. To make the buffer area between the fencing and stream more slightly, one farmer flash grazed the riparian zone with sheep to "mow" the vegetation down (Zeckoski et al., 2007).

2.10.1 Cattle Exclusion Economics

Although fencing is expensive, there can be a benefit as well as a cost. With implementation of fencing and off-stream waterers, cattle weight and milk production can even increase. Over a 10 month period, one producer noticed a weight gain of 5-10% in their cattle with the installation of streamside fencing (Zeckoski et al., 2007). Also, because the cattle are not drinking out of water that may contain a high concentration of bacteria, diseases such as pink eye or mastitis are also possibly reduced (Zeckoski et al., 2007). Salmonellosis and leptospirosis are the most common diseases associated with contaminated water supplies (Buckhouse and Gifford, 1976). A decrease in infection reduces the need for costly antibiotics and decreases the chance of cattle lameness and death.

2.11 Summary

Although each stream may be considered a relatively small body of water, the regional impact of many streams has great implications. Efforts to clean up the nation's water systems include farmers implementing livestock exclusion fencing to keep animals out of stream water. Through the studies and articles mentioned, livestock have a large influence on not only water quality but the ecosystem that surrounds them. Fencing may not be the perfect solution for every situation, but through understanding animal behavior and good cattle management, smarter decisions can be made to help clean up the waters that are very important to humans, animals, and the ecosystem.

3 Methods

3.1 Site Descriptions

The project site is located in Rockingham County, Virginia (fig. 3.1). The site was chosen because it was easily accessible, had permanent water samplers already in place, and the operators were known to have previously flash grazed. Permanent fencing was installed on this farm in 2009, so cattle were excluded from the streams for approximately two years before sampling for this research was initiated. Cattle were also permanently excluded from the CREP zone. However, the farmer occasionally allows cattle to flash graze the riparian zone outlined in figure 3.1. While grazing in the riparian zone, cattle still have access to the pasture area at all times.

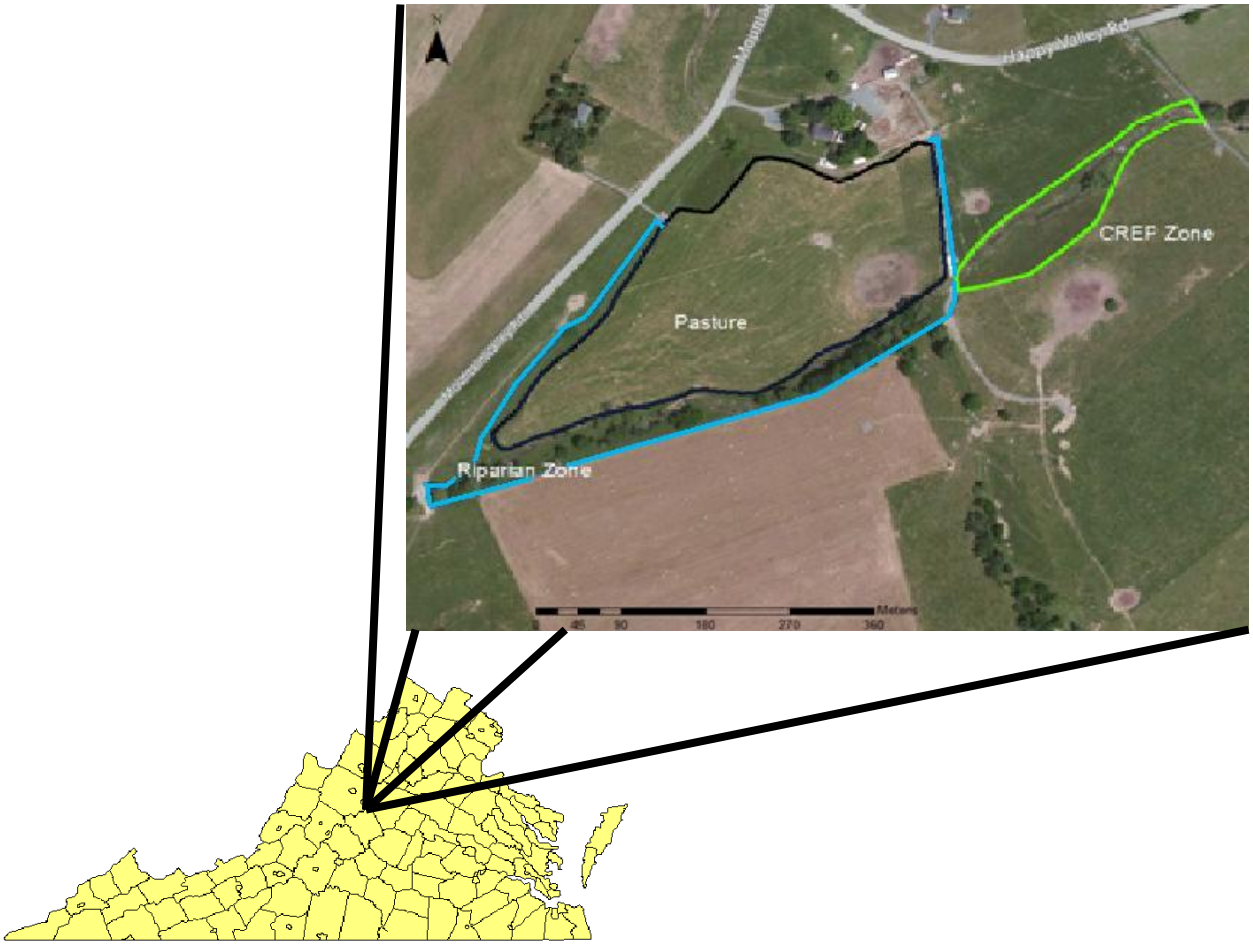

Figure 3.1: Project site pasture area, riparian zone for flash grazing, and CREP fencing zone located in Rockingham County, Virginia. (Source: Google Earth)

There were two streams: Cub Run (CR), and an unnamed tributary referred to here as Mountain Valley Road (MV) tributary. Both streams were first order headwater streams where MV flows into CR downstream of the study area. Cub Run eventually flows into the South Fork Shenandoah River, then to the Potomac River, and ultimately into the Chesapeake Bay. Both streams have unrestricted cattle access upstream of the study site. Upstream from the study, MV flows through an old barnyard/farmstead presently used to pasture and winter-feed dairy replacement heifers whereas upstream CR has beef cattle on pasture.

The MV tributary is a relatively straight, small stream with baseflow at approximately 5 L/s. As seen in figure 3.2, tall grasses are the primary vegetation along the banks with only one tree along the study reach. The reach length accessible during the flash grazing study is approximately 356 m, and the MV reach from Mountain Valley Road to the confluence to Cub Run is approximately 467 m.

Figure 3.2: Mountain Valley Road Tributary looking downstream (Source: Nancy Maschke)

Unlike MV, CR (fig. 3.3) has no major anthropogenic influences, and upstream of the free-range cattle pasture is mostly forest. Cub Run has a greater flow than MV with a base flow of approximately 9.5 L/s. The stream has a more natural meander than MV and the bed material is cobble/stone, which promotes more riffles. Cub Run's riparian zone has numerous hardwood trees and does not have the heavy grass vegetation like MV. The total length of Cub Run within the flash grazing zones is 444 meters, and the upstream CREP zone is 231 meters long.

Figure 3.3: Cub Run looking downstream (Source: Nancy Maschke)

3.2 Sampling

Three main types of sampling schemes were used: flash grazing, weekly, and storm. The weekly and storm samples used in this research are part of a more comprehensive study. The data from these samples were incorporated in this research project to get a broader understanding of the impact that streamside fencing and cattle management practices may have on water quality. The two flash grazing studies were sampled in July, 2011 (Study 1) and August, 2011 (Study 2).

3.2.1 Flash Grazing Sampling

The flash grazing study was done in three periods: baseline, cattle influence, and recovery referred to as periods 1, 2, and 3 respectively. Baseline (period 1) consisted of the first two days of the study in order to determine pollutant concentrations before cattle were introduced to the riparian area. The cattle influence period (period 2) was the following two days of sampling, and cattle were able to move freely throughout the MV and CR flash grazing reaches as well as adjacent pasture area. In order to quantify the time it takes pollutant concentrations to return to a baseline level, the last day of the study (period 3) was sampled when cattle were prevented from entering the streams.

As shown in figure 3.4, eight automated samplers (ISCOs) were used. Stations MV1, MV2, CR1, and CR3 were permanent and were in the field for two years prior to this study. Stations MV1b, CR2, CR2b, and CM were added in order to get a better representation of characteristics within the study site.

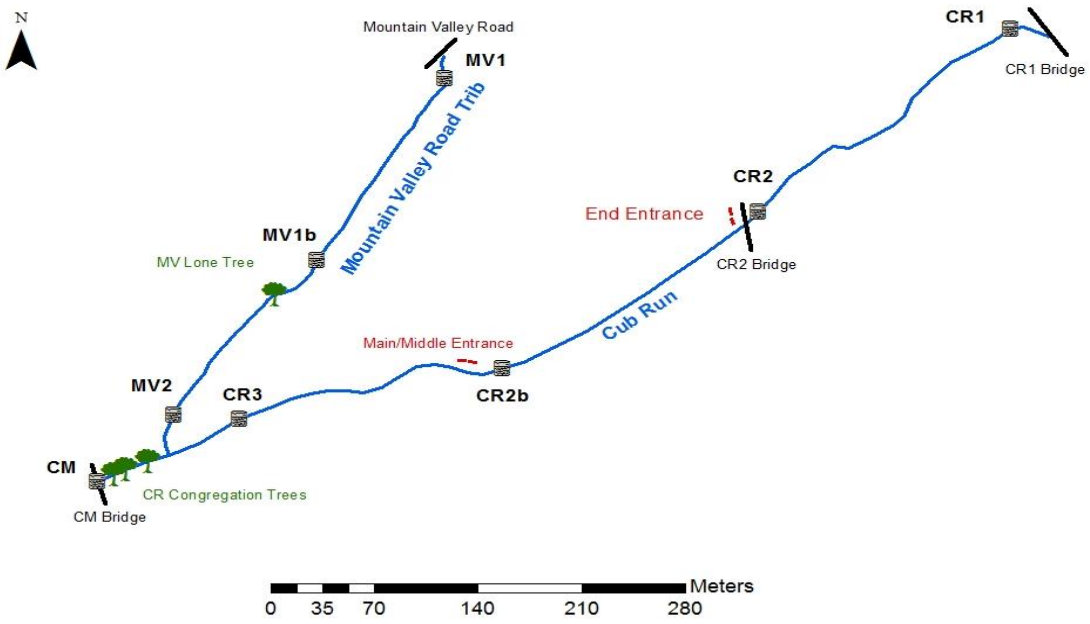

Figure 3.4: Schematic of study site showing sampling locations

The newly added ISCOs were placed upstream of points of high priority. Because the farmer had previously flash grazed, he had noticed that on MV, cattle tended to congregate at the single tree on the reach. Therefore, an intermediate sample point, MV1b, was placed just upstream of this tree. Because cattle were noticed to congregate at the confluence of MV and CR, a sampling station, CM, was placed below this area. Additional areas of priority included the main entrance point from the pasture to the riparian zone, CR2b, and the end entrance upstream of the study site along Cub Run, CR2 (control).

Each ISCO was programmed to take a 120 ml subsample every 15 minutes. Each 1-L sample bottle thus represented a composite of eight subsamples representing a two-hour composite. The 15-minute interval was chosen in order to capture brief instances of cattle impact. Sampling could not have been taken in increments less than 15 minutes due to ISCO limitations. Two hour composites were used to ensure that spikes could be seen without having to increase sample frequency.

Samples were removed from the ISCOs twice a day at 6:00 and at 16:00 and placed in ice filled coolers for transport to the lab for pollutant concentration analysis. The ISCOs were also filled with ice (fig. 3.5) during collection time periods to keep the samples cool.

Figure 3.5: Automatic sampler (ISCO 6712) with 24 1-L bottles. (Source: Nancy Maschke)

3.2.2 Cattle

For Study 1 there were 30 cattle (Angus cows) and 7 calves in the pasture that were able to go into the riparian zone. Because it was later in the season, Study 2 had 30 cattle and 12 calves.

3.2.3 Determining Baseflow Conditions

Both of the studies were done during baseflow conditions for several reasons. First, the project was designed to, as accurately as possible, mimic real-life situations. Because farmers would be likely to flash graze during periods of drought for food or hot weather for shade, this practice would imply that flow would be during periods of baseflow.

Secondly, baseflow conditions would be the easiest way to eliminate outside factors such as pollutants from land runoff that could cause additional inputs into the system. Previous storm data at this site showed that pollutants such as bacteria increase greatly with rainfall events.

Also, at baseflow conditions it is assumed that the riparian areas are dry and the soil has a low moisture content. When soil has a greater moisture content, cattle trampling can have a greater impact on the ground surface. Conducting the study during periods of low soil moisture allows for easier replication and standardization.

To ensure that baseflow conditions were present during the flash grazing studies, flow was measured once during Study 1 (20 July 20 2011) and twice during Study 2 (16 and 19 August 16 2011). Flow was measured using the equal-width flow measurement technique with a Marsh McBirney flow meter at each permanent ISCO station (MV1, MV2, CR1, and CR3) and at the CM site to capture the flow downstream of the confluence.

3.2.4 Weekly Sampling

Grab samples were collected weekly, on the same day from June 7 2010 to 16 November 2010 and from 19 May 2011 to 16 August 2011. Samples were collected at the two permanent ISCO stations on CR (CR1 and CR3) and two at MV (MV1 and MV2). The flash grazing CR1 was labeled CR1b during the weekly grab samples. CR1a was an additional sample that was taken just upstream of CR1b, which is also just upstream of the CR1 bridge cattle crossing. Sample time was rotated each week in order to help capture any diurnal variations.

Weekly grab samples were collected mid-stream and mid-depth in a 250ml bottle for bacteria analysis and in a 1-L bottle for TSS and nutrient analysis. From the 1-L sample, 2-10ml subsamples were taken in scintillation vials for total nutrient analysis and 3-10ml filtered subsamples were collected for dissolved nutrient analysis.

3.2.5 Storm Sampling

For the 2010 sampling season, four storms events were sampled on 13 July, 14 July, 27 September, and 30 September. For the 2011 season, five storms events were sampled on 17 May, 8 July, 15 August, 5 September, and 12 October. Storm samples were collected using the four permanent ISCOs. When weather forecasters predicted a storm, the ISCOs were programmed to take a subsample every 10 minutes with six subsamples in each 1-L bottle comprising a one-hour composite.

3.2.6 Quality Control/Quality Assurance

Quality control and quality assurance checks were also run through various procedures of this research to ensure the most accurate data. Appendix E and F show a comparison between the manual grab samples and ISCO samples to ensure that the modes of collection are comparable. Other checks such as determining residual bacteria in samplers and supplies can be found in Appendix E and F as well.

3.3 Sample Analysis

3.3.1 pH/Electrical Conductivity (EC)

The pH and electrical conductivity were measured using a Hanna Hi 98129 Combo meter. The instrument was calibrated each day before it was used with a 3-point (4,7,10) pH calibration and electrical conductivity calibration using a standard solution of 1413 µS. At the end of the day, the meter was checked with the standards to assess instrument drift. The meter was rinsed with distilled (DI) water between samples.

3.3.2 Turbidity

Turbidity was measured using a HACH 2100Q Portable Turbidimeter calibrated using a 10 NTU stock solution. To ensure that particles had not settled, the stock vial was inverted several times, wiped off with a Kim Wipe to remove any finger prints, and placed immediately in the machine. After calibration, the 10 NTU standard was inverted, wiped, and run again for an initial measurement. The same was done after samples were run to find instrument drift. The Turbidimeter has a maximum reading of 800 NTU.

3.3.3 Total Suspended Solids (TSS)

Total suspended solids, or TSS, is defined as the mass of particulate matter per unit volume. TSS is often sediment but can be any matter that is suspended in the water column. To capture the solids from the water, a Millipore glass fiber filters with a 0.7 um pore size, 47 mm diameter, and 90% porosity is used. A beaker with an open bottom and a magnetic bottom perimeter is placed over the filter to hold it in place while the water is pulled through by means of a vacuum pump.

In order to help reduce glass dust from the manufacturing process, the filters were rinsed three times with DI water and then placed on a metal tray. Samples were then dried in the oven at 105^{o}C for at least two hours then placed in a dessicator for 15 minutes to cool. The filter papers were weighed to 0.xxxx mg and placed in labeled covered petri dishes to ensure that dust or particulates do not contaminate the filter.

Water samples were then run using the same process. The total suspended solids, total filtrate volume, initial filter paper weight, and final filter paper weight were used to calculate total suspended solids as:

$$TSS\ \left(\frac{mg}{L}\right) = \left(\frac{final\ weight\ (g) - initial\ weight\ (g)}{total\ filtrate\ volume\ (ml)}\right)\left(\frac{1000\ (ml)}{(L)}\right)\left(\frac{1000\ (mg)}{(g)}\right) \quad (1)$$

3.3.4 E. Coli Bacteria

Escherichia coli or, *E. coli*, bacteria was tested within 24 hours of collection in order to preserve the integrity of the sample. Two replicates were created using IDEXX Quanti-Tray 2000s to get a clear representation of the water sample. The average, upper, and lower confidence levels of *E. coli* concentrations were found using the procedure outlined in Hurley and Roscoe (1983). Dilutions of the stream sample to distilled water were determined using a guess and check system. The greatest dilution 1 or 100% of stream sample was used first, and diluted further in magnitudes of ten.

3.3.5 Nutrients

After collection, the samples were also poured into scintillation bottles for nutrient analysis and kept frozen until analysis. Two – 10ml composites were not filtered to be analyzed for total nutrients. Three – 10ml composites were filtered for dissolved nutrient analysis. For the flash grazing study, two of the ISCO samples were composited to create a four hour nutrient composite. Storm samples were composited according to characteristics of the hydrograph, and weekly samples were not composited.

Back in the lab at Virginia Tech, the samples were analyzed using the SEAL Analytical continuous flow liquid chromatography machine for NO_3-N, NH_3-N, PO_4-P, total nitrogen (TN), and total phosphorus (TP). Totals were digested using a potassium persulfate digestion. The instrument detection limits were: NH_3-N 0.29 µM, NO_3-N 0.05 µM, PO_4-P, 0.02 µM, TN unknown, and TP 0.04 µM.

3.4 Salt Tracer

A salt tracer study was performed to determine stream travel times in order to establish lag times for paired data. First, plain salt was weighed out in 200 and 500g increments, recorded, and placed into plastic bags. A mixture of 1-L of distilled water and three grams of salt was used to calibrate the electrical conductivity meters. The instruments were then placed at a downstream station to record values every five seconds. Upstream, the salt was dissolved in a 5-gallon bucket of stream water then poured in the stream.

The time series of the electrical conductivities were graphed, and travel time was calculated based on the time of peak concentration of an upstream station (i.e. MV1b) to the time of peak at a downstream station (i.e. MV2). Results from the salt tracer can be found in Appendix G.

3.5 Cameras

Five different types of hunting cameras were placed in the field to track cattle movement throughout the riparian zone: time-lapse Moultrie M-80, motion-sensored Moultrie D55IR, time-lapse Stealth Cam STC-AC540IR, motion-sensor Stealth Cam STC-U840IR, and time-lapse Plant Cam by Windscapes. Ten cameras were used in Study 1 and twelve were used in Study 2. The cameras were rotated to get the best representation of the area and were labeled by positions (P1, P2, etc). The M-80 cameras were programmed to take a photo every minute during daylight and an infrared photo at night when the 40 ft proximity sensor trips.

The Stealth Cam STC-U840IR cameras took photos during day and night but only when the motion-sensor is triggered. Because these cameras did not show a full view of the stream reach, they were less reliable in understanding cattle movement and had the potential to "miss" when cattle were present.

All the motion cameras were set on a one-minute photo delay in order to match the time-lapse cameras' interval. Dates and times on each camera were set specific to GPS satellite time to ensure the highest accuracy as well to ensure synchronization of the photos. The cameras were programmed to label each picture with the time, date, temperature in degrees Celsius, and camera name and number.

Cameras were placed strategically throughout the study area to give the best views of each reach. Because the motion-sensing cameras only took pictures when triggered, these cameras were placed in upstream areas of Cub Run where it was assumed that the cattle travelled least based on the farmer's past experiences with flash grazing.

For Study 2, two cameras pointed upstream of MV1 and CR1 in order to represent the condition above these sampling points. Each site has free-range cattle access upstream which has the potential to affect the pollutant concentrations; therefore, it was important to monitor when the cattle were in the stream.

3.5.1 Determining Livestock Densities

Using the camera images and an aerial view of the study site, areas were drawn out in ESRI Arc Map 10, which can be seen in figure 3.6. Because the viewing areas of several of the cameras such as P1 and P2 overlap, imaginary boundaries were established to ensure that the same cow was not counted twice at the same time. The area of each camera view within the riparian zone is listed in table 3.1.

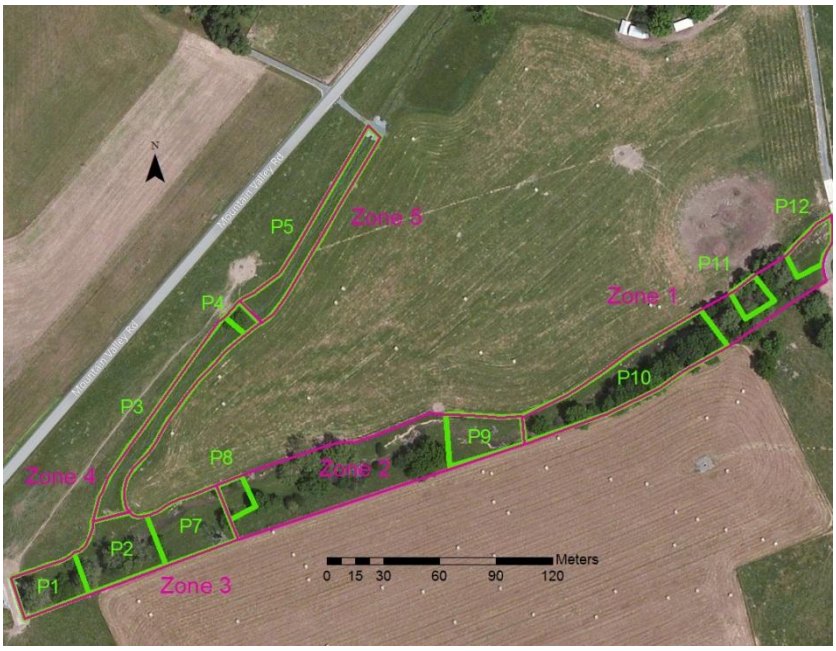

Figure 3.6: Camera areas and zones(Source: Google Earth)

Table 3.1: Camera areas and stream lengths

Camera Position	Area (m^2)	Stream length (m)
P1	821	38
P2	1323	69
P3	1315	128
P4	157	9
P5	1150	124
P7	1213	41
P8	275	16
P9	855	47
P10	2376	115
P11	278	18
P12	427	29

To compare cattle densities to sample concentrations, zones were established as illustrated in figure 3.6. Some zones such as zone 3 included several different cameras, P1, P2, and P3. The data from all the cameras in the same zone were then added together to represent the whole zone. However, some cameras, such as P7, had a field of view in two different zones (e.g. zone 2 and 3). Therefore, when counting the number of cattle, it was noted in which zone the cattle were located in.

The cameras pointing upstream of MV1 and CR1 do not have a density associated with them because the cattle were not confined by fencing. Although the camera views do not show the whole representation of cattle upstream, it captures the area closest to station CR1, where there was assumed to be the greatest impact. Cattle counts and densities can be found in Appendix H.

3.6 Summary

This project encompasses water quality data from two flash grazing studies sampled in July and August of 2011, weekly samples collected in the summer and fall of 2010 and 2011, and storm samples throughout 2010 and 2011 (table 3.2). The flash grazing studies were week-long intensive sampling regimes using two-hour composites in 1-L ISCO bottles. Weekly samples were collected manually, and the storm samples were one-hour composites in 1-L ISCO bottles collected using the four permanent ISCO samplers.

Table 3.2: Summary of sample collections and corresponding dates

Sample Collections	Date
Flash Grazing Study 1	20 July 2011 - 27 July 2011
Flash Grazing Study 2	15 August 2011 - 19 August 2011
Weekly	Summer-fall of 2010-2011
Storm	Summer-fall of 2010-2011

The flash grazing study was split into three different periods (table 3.3). Period 1, or baseline, was the first day of sampling and showed the natural fluxes in concentrations of the system without direct cattle influence. During period 2, the gates to the riparian zone were opened and cattle were allowed to roam freely into the stream for approximately two days. The last day of sampling, period 3, was used to determine the time it takes for peak concentrations during period 2 to return to a baseline concentration.

Table 3.3: Summary of flash grazing study characteristics (periods and zones) with corresponding sections and descriptions

Study Characteristic	Sections	Description
Periods	1	Baseline (no cattle)
	2	Cattle access
	3	Post cattle access (no cattle)
Zones	CREP	CR1-CR2
	1	CR2-CR2b
	2	CR2b-CR3
	3	(MV2 + CR3) - CM
	4	MV1b-MV2
	5	MV1-MV1b

Table 3.3 also summarizes the ISCO stations that were associated with each zone within the riparian area. The CREP zone was upstream of the flash grazing study site along Cub Run and had cattle permanently fenced out. Zones 1, 2, and 3 were along Cub Run from upstream to downstream respectively. Zones 5, 4, and 3 were along Mountain Valley Road Tributary from upstream to downstream respectively. Zone 5 did not have a significant number of cattle in the study, so is not mentioned further in this report.

4 Results

4.1 Weather Data

Weather data were taken with an Onset HOBO weather station placed at the MV1 location. The station was checked for maintenance approximately every month as well as periodically throughout the flash grazing studies. The station was set up with a HOBO Micro Station Data Logger as well as with sensors that collect rain, solar radiation, temperature, relative humidity (RH), dew point, wind speed, gust speed, and wind direction measurements.

Although the station was checked for maintenance issues, a spider web was noticed in the tipping bucket on 5 August 2011. Precipitation data throughout July and the beginning of August 2011 were acquired from a nearby weather station at Weather Underground.

4.1.1 Study 1

The first flash grazing study began on 20 July 2011 and ended 27 July 2011. The weather data pertinent to this study are rainfall, temperature, solar radiation, and relative humidity. This data should help explain cattle movement and behavior as well as stream and landscape conditions. The variations of these values during Study 1 can be found in figures 4.1-4.5. July experienced one storm event at the beginning of the month but dry conditions followed. The HOBO and Weather Underground stations (figs. 4.1 and 4.2) show the same rainfall pattern.

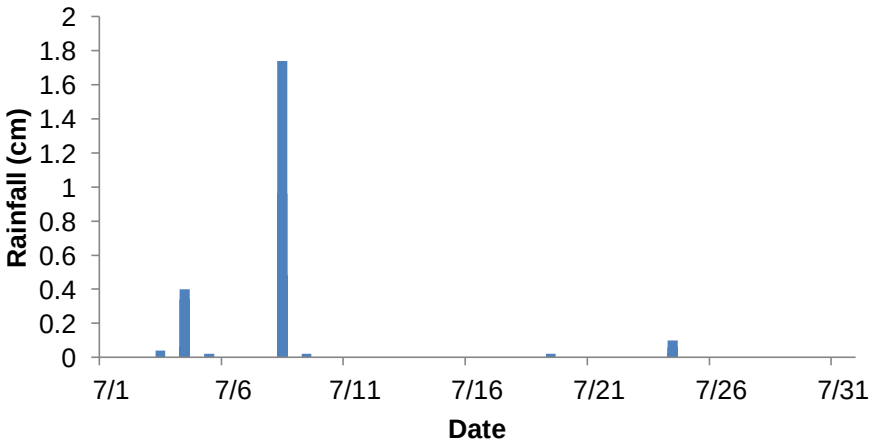

Figure 4.1: July rainfall from the HOBO weather station at Mountain Valley Road

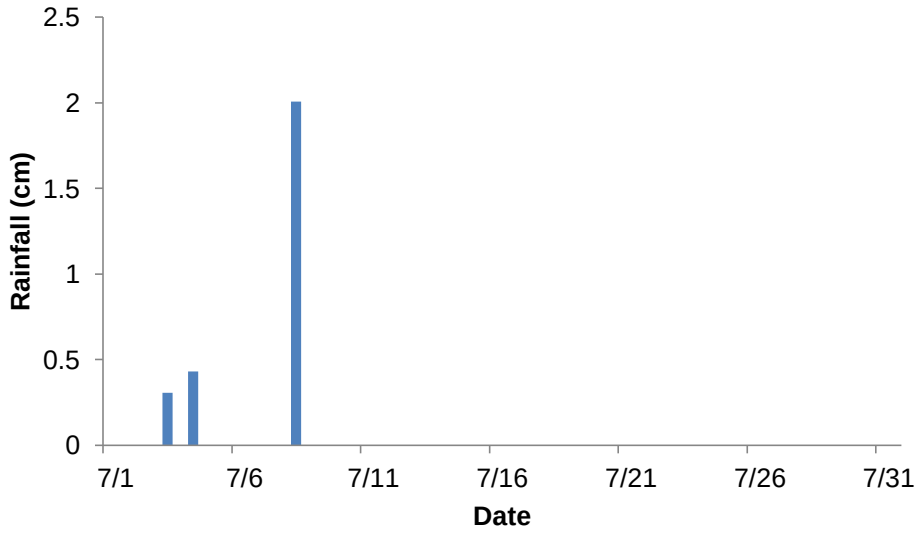

Figure 4.2: July rainfall from KVAMCGAH2 station in McGaheysville, VA found through Weather Underground

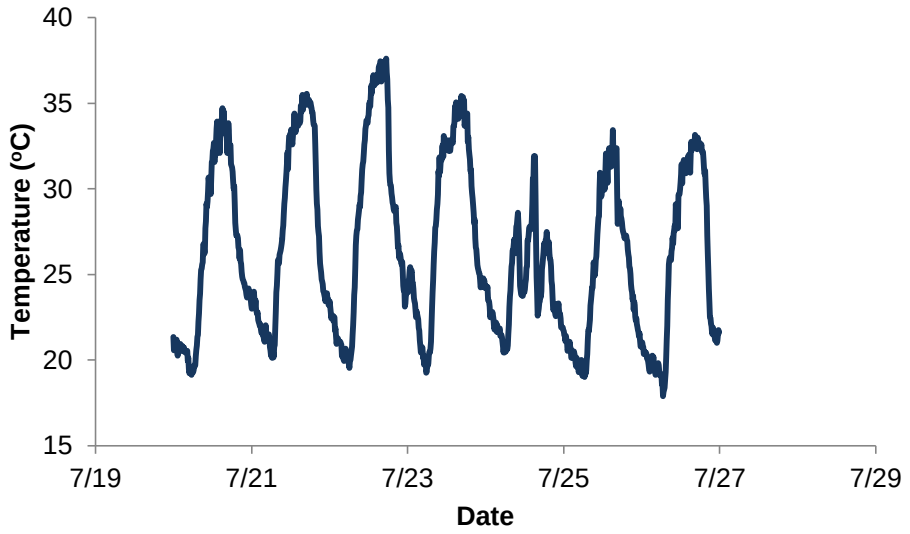

Figure 4.3: Temperature data, Study 1

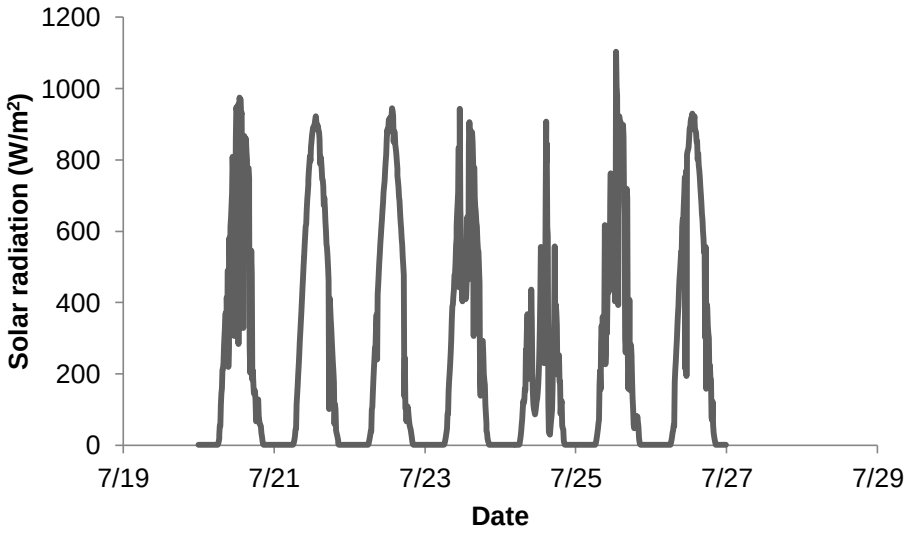

Figure 4.4: Solar radiation data, Study 1

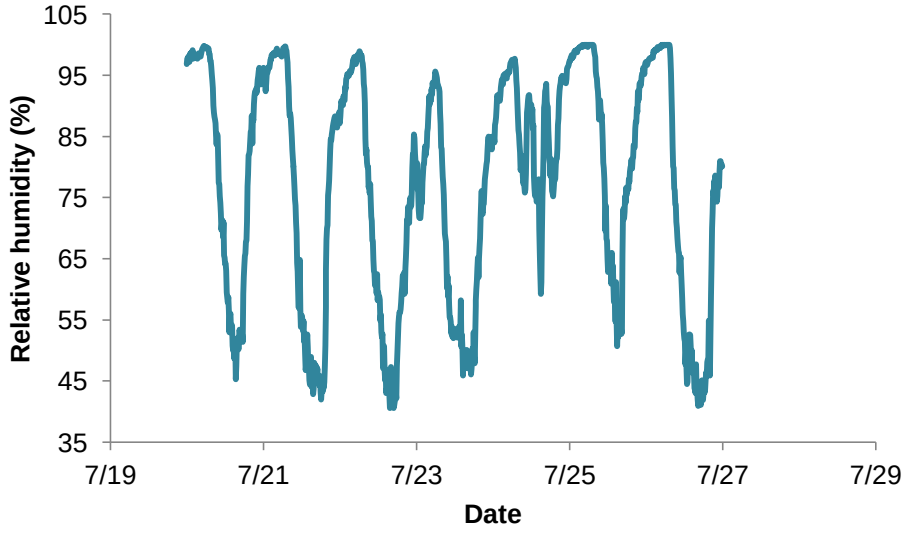

Figure 4.5: Relative humidity data, Study 1

4.1.2 Study 2

The second flash grazing study began on 15 August 2011 and stopped on 19 August 2011. Figures 4.6-4.10 show the rainfall, temperature, relative humidity, and solar radiation for Study 2. There were many more rainfall events in August than in July 2011. There was a storm before sampling started on 15 August 2011, but it did not affect stream flow or baseline levels because rainfall amount were so small.

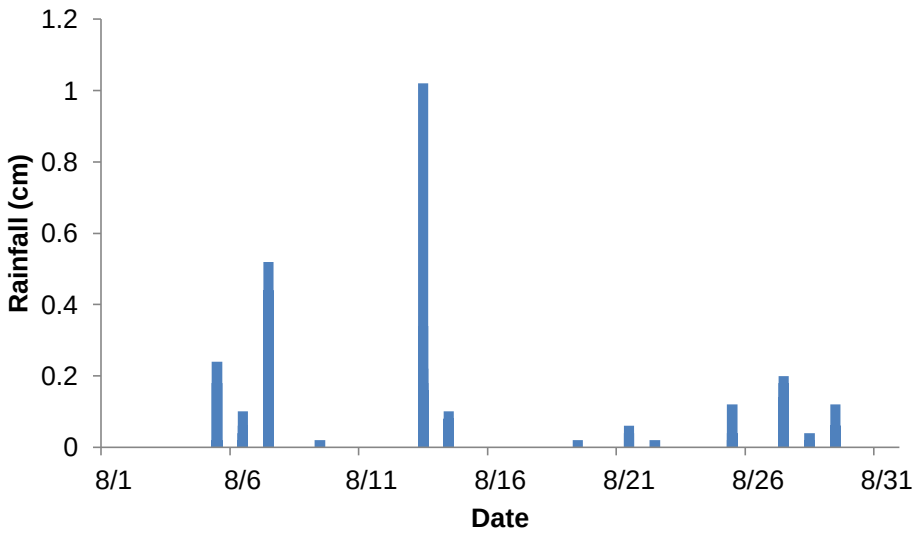

Figure 4.6: August rainfall from the HOBO station at Mountain Valley Road

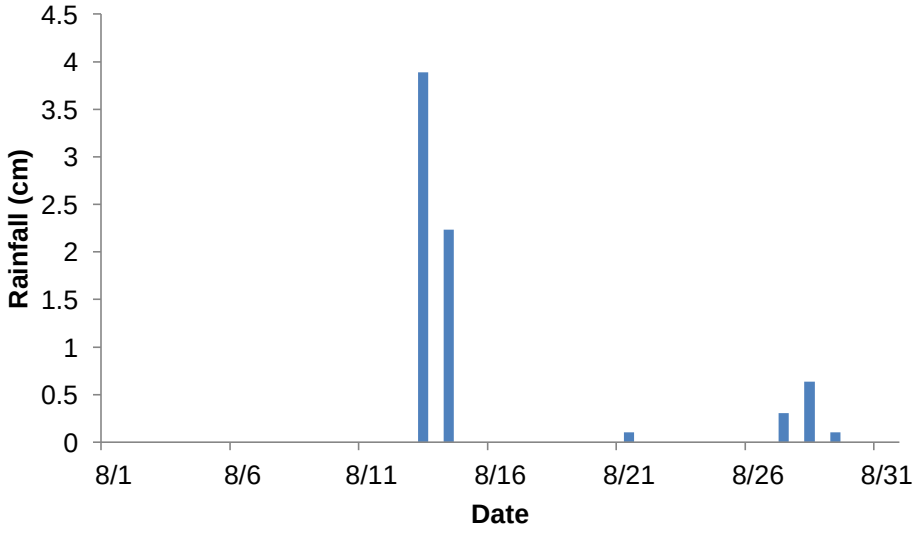

Figure 4.7: August rainfall from KVAMCGAH2 station in McGaheysville, VA found through Weather Underground

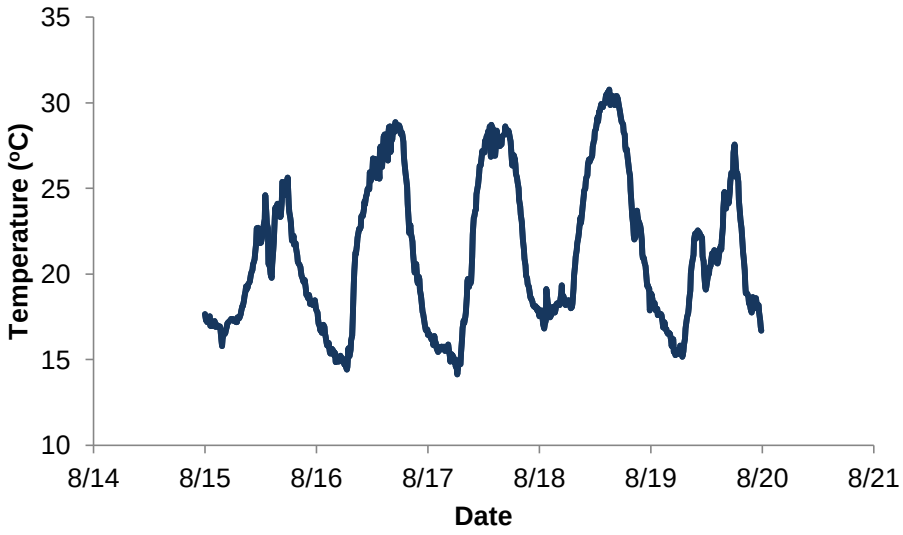

Figure 4.8: Temperature data, Study 2

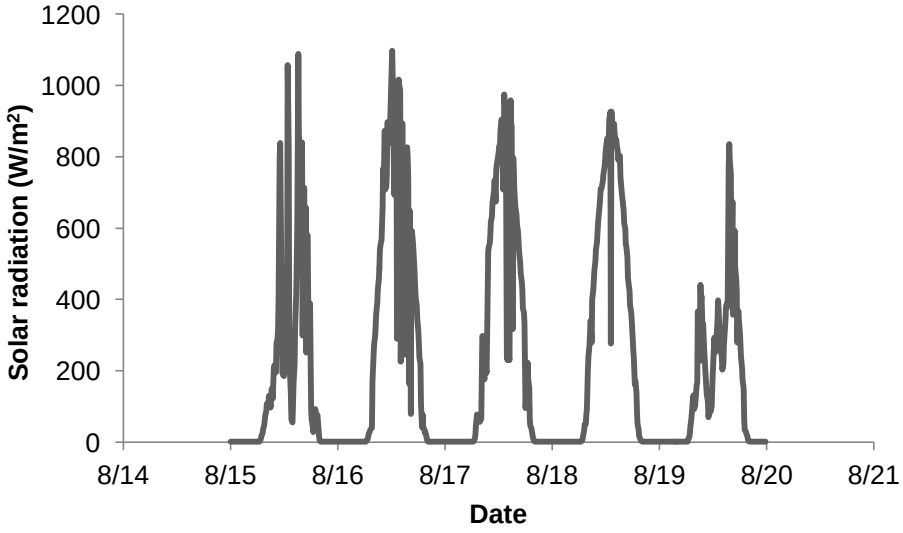

Figure 4.9: Solar radiation data, Study 2

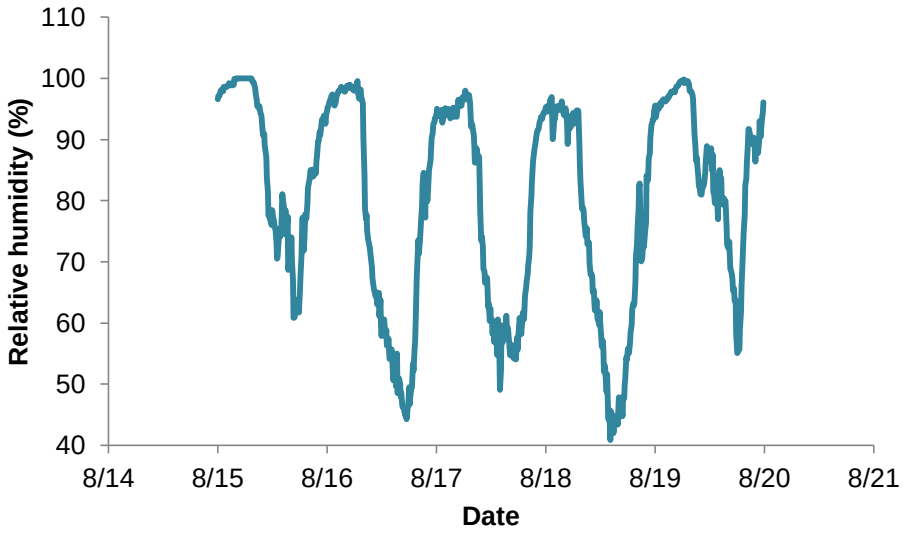

Figure 4.10: Relative humidity data, Study 2

4.2 Flow

Flow measurements were taken during each flash grazing study and figure 4.11 shows the flow values taken at sites CR2, CR3, CM, MV1, and MV2 for dates 20 July 2011 and 19 August 2011. Because there was a 1.1cm rainfall event in two days before Study 2, flow was taken before and after the study to ensure that the event did not affect baseflow conditions. Because the flow rates on 16 August 2011 and 19 August 2011 were within a margin of error of 10%, the rainfall that occurred prior was not considered to change baseflow conditions. By averaging the flow measurements on 20 July, 16 August, and 19 August of the CR3 site, CR had a flow of approximately 0.012 m^3/s. Mountain Valley Road Tributary had a baseflow of approximately 0.007 m^3/s by averaging the flow values from all three dates for stations MV1 and MV2. The confluence of both the streams had a flow of approximately 0.022 m^3/s at CM by averaging the flow measurements on 20 July and 19 August.

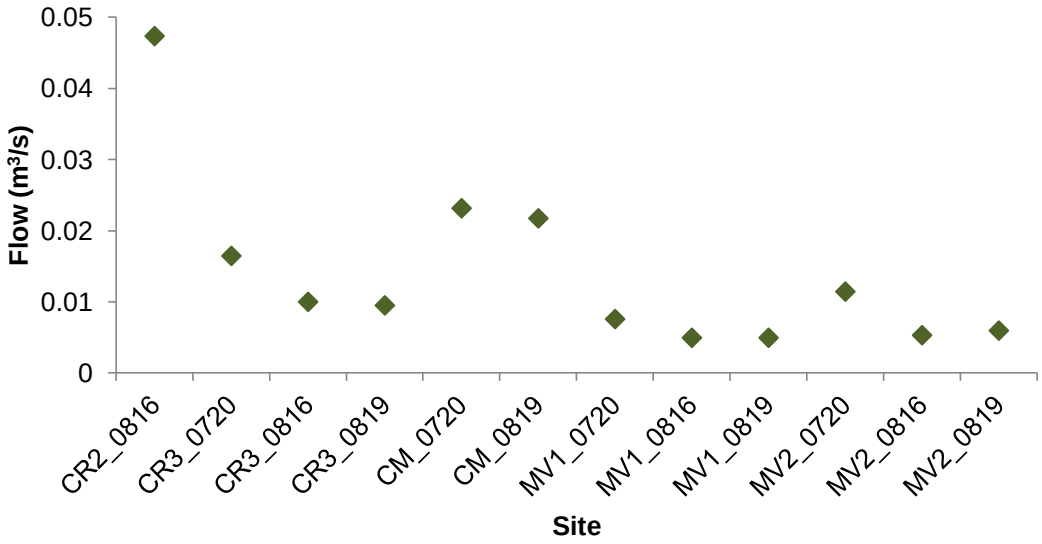

Figure 4.11: Flow by site and date

Along with flow measurements in figure 4.11, additional flow values were taken throughout the 2011 year and were compiled into a stage-discharge graphs (Appendix A). There are different stage-discharge relationships for 2010 and 2011 due to a change in pressure transducer datum. An exponential line of best-fit was determined, and the equation of that line was used to convert ISCO levels from storm events into a representation of flow.

4.3 Cattle Density and Pollutant Concentrations

To help determine the impact of cattle on water quality, the hunting cameras were used to track cattle movement and behavior. The data from these cameras were downloaded and cattle were counted and categorized as in-stream or in-fencing. Because there were no further flash grazing studies in the literature review to help define cattle density, the following parameters were calculated and compared:

- Ave/Max # in stream
- Ave/Max # in fencing
- Ave/Max # in stream per stream length
- Ave/Max # in fencing per riparian area

The stream parameter defines those cattle that were considered to be in the stream channel. The fencing parameter defines the total number of cattle in the zone including those in the stream and in the riparian area. The average and max values are based on two hour increments to match the two hour water samples. These were then compared with the corresponding bacteria and TSS times and concentrations to determine the best way to classify cattle density.

First, the number and densities of cattle were compared with the downstream ISCO of each zone. The camera data were then compared to the difference between the upstream and downstream sites to account for any changes just in that particular zone. Once the concentrations and densities were graphed against each other, a linear trendline was added along with the corresponding coefficient of determination or R^2 value. This was done for every density parameter, and the one that had the greatest R^2 value was chosen to be the most correlated with the pollutant. Tables 4.1-4.6 show the best method and R^2 value for each zone for each study, and tables 4.5 and 4.6 show the combined data representing Studies 1 and 2 together.

Table 4.1: Cattle density method and R^2 value for downstream and upstream-downstream zones compared with bacteria concentrations, Study 1

		Zone 1	Zone 2	Zone 3	Zone 4
Downstream Site	Method[1]	Max in fencing/area (#/m^2)	Max in fencing (#)	Max in stream/length (#/m)	-
	R^2 [2]	0.54	0.105, (- slope)	0.309	-
Difference Upstream-Downstream	Method	Ave in stream (#), per length (#/m)	Max in fencing (#)	Max in stream/length (#/m)	-
	R^2	0.37	0.106, (- slope)	0.307	-

[1] Cattle density method found in Appendix H that has the greatest R^2 value as compared to bacteria
[2] Coefficient of determination, R^2, that has the greatest value based on a linear trendline comparing each density method and bacteria concentrations

Table 4.2: Cattle density method and R^2 value for downstream and upstream-downstream zones compared with bacteria concentrations, Study 2

		Zone 1	Zone 2	Zone 3	Zone 4
Downstream Site	Method[1]	Ave in fencing/area (#/m^2)	Ave in stream (#), /area (#/m^2), and /length (#/m)	Ave in fencing (#)	Max in fencing (#)
	R^2[2]	.0412, (- slope)	0.09	0.2124	0.1918
Difference Upstream-Downstream	Method	Ave in stream (#), per length (#/m)	Max in stream (#), /area (#/m^2), and /length (#/m)	Ave in fencing (#)	Max in fencing (#)
	R^2	0.238	0.518	0.2579	0.1055

[1] Cattle density method found in Appendix H that has the greatest R^2 value as compared to bacteria
[2] Coefficient of determination, R^2, that has the greatest value based on a linear trendline comparing each density method and bacteria concentrations

Table 4.3: Cattle intensity method and R^2 value for downstream and upstream-downstream zones compared with TSS concentrations, Study 1

		Zone 1	Zone 2	Zone 3	*Zone 4*
Downstream Site	Method[1]	Max in fencing/length (#/m)	Max in fencing (#)	Ave in stream/length (#/m)	-
	R^2 [2]	0.115	0.1378, (- slope)	0.851	-
Difference Upstream-Downstream	Method	Ave in stream (#) and /length (#/m)	Max in fencing (#)	Ave in fencing/area (#/m^2)	-
	R^2	0.108	0.204, (- slope)	0.72	-

[1] Cattle density method found in Appendix H that has the greatest R^2 value as compared to TSS
[2] Coefficient of determination, R^2, that has the greatest value based on a linear trendline comparing each density method and TSS concentrations

Table 4.4: Cattle intensity method and R^2 value for downstream and upstream-downstream zones for compared with TSS concentrations, Study 2

		Zone 1	Zone 2	Zone 3	Zone 4
Downstream Site	Method[1]	Ave in stream(#) and /length (#/m)	Ave in stream (#), /area (#/m^2), and /length (#/m)	Ave in fencing (#)	Max in stream (#)
	R^2 [2]	0.296	0.99	0.3998	0.27
Difference Upstream-Downstream	Method	Ave in stream (#) and /length (#/m)	Max in stream (#), /area (#/m^2), and /length (#/m)	Ave in fencing (#)	Max in stream (#)
	R^2	0.276	0.684	0.4545	0.265

[1] Cattle density method found in Appendix H that has the greatest R^2 value as compared to TSS
[2] Coefficient of determination, R^2, that has the greatest value based on a linear trendline comparing each density method and TSS concentrations

Table 4.5: Bacteria concentrations for both studies combined versus cattle density methods

		Zone 1	Zone 2	Zone 3
Downstream Site	Method[1]	Max in fencing/area (#/m^2)	Max in stream/length (#/m)	Max in stream/length (#/m)
	R^2 [2]	0.41	0.1238	0.347
Difference Upstream-Downstream	Method	Ave in stream and /length (#/m)	Max in fencing (m)	Max in stream/length (#/m)
	R^2	0.28	0.0816, (- slope)	0.348

[1] Cattle density method found in Appendix H that has the greatest R^2 value as compared to bacteria
[2] Coefficient of determination, R^2, that has the greatest value based on a linear trendline comparing each density method and bacteria concentrations

Table 4.6: TSS concentrations for both studies combined versus cattle density methods

		Zone 1	Zone 2	Zone 3
Downstream Site	Method[1]	Ave in stream (#) and /length (#/m)	Ave in stream (#)	Ave in stream/length (#/m)
	R^2 [2]	0.161	0.1554	0.668
Difference Upstream-Downstream	Method	Ave in stream (#) and /length (#/m)	Ave in stream (#)	Ave in stream/length (#/m)
	R^2	0.153	0.182	0.674

[1] Cattle density method found in Appendix H that has the greatest R^2 value as compared to TSS
[2] Coefficient of determination, R^2, that has the greatest value based on a linear trendline comparing each density method and TSS concentrations

The tables depict that there is not one method of best defining cattle densities. Some of the methods are best correlated using averages, some with maximum values, some with the stream counting, and some within fencing. The downstream and downstream – upstream sites have approximate values for each method. Both of the studies have roughly the same R^2 values for each of the zones in tables 4.1 and 4.3 and tables 4.2 and 4.4. To look at both studies as a whole, the time of cattle presence and pollutant concentrations were graphed using both Study 1 and Study 2 data. New methods and R^2 values were calculated and found in tables 4.5 and 4.6. These tables depict that there are inconsistencies when determining a density method.

The combined zone 2 (table 4.5) has a negative slope for the difference from upstream to downstream. This could be because Study 1 bacteria (table 4.1), although having an R^2 of approximately 0.082, the slope of the trendline is negative whereas the slopes on all the other trendlines are positive. When combining this negative trendline values with the positive slope of Study 2 (table 4.2), a negative R^2 value is resulted as well. The negative slope could represent too few cattle in the stream to account for any increases and the decreases would be due to the natural flux of the water system. Also, when looking at the statistical charts in 4 Results – Study 2 – Statistical Analysis – table 4.11 for zone 2 (CR2b-CR3), the bacteria concentration statistically decreased representing that negative slope.

Along with the bacteria, TSS concentrations also show different fluxes in changes when comparing the combined studies (table 4.6) with the separate ones (tables 4.3 and 4.4) – sometimes the combined data set has a greater R^2 and sometimes a smaller R^2. Unlike the bacteria for zone 2 with a negative slope, zone 2 TSS has a positive slope with an R^2 of 0.155 (table 4.6) even though zone 2, Study 1 TSS has negative slopes (table 4.3). Zone 2, Study 1 TSS even has stronger R^2 values than that of bacteria.

Also, although tables 4.5 and 4.6 show the greatest correlation between cattle densities and bacteria and TSS concentrations, the R^2 values are not very high. However, TSS does have much stronger correlation values for most of the zones and studies, except zone 1. TSS is expected to have higher correlation values because cattle stir up bed material by trampling but do not necessary defecate in the stream.

The strongest R^2 values overall can also be found at zone 3 or the CM site. The stronger correlation at zone 3 could be due to the fact that this zone experienced much higher values and increases than did the other zones. These higher values have a large influence on the trendline and could make the R^2 value appear to be more correlated. Although these higher

points may influence the trendline more, they also give a better representation of the cattle influence on the stream.

For zone 2, cattle were found in the stream less often, and therefore had fewer two-hour periods that cattle were in the stream or that zone. Zone 2 has very high R^2 values for TSS in table 4.4 for Study 2, and this could be due to having just a few points that are very closely aligned. Therefore, the R^2 values are based off just a few points with possibly lower pollutant concentration and cattle density values.

The influence of cattle on the TSS could also be partially due to the bed material of that site being very mucky and free of cobble rocks that were present in upstream parts of Cub Run. Cattle were seen in other parts of the stream; however, concentrations increased at a greater rate in zone 3. A silty, mucky stream bed was much more mobile when disturbed versus a stream bed full of rocks, cobbles, and debris.

4.4 Statistical Analysis

4.4.1 Study 1

In order to define period 2, the number of cattle in the stream and fencing areas were determined using photographs from the hunting cameras. Period 2, or cattle influence, began when two or more cattle were in the stream zone. However, if two or more cattle were found in the stream of an upstream zone before a downstream zone, the downstream zone's period 2 would begin at the time of the upstream zone's period 2 starts. The start times for each of the sites/zones can be found in table 4.7. Because zone four and five never had two or greater cattle in the stream, there was no significant cattle influence to define period 2. Because sampling for Study 1 had stopped on 24 July to conserve time and resources, the end of period 2 for all the zones is 24 July 4:00.

Table 4.7: Start and end dates and times for period 2 by zone, Study 1

	Zone 1	Zone 2	Zone 3
Start	21 July 2011 18:00	21 July 2011 18:00	21July 2011 18:00
End	24 July 2011 4:00	24 July 2011 4:00	24 July 2011 4:00

In R statistics package, data sets were first tested for normality using a Shapiro test and found to have a p-value less than alpha of 0.05, which indicates that the data sets are not normal. An alpha of 0.05 was used for all the statistical tests because it is often used when analyzing environmental data. The data was then natural log transformed and found to be normal. Under the student's t-test assumptions, the data must also have equal variance. Using a Bartlett test, the data sets were found to not have equal variance.

Therefore, nonparametric tests were used to statistically analyze samples. A Wilcox test with a Bonferroni correction was used to compare between periods for each station. Paired stations, or upstream-to-downstream stations, were first compared using a Friedman's test because it has the most conservative p-value. The Friedman's test compared the differences between the four paired groups (CR1-CR2, CR2-CR2b, CR2b-CR3, FW-CM) along Cub Run. If the groups were found to be different, a pairwise Wilcox test with a Bonferroni correction was used to determine which pairs were dissimilar. The Bonferroni correction divides the p-value by the number of samples and was used to maintain the error of making a false significance or Type I error when performing multiple comparisons. Because there were only two pairs along MV, simple paired Wilcox tests were used with the Bonferroni correction.

The Friedman and Wilcox test will signify whether the data sets are different or not. A two-sample bootstrap was used to find the means of two unpaired data sets to determine whether the difference is an increase or decrease. Paired data were subtracted and then entered into a one-sample bootstrap. The bootstrap was also used to determine confidence intervals to determine variability within the data sets (Appendix C). The R statistics code used can be found in Appendix B.

4.4.2 Study 2

The start and end times for period 2, Study 2 can be found in table 4.8. For Study 2, there was a significant presence of cattle in zone 4, along the MV tributary. Therefore, Study 2 has statistical evaluations based on using MV1b and MV2. However, zone 5 did not experience significant cattle presence. The end times were determined at the point cattle were no longer in the stream zone or in the upstream stream zone.

Table 4.8. Starting and ending dates and times of period 2, Study 2

	Zone 1	Zone 2	Zone 3	Zone 4
Start	8/16/2011 8:00	8/16/2011 8:00	8/16/2011 8:00	8/17/2011 16:00
End	8/18/2011 8:00	8/18/2011 8:00	8/18/2011 20:00	8/18/2011 20:00

Samples for Study 2 were also tested for normality using a Shapiro test and were found to not be normal. Non-parametric Wilcox tests with a Bonferroni correction were used for period-to-period comparisons as in Study 1. However, paired data sets along Cub Run did not have equal lengths per requirements of the Friedman's test. Because CM has significant influence from MV, the length of period 2 takes into consideration the start and end times from both streams. Because period 2 of MV ends at a later time than the CR stream, the CM site has a longer period 2 than the rest of the CR stations. Therefore, CR2, CR2b, and CR3 were of equal length, CM and FW were equal, and MV1b and MV2 were equal. Therefore, individual paired Wilcox tests with a Bonferroni correction were used to analyze data. Similar bootstraps to Study 1 were run to find the means and confidence intervals to find statistical increases and decreases.

4.4.3 Weekly Samples

The weekly grab samples were also analyzed using non-parametric Friedman and Wilcox tests. When evaluating the paired sites, a Friedman's test was first run separating the Cub Run sites from the Mountain Valley Road sites in 2010 and 2011. The data sets were blocked by date because each week could have different conditions. Similar to the flash grazing samples, a

pairwise Wilcox test was used when weekly samples were found to be dissimilar. Paired data was analyzed using paired Wilcox tests, and bootstraps were used to determine increases and decreases between the two sets of data.

4.5 Study 1

4.5.1 Time Series Data

Samples were taken in two hour composites from 20 July 2011 to 27 July 2011. Sampling had stopped at noon on 24 July and began again at noon on 25 July to conserve resources and supplies. CR1 stopped sampling when cattle were first introduced to the riparian area also to conserve time and resources.

The time series bacteria and TSS data for Cub Run during Study 1 can be seen in figures 4.12-4.15. Points on the graph represent the beginning time of the two-hour sampling period. For example, a point at 14:00 represents data from 14:00 – 15:45. CM was graphed with CR3 and MV2 to show influence from each of the streams. Mountain Valley Road Tributary was not graphed because cattle did not venture into this reach during the study. Because pH and EC did not fluctuate throughout the study period, these parameters are not included in the analysis; however, summary boxplots of the data are included in Appendix I.

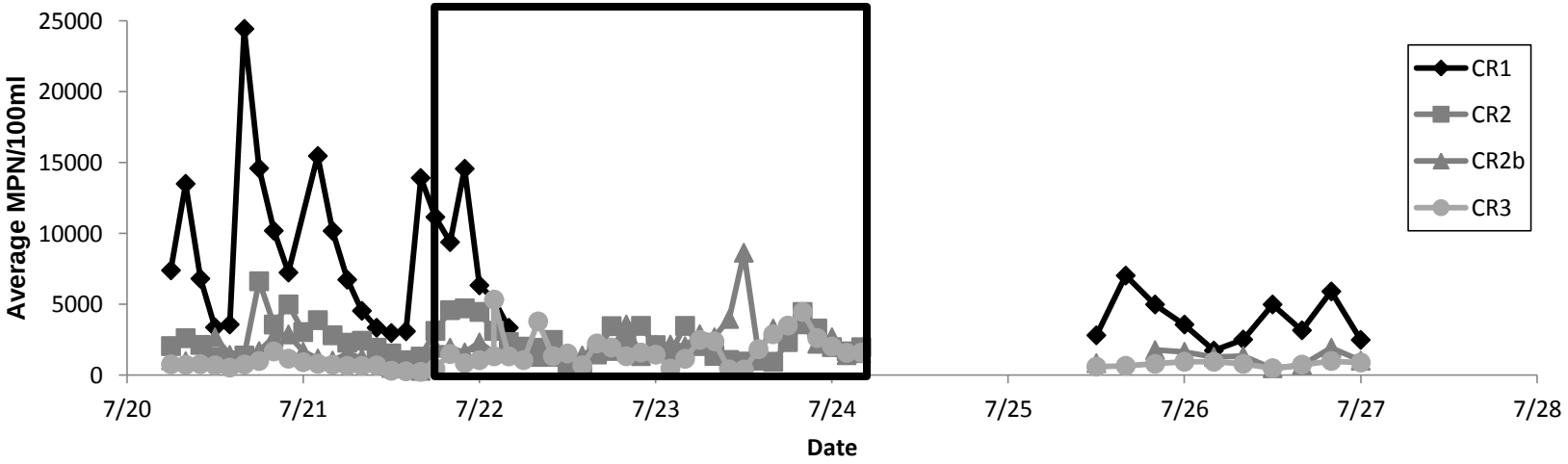

Figure 4.12: Bacteria (*E. coli*) count time series for Cub Run stations (box indicates period 2), Study 1

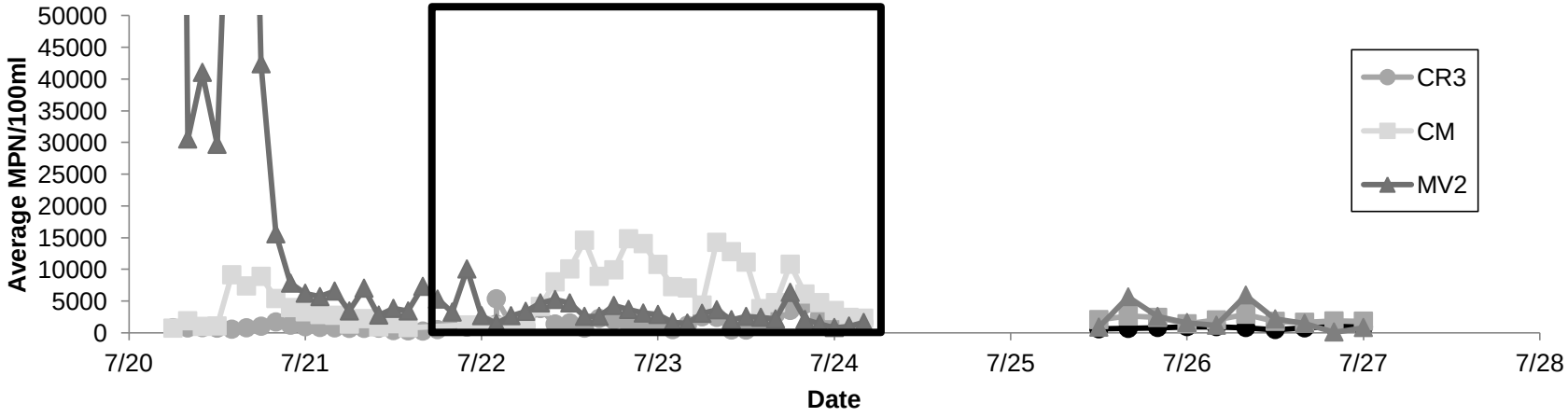

Figure 4.13: Bacteria (*E. coli*) count time series for CM, CR3, and MV2 (box indicates period 2), Study 1

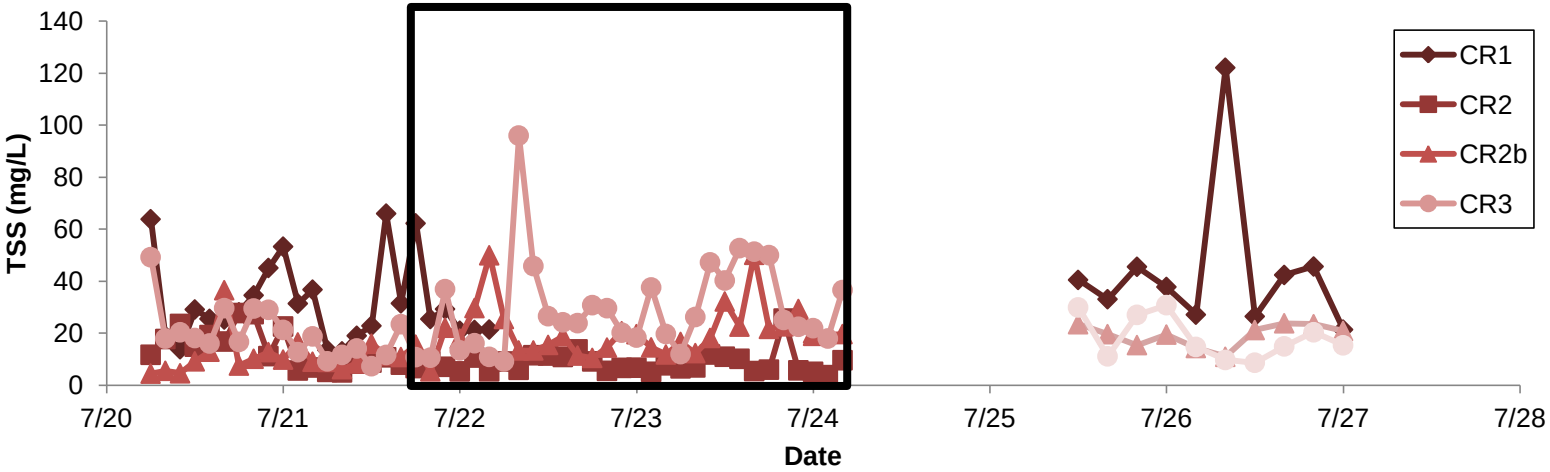

Figure 4.14: TSS time series for Cub Run sites (box indicates period 2), Study 1

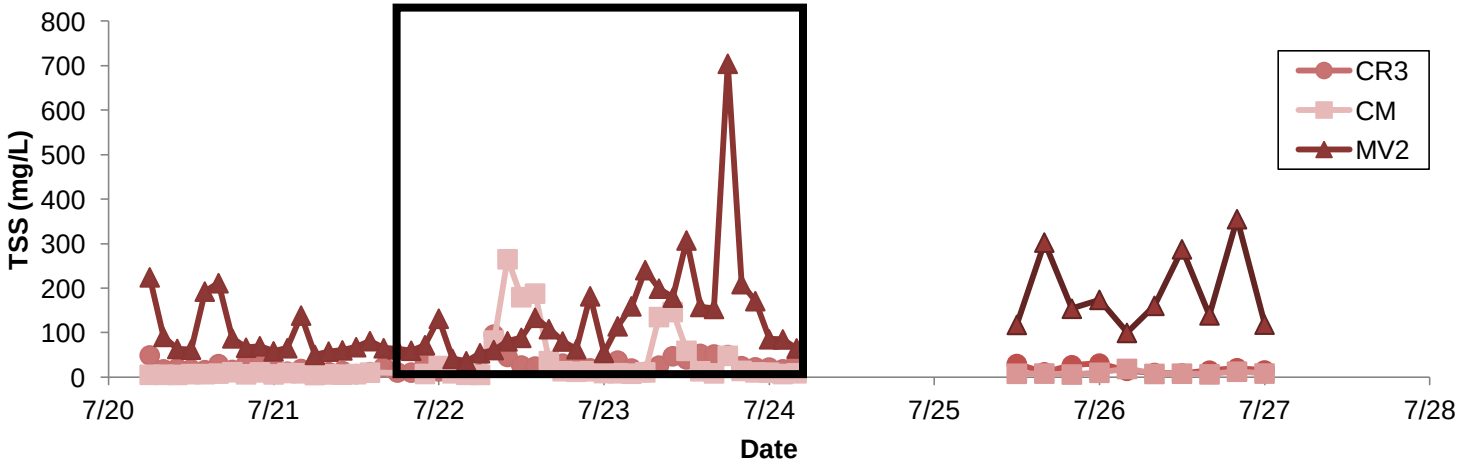

Figure 4.15: TSS time series for CR3, CM, and MV2 (box indicates period 2), Study 1

In figure 4.12, the upstream influence from CR1 appears to vary considerably which is most likely due to the free range cattle influence just upstream of this site. Because of this influence, it is difficult to define a baseline concentration. Figure 4.12 also shows the general decrease in bacteria concentrations in moving from upstream sites to downstream sites.

Figure 4.13 shows the influence that Mountain Valley Road Tributary has on the confluence site, CM. Although the majority of the flow at the confluence is from Cub Run, MV noticeably increased CM bacteria concentrations as seen at point 20 July 2011 14:00. However, when cattle were allowed to graze within the riparian zone (period 2), the concentrations of CM increased above those of MV2 and CR3 because of the additional cattle input.

Unlike the bacteria counts, the TSS concentrations of the upstream CR1 site does not appear to have as much of an influence on TSS when looking comparing downstream sites (figs. 4.14 and 4.15). However, the concentrations are still variable, which also creates difficulty when defining a baseline concentration. TSS concentrations also do not have the same pattern of decreasing from upstream-to-downstream like the bacteria counts. Upstream cattle may have a greater influence on bacteria concentrations than TSS through the CR reach.

4.5.2 Statistical Analysis

Period 1 was sampled before cattle were in the stream, and period 3 started when cattle exited the stream riparian zone. Ideally, these two sets of samples should be equal because neither period had cattle in the stream. If period 1 and 3 are not similar, any lingering influence of the cattle may be seen in period 3. Looking at the statistical differences between periods 1 and 3 in table 4.9, CR2b and FW (flow weight of MV2 and CR3) had the most significant increases and decreases of all the sites. CR2b was found to have mostly increases from period 1 and 3 with a decrease in TSS and equal bacteria concentrations. FW also had statistical increases in TSS and PO_4-P and a decrease in bacteria.

Table 4.9: Statistical comparisons of water quality parameters (concentrations) between no cattle access periods 1 and 3 and baseline period 1 to cattle access period 2, Study 1.

		Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1, 3	CR2b	=[2]	↑	↓	↑	↑	↑
	CR3	=	=	=	=	=	=
	CM	=	=	↑	=	=	=
	FW[1]	↓	↑	↑	=	=	=
Period 1, 2	CR2	=	↓	=	=	=	=
	CR2b	↑	↑	↓	=	↑	↑
	CR3	↑	↑	=	=	↑	=
	CM	↑	↑	↑	=	↑	=
	FW	↓	↑	=	=	↑	=

[1] FW = flow weight of MV2 and CR3 stations

[2] Comparisons between periods were determined using non-parametric Wilcox tests to determine whether the two data sets are equal or not equal by finding the differences by subtracting upstream from downstream. If statistically dissimilar, a two-sample bootstrap calculated means and confidence intervals on each data set to determine an increase or decrease.

Symbols in the table indicate the following:

↓ Statistical decrease from period 1 to 3 or period 1 to 2

↑ Statistical increase from period 1 to 3 or period 1 to 2

= Statistically equal from period 1 to 3 or period 1 to 2

- No data

Statistically significant decrease from period 1 and 3 to period 1 and 2

Decrease in mean from period 1 and 3 to period 1 and 2

Statistically significant increase from period 1 and 3 to period 1 and 2

Mean increase from period 1 and 3 to period 1 and 2

When analyzing periods 1 and 2, CR2 shows roughly all statistically equal pollutants with the exception of a decrease in TSS. This is to be expected because CR2 is the control sampling station above the flash grazing cattle influence. However, CR2b, CR3, and CM show increases from period 1 to period 2 in bacteria, TSS, and total phosphorous. FW also shows an increase in TSS and total phosphorous but shows a decrease in bacteria concentrations. The decrease in FW bacteria concentrations could be due to the decrease in concentrations of Mountain Valley Road Tributary from period 1 to period 2.

By comparing periods 1 and 3 to periods 1 and 2, flash grazing cattle impacts can be seen. The comparison between the two groups of periods can be seen in the shading scheme in table 4.9. The lighter shades show when there was an increase in means comparing between periods 1 and 3 to periods 1 and 2 (and if it is statistically significant), and darker shades represent decreases. When comparing period 1 to 2 in table 4.9, more statistical increases can be seen than from period 1 to 3. The additional statistical increases are seen in bacteria, TSS, and TP. Nitrogen concentrations did not change from baseline periods to the cattle access period. Most of the deceases from period 1 and 3 to period 1 and 2 can be seen at the CR2b station. Therefore, it is possible to infer that cattle increase bacteria, TSS, and TP concentrations at most of the stations along Cub Run.

Table 4.10 shows the paired differences from upstream to downstream sites during the baseline period 1 and the cattle influenced period 2. Pairing the sites by subtracting downstream - upstream will eliminate input concentrations into each zone. The increases and decreases in concentrations within each zone highlight cattle impacts within each zone. Finding the differences in period 1 helps explain concentration fluxes in the stream without direct cattle impact.

Table 4.10: Paired statistical comparisons of water quality parameters (concentrations) from upstream to downstream sites for baseline (period 1) and cattle access (period 2), Study 1.

		Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1	CR2-CR2b	↓[2]	=	=	=	=	=
	CR2b-CR3	↓	↑	=	=	↑	=
	FW[1]-CM	↑	↑	↑	↑	=	=
Period 2	CR2-CR2b	=	↑	↓	=	↑	=
	CR2b-CR3	=	=	=	=	=	=
	FW-CM	↑	↑	↑	↑	↑	↑

[1] FW = flow weight of MV2 and CR3 stations

[2] Comparisons between periods were first determined using non-parametric Friedman's test to determine if all of Cub Run is equal or not equal. If not equal, pairwise Wilcox tests with a Bonferonni correction was used to determine which paired sites are not equal by finding the differences by subtracting upstream from downstream. If statistically dissimilar, a one-sample bootstrap calculated means and confidence intervals on each data set to determine an increase or decrease.

Symbols in the table indicate the following:

↓ Statistical decrease from upstream-to-downstream

↑ Statistical increase from upstream-to-downstream

= Statistically equal from upstream-to-downstream

- No data

Statistically significant decrease from period 1 to period 2

Decrease in mean from period 1 to period 2

Statistically significant increase from period 1 to period 2

Mean increase from period 1 to period 2

The majority of the statistical changes in all the pollutants in period 1 came from the flow weighted FW and CM sites (table 4.10). The increases may explain that there are natural inputs from the MV2 and CR3 sites to the CM site. Because the farmer had flash grazed many times before this study, the previous influence of cattle may explain the increases in pollutant concentrations with previously placed fecal piles and stream bank impacts within that zone. For period 2, FW – CM also saw all increases in concentrations. However, the mean difference for period 1 is 2,903 MPN/100ml where the mean difference for period 2 is 6,945 MPN/100ml which is greater than a 2 times increase. These means can also be found in Appendix C. Therefore, although bacteria concentrations increased in times of no direct cattle influence from FW to CM, concentrations increased much more in times of cattle influence.

Decreases in bacteria concentrations in period 1 from CR2 – CR2b and CR2b – CR3 sites may be due to attenuation downstream from the upstream free cattle access influence. Contrary to results from the FW-CM sites, CR2-CR2b showed varying results and CR2b-CR3 had no statistical change in any of the pollutants during period 2. The two pairs also showed increases and decreases from period 1 to period 2. Thus, an impact from cattle is not significant within zone 1 and 2 from CR2 to CR3.

Overall, table 4.10 illustrates that cattle impacts are variable except in zone 3 from FW to CM. Similarly with Study 1, the majority of increases from period 1 to period 2 were seen in bacteria, TSS, and TP concentrations. Also, NO_3-N and TN had little change between periods and sites.

4.6 Study 2

4.6.1 Time Series Data

Samples were collected from 15 August 2011 to 19 August 2011. Figures 4.16 – 4.21 show the time lapse data split between CR, CM and upstream sites, and MV. Mountain Valley Road Tributary graph was included in Study 2 because there was a significant presence of cattle. Along with Study 1, Study 2 did not show any changes through the different periods for pH or EC; therefore, boxplots of this data can be found in Appendix I. Also for Study 2, CR1 was sampled during the entire study period to capture effects from the upstream cattle.

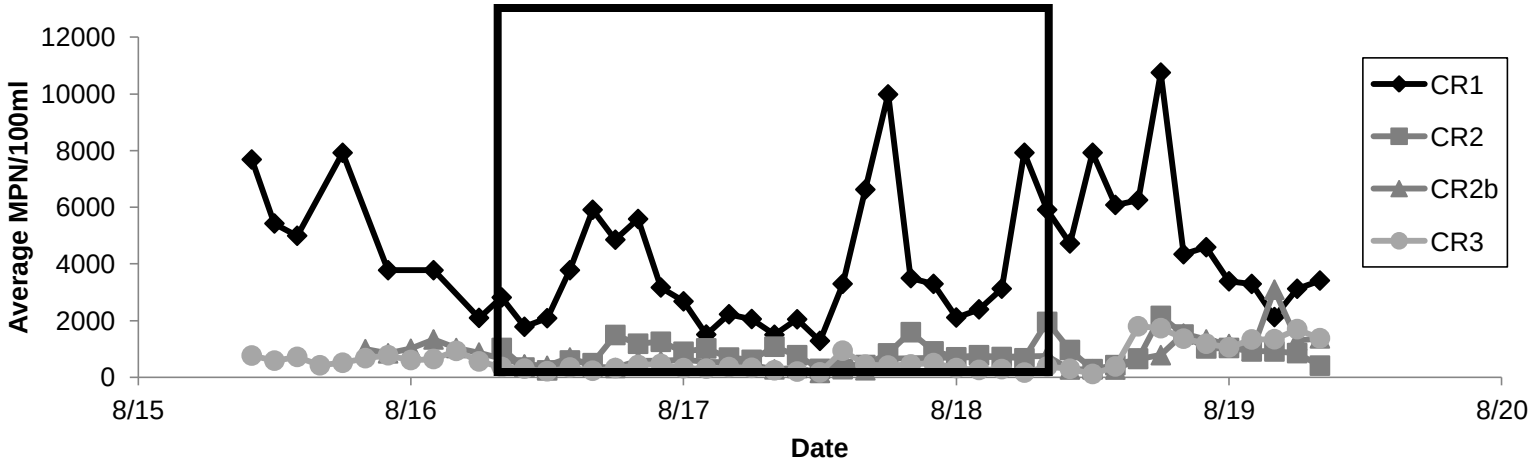

Figure 4.16: Bacteria (*E. coli*) count time series for Cub Run (box indicates period 2), Study 2

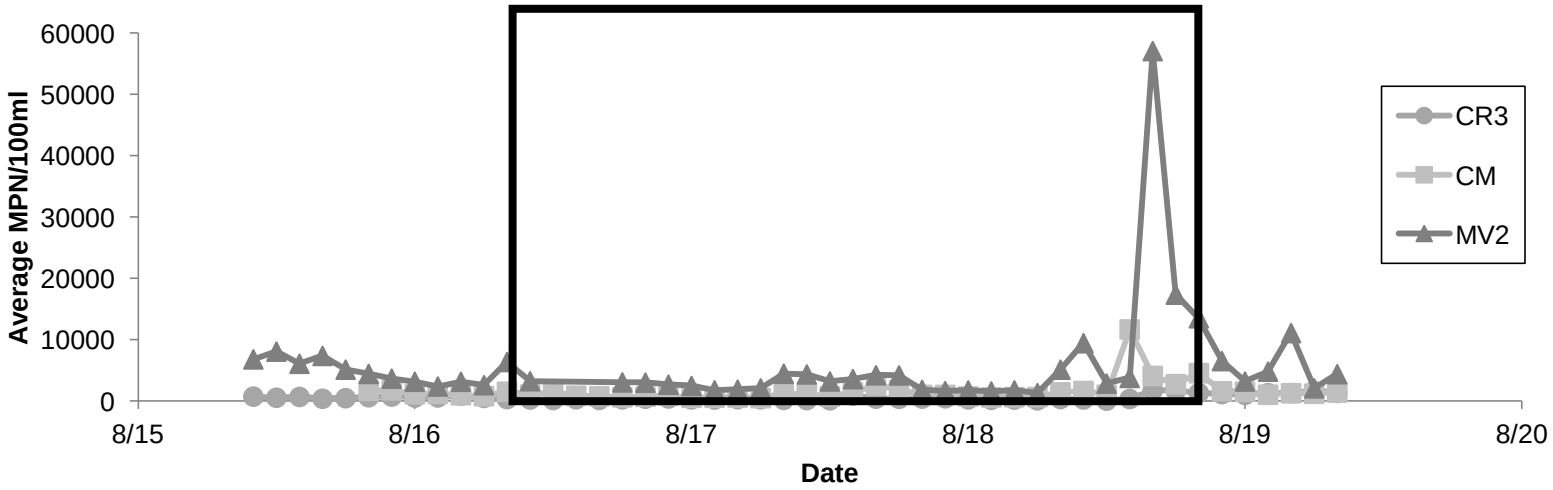

Figure 4.17: Bacteria (*E. coli*) count time series for CM, CR3, and MV2 (box indicates period 2), Study 2

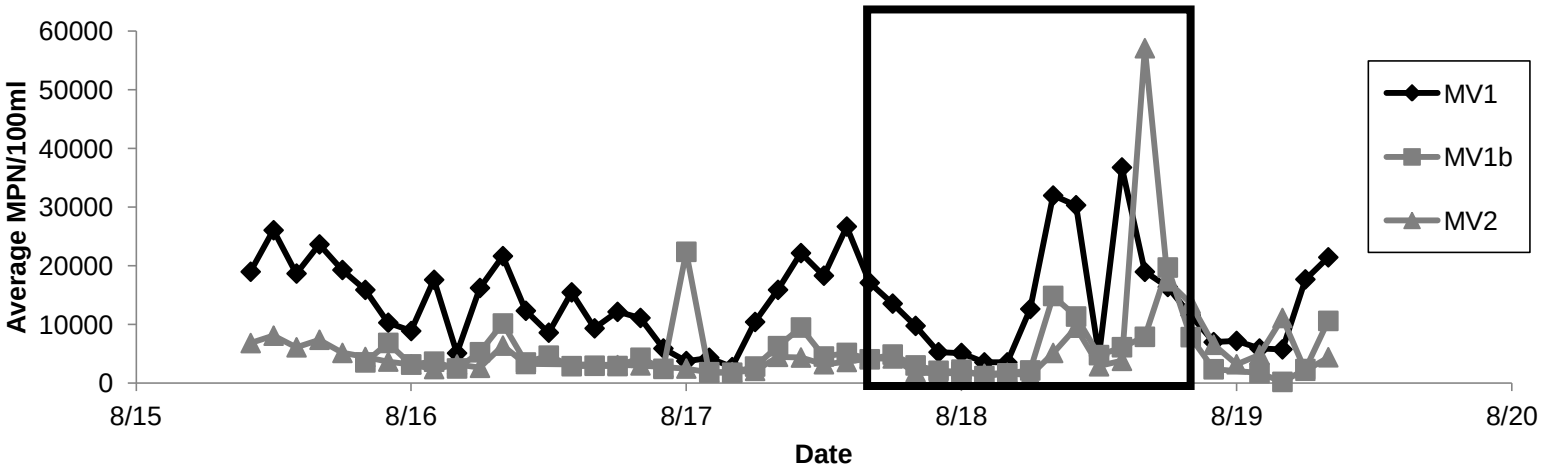

Figure 4.18: Bacteria (*E. coli*) count time series for Mountain Valley Road Tributary (box indicates period 2), Study 2

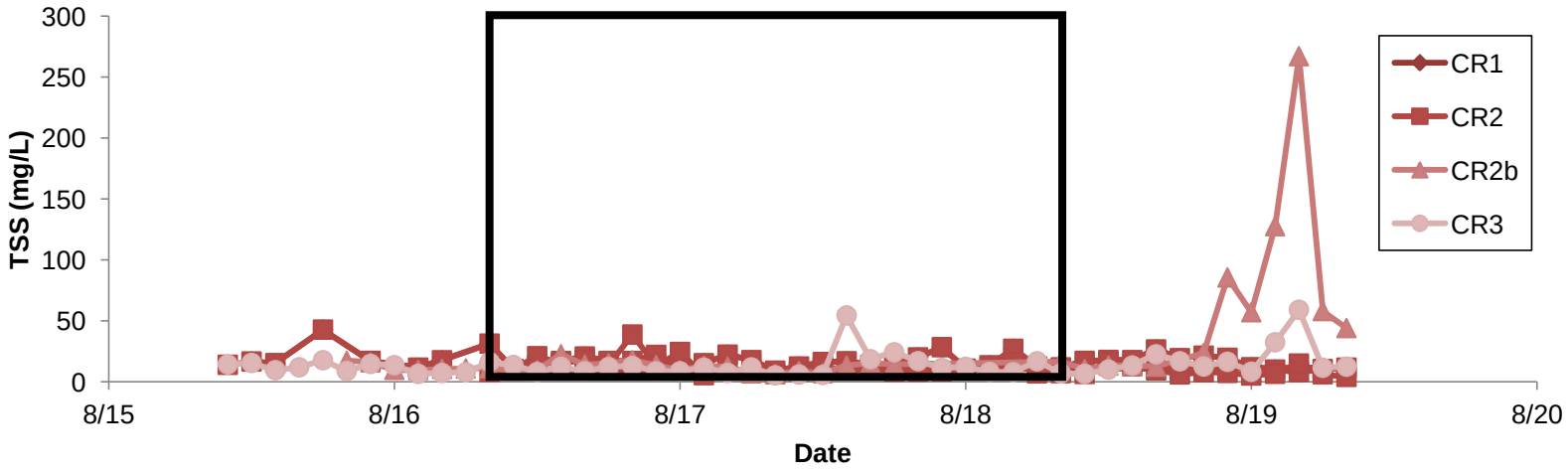

Figure 4.19: TSS time series for Cub Run (box indicates period 2), Study 2

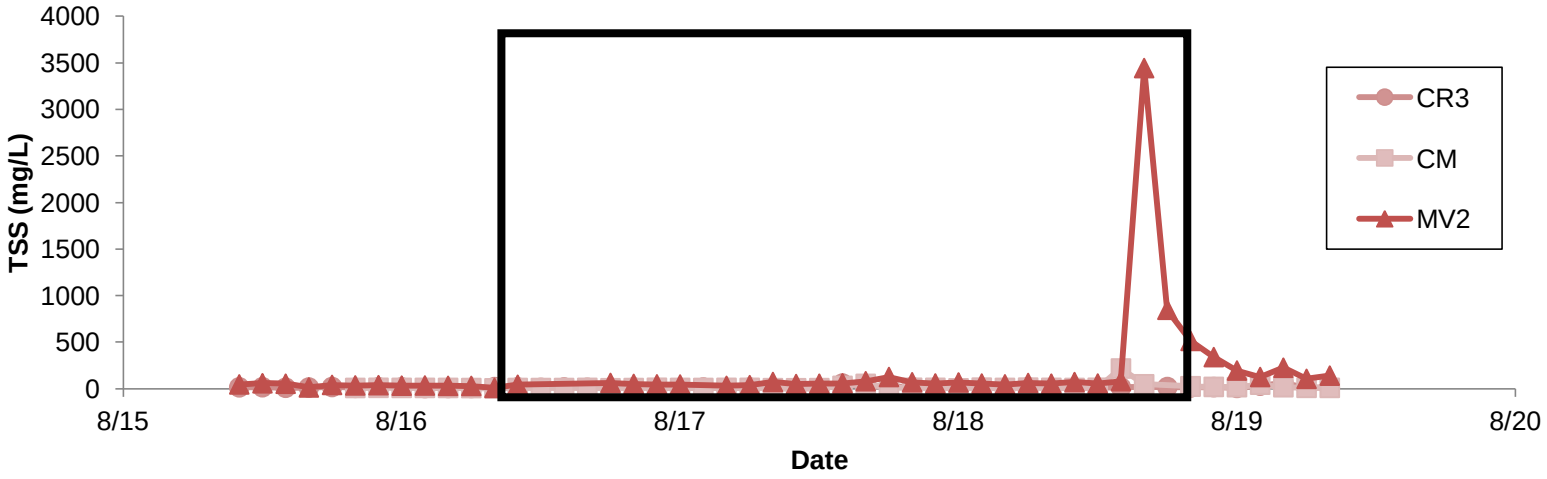

Figure 4.20: TSS time series for CM, CR3, and MV2 (box indicates period 2), Study 2

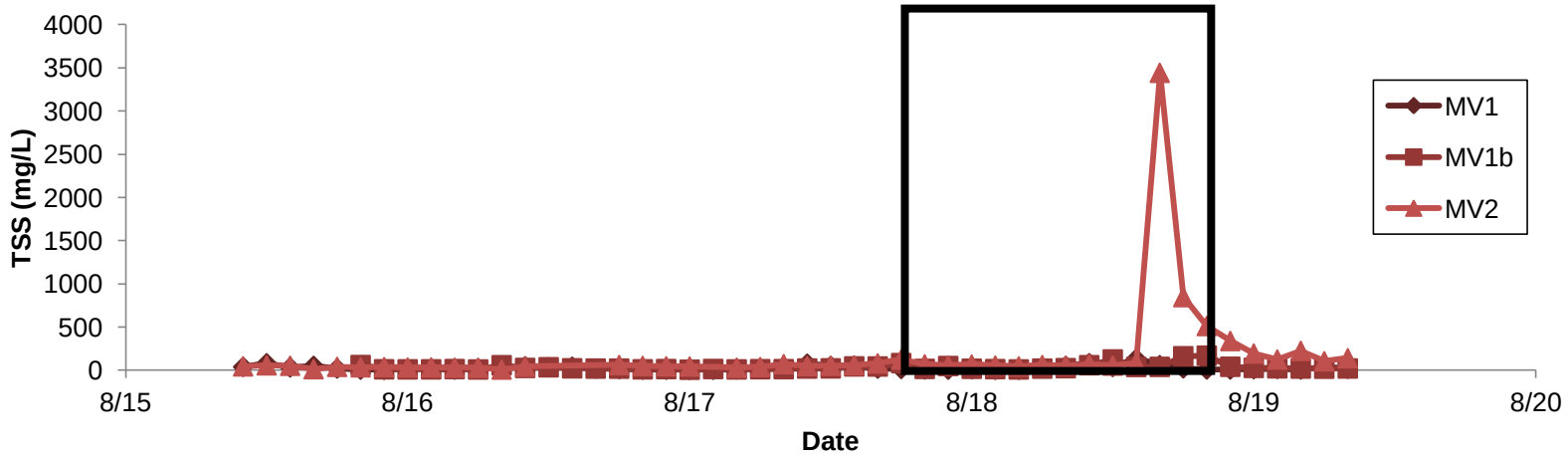

Figure 4.21: TSS time series for Mountain Valley Road Tributary (box indicates period 2), Study 2

Study 2 also shows fluctuating bacteria concentrations at CR1 in figure 4.16. The increases come during late afternoon, which is consistent with the times that cattle are in the stream found in Appendix H. Fluctuating concentrations makes baseline levels very difficult to determine. Figure 4.16 also shows that bacteria concentrations decrease rapidly downstream of the cattle site, and concentrations continue to decrease further downstream as well. Therefore, these decreases in bacteria conventions makes finding a baseline level for the downstream Cub Run sites more feasible. CM also does not show many fluctuations, which is due to upstream streams not having large fluctuations. Figure 4.18 also shows a large fluctuation at MV1, just downstream of free range cattle. Just like Cub Run, bacteria counts attenuate downstream creating more consistent concentrations to MV1b and MV2.

For TSS, figures 4.19-4.21 appear to have steady, baseline levels of sediment. Even the upstream sites of CR1 and MV1 do not have the fluctuations like those seen in the bacteria graphs. Therefore, baseline levels of sediment are much easier to define. The peaks in period 2 in figures 4.19-4.21may be due to flash grazing cattle influence.

4.6.2 Statistical Analysis

Table 4.11 shows the statistical results between the flash grazing periods. Periods 1 and 3 were compared to look at differences between the non-cattle influenced periods. Periods 1 and 2 were compared to look at any changes from pre-cattle influence to during cattle influence time frames. When comparing periods 1 and 3 for all the sites and all the pollutants, very little changes can be seen. There was only one change in nutrients found in NO_3-N at MV2. The majority of the changes, which were increases, are found in TSS concentrations of various sites in the study area.

Table 4.11: Statistical comparisons of water quality parameters (concentrations) between no cattle access periods 1 and 3 and baseline period 1 to cattle access period 2, Study 2.

		Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1, 3	CR2	-[2]	-	-	-	-	-
	CR2b	=	↑	=	=	=	=
	CR3	↑	=	=	=	=	=
	CM	=	↑	=	=	=	=
	FW[1]	=	↑	=	=	=	=
	MV1b	=	=	=	=	=	=
	MV2	=	↑	=	↓	=	=
Period 1, 2	CR2	-	-	-	-	-	-
	CR2b	↓	=	=	=	=	=
	CR3	↓	=	=	↑	=	=
	CM	=	=	=	=	=	=
	FW	↑	↑	=	↓	=	=
	MV1b	=	↑	=	=	=	=
	MV2	=	↑	↓	=	=	=

[1] FW = flow weight of MV2 and CR3 stations

[2] Comparisons between periods were determined using non-parametric Wilcox tests with a Bonferroni correction to determine whether the two data sets are equal or not equal. If statistically dissimilar, a two-sample bootstrap calculated means and confidence intervals on each data set to determine an increase or decrease.

Symbols in the table indicate the following:

↓ Statistical decrease from period 1 and 3 to period 1 and 2

↑ Statistical increase from period 1 and 3 to period 1 and 2

= Statistically equal from period 1 and 3 to period 1 and 2

- No data

Statistically significant decrease from period 1,

Decrease in mean from period 1 to period 2

Statistically significant increase from period 1 to period 2

Mean increase from period 1 to period 2

Although there are not many changes in period 1 to 3, many changes can be seen between the two groups of period comparisons. Similarly with Study 1, the majority of these changes can be seen in bacteria and TSS. The changes are about equally increases and decreases giving an unclear representation of cattle impact. Unlike Study 1, there are several changes in NO_3-N between periods for Study 2. TN and TP did not fluctuate between periods for any of the stations, and there was only one change in PO_4-P at the MV2 site.

Reviewing table 4.11 shows that TP and TN did not statistically change except between FW to CM in period 2. Another point of interest is that PO_4 did not change at all except when comparing MV2 period 1 and 2 and the same CM to FW in period 2. Therefore, in general, nutrients did not change much from period-to-period and upstream-to-downstream.

Table 4.12 shows the differences between paired sites for period 1 and period 2. Similar to table 4.11, there are not many changes in pollutant concentrations in the paired sites with the only changes in bacteria and TSS. With all of the paired sites, only period 2 FW-CM showed increases in nutrient concentrations.

Table 4.12: Paired statistical comparisons of water quality parameters (concentrations) from upstream to downstream sites for baseline (period 1) and cattle access (period 2), Study 2.

		Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1	CR2-CR2b	-[2]	-	-	-	-	-
	CR2b-CR3	↓	=	=	=	=	=
	FW[1]-CM	↑	↑	=	=	=	=
	MV1b-MV2	=	↑	=	=	=	=
Period 2	CR2-CR2b	↓	=	=	=	=	=
	CR2b-CR3	↓	=	=	=	=	=
	FW-CM	↑	↑	↑	↑	↑	↑
	MV1b-MV2	=	↑	=	=	=	=

[1] FW = flow weight of MV2 and CR3 stations

[2] Comparisons between periods were determined using non-parametric Wilcox tests to determine whether the two data sets are equal or not equal by finding the differences by subtracting upstream from downstream. If statistically dissimilar, a one-sample bootstrap calculated means and confidence intervals on each data set to determine an increase or decrease.

Symbols in the table indicate the following:

↓ Statistical decrease from upstream-to-downstream

↑ Statistical increase from upstream-to-downstream

= Statistically equal from upstream-to-downstream

- No data

Statistically significant decrease from period 1 to period 2

Decrease in mean from period 1 to period 2

Statistically significant increase from period 1 to period 2

Mean increase from period 1 to period 2

Another point of interest is that FW-CM increased in every pollutant from period 1 to 2. An increase can be seen in period 1 for bacteria and TSS; however, the mean difference for bacteria in period 1 is 1,250 and the mean difference for period 2 is 1,695 MPN/100ml. For TSS, period 1 has a mean difference of 7.3 mg/L for period 1 and 18.4 mg/L for period 2 also suggesting that cattle have the potential to increase sediment concentrations. The CM and FW sites are the only sites that show a statistical increase from period 1 to period 2 with the exception of MV1b-MV2 TSS. Because FW-CM was the only sites to experiences significant increases, flash grazing cattle do not appear to influence any of the other sites.

4.7 Return to Baseline Concentrations

The time it takes for concentrations to return to baseline concentrations is important to understand when trying to characterize the intensity of an event as well as how the system interacts with pollutants. It also helps quantify the impact of a flash grazing event. As seen in the time series graphs for both studies (figs. 4.12-4.21), CR1 and MV1 have bacteria concentrations that are variable, and most of the peaks can be seen during the afternoon when cattle are more likely to be in the stream zone due to hotter temperatures. The lowest values found in the fluctuations may not be baseline concentrations due to bacteria still in the system from cattle presence. Determining the time it takes for pollutants to return to baseline can help characterize whether the system can fully recover before a new event the next day. If concentrations never return to a baseline level, then there is a continuing input of bacteria into the system, and cattle have a lasting effect beyond the immediate disturbance.

To determine a baseline level for TSS, period 1 concentrations were averaged. However, bacteria concentrations were quite variable and often did not have a clear baseline because of the prominent upstream influence. Therefore, upstream samples were subtracted from downstream sites to determine a difference in concentrations. Pairing data sets may provide a steadier level by subtracting out upstream influence. However, this is not the case, and concentrations were still quite inconsistent. When determining the time of peak impact, the peak latest in time was used. The lated peak in period 2 is used because no other inputs should be affecting concentrations. The date and time of this peak is then recorded. Cattle did not always have a defined peak though such as zone 2 or CR3 – CR2b for study 1. When concentrations did not appear to change from baseline, there was no need to define a baseline.

When concentrations reached the baseline concentrations after the peak, the date and time were noted. The number of hours between the peak and the baseline concentrations were found by subtracting the peak time and the time at which the concentration returned to baseline. However, many of these concentrations, as seen in tables 4.13 and 4.14, do not return to baseline levels because sampling had stopped too soon. Therefore, the percent recovery was calculated instead, and these values are very close to being fully recovered. Because the percent recoveries were very high, the time it takes these concentrations to return to baseline are parallel with the times it took for fully recovered concentrations to return to baseline.

Table 4.13: Time it takes for bacteria concentrations to return to baseline by finding baseline concentrations, peak impact, and percent recovery for each zone in Studies 1 and 2

		CR2b-CR2	CR3-CR2b	CM-FW[1]	MV2-MV1b
Study 1	Baseline Concentrations (MPN/100ml) [2]	no baseline	no peak	1077	-
	Time of peak	no baseline	no peak	7/23/2011 18:00	-
	Percent recovery	no baseline	no peak	75%	-
	Number of hours to baseline	no baseline	no peak	10	-
Study 2	Baseline Concentrations (MPN/100ml)	no baseline	no peak	993	-916[3]
	Time of peak	no baseline	no peak	8/18/11 14:00	8/18/11 16:00
	Percent recovery	no baseline	no peak	86%	100%
	Number of hours to baseline	no baseline	no peak	12	4

[1] FW = flow weighted average of MV2 and CR3
[2] Subtracting downstream – upstream
[3] Negative concentration denotes a decrease from upstream to downstream

Table 4.14: Time it takes for TSS concentrations to return to baseline by finding baseline concentrations, peak impact, and percent recovery for each zone in Studies 1 and 2

		CR2b-CR2	CR3-CR2b	CM-FW[1]	MV2-MV1b
Study 1	Baseline Concentrations (mg/L)[2]	no baseline	5.8	6.5	-
	Time of peak	no baseline	7/22/11 8:00	7/22/11 10:00	-
	Percent recovery	no baseline	100%	100%	-
	Number of hours to baseline	no baseline	6	18	-
Study 2	Baseline Concentrations (mg/L)	-1.7[3]	no peak	6.4	20.3
	Time of peak	8/19/11 4:00	no peak	8/18/11 14:00	8/18/11 16:00
	Percent recovery	85%	no peak	97%	96%
	Number of hours to baseline	4	no peak	18	16

[1] FW = flow weight of MV2 and CR3
[2] Subtracting downstream – upstream
[3] Negative concentration denotes a decrease from upstream to downstream

Zone 3 (CM- FW) generally had the longest times to return to baseline, which could be due to having greater peak impacts than other sites such as zones 1 and 2. Zone 4 (MV2-MV1b) had a quick return in bacteria levels (4 hrs), with a longer time taken for TSS concentrations to return to baseline conditions (16 hrs). TSS concentrations also appeared to have more peak impacts in the zones, which could be due to steadier baseline concentrations. Impacts are more readily seen when there are steadier baseline levels as with TSS versus bacteria concentrations.

4.8 Turbidity as an Indicator of Impact

Analyzing concentrations of pollutants takes an extensive amount of time and resources such as access to a laboratory. The general public does not have access to such equipment and time. Because turbidity can be easily seen, it could make a useful measure of impact. There is no special equipment or needs associated with looking at the stream and determining how turbid or cloudy it is. Although the exact concentration of the stream would not be easy to determine, relative levels can be seen. In contrast, visual observations are not useful when determining different levels of bacteria or nutrients, for example.

Figures 4.22-4.25 show the time series turbidity data for Cub Run and CM with corresponding upstream sites for Study 1 and CM with corresponding upstream sites and Mountain Valley Road Tributary for Study 2. Not all graphs and sites are included because the only sites with peaks are zone 2 and 3 for Study 1 and zone 3 and 4 for Study 2. The other sites have fairly constant baseline turbidity levels throughout the whole study. Because there was no significant cattle influence in zone 4 during Study 1, the increase in turbidity at MV2 in figure 4.23 is likely due to upstream conditions and not flash grazing activity.

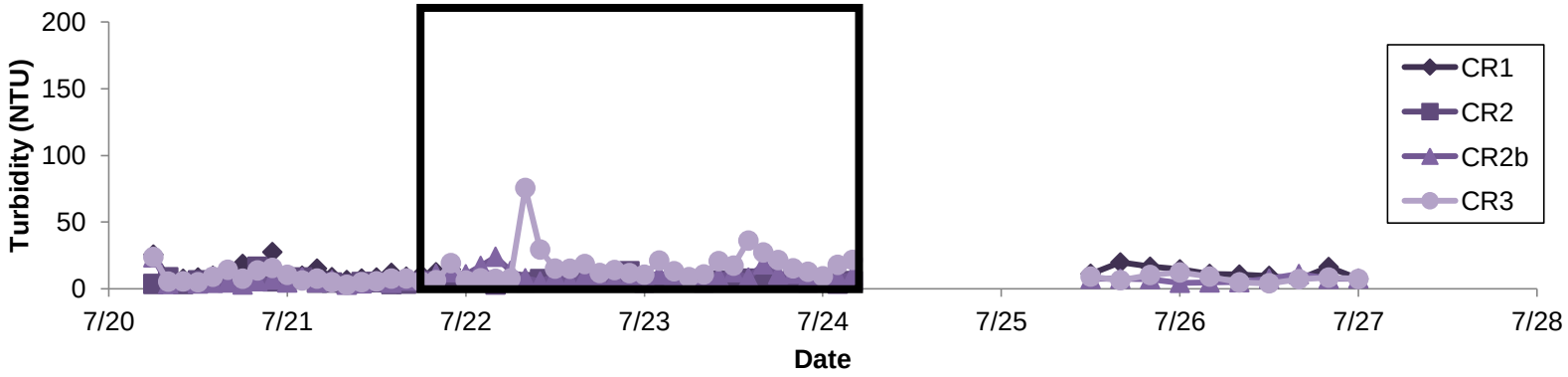

Figure 4.22: Turbidity time series for Cub Run (box indicates period 2), Study 1

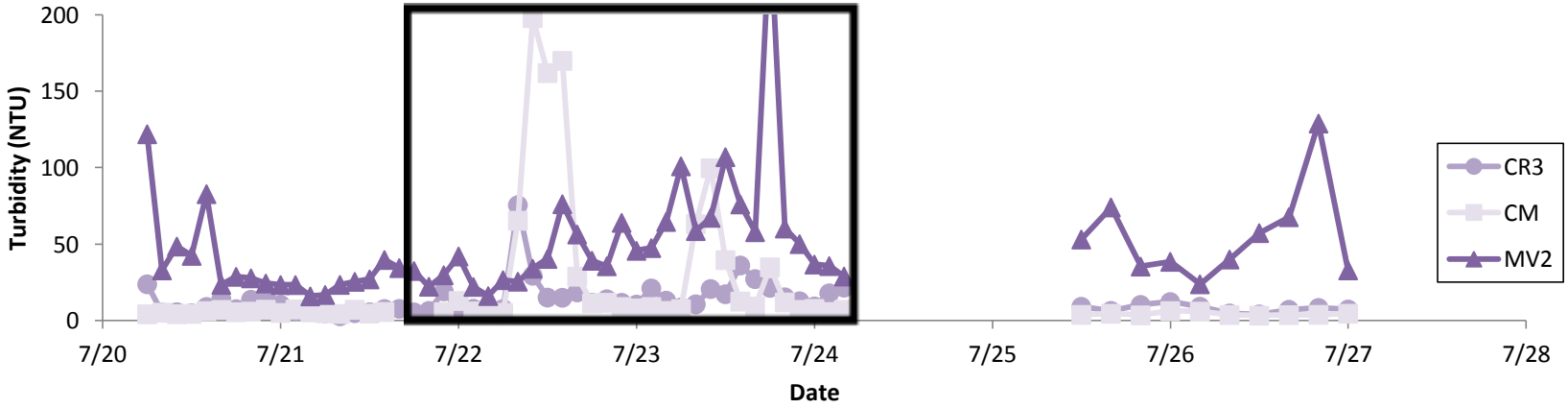

Figure 4.23: Turbidity time series for CM, CR3, and MV2 (box indicates period 2), Study 1

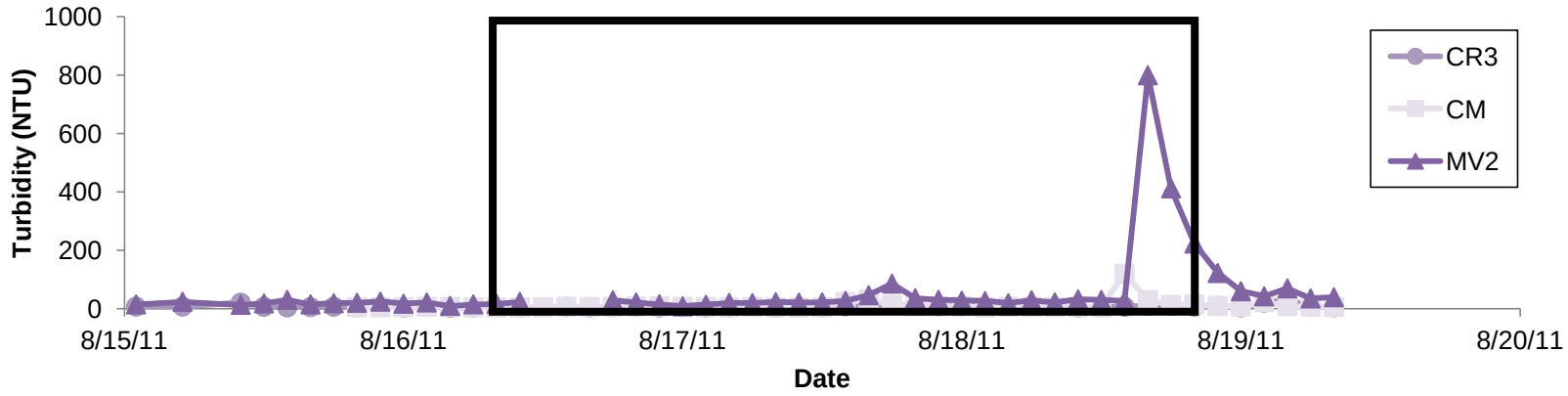

Figure 4.24: Turbidity time series for CM, CR3, and MV2 (box indicates period 2), Study 2

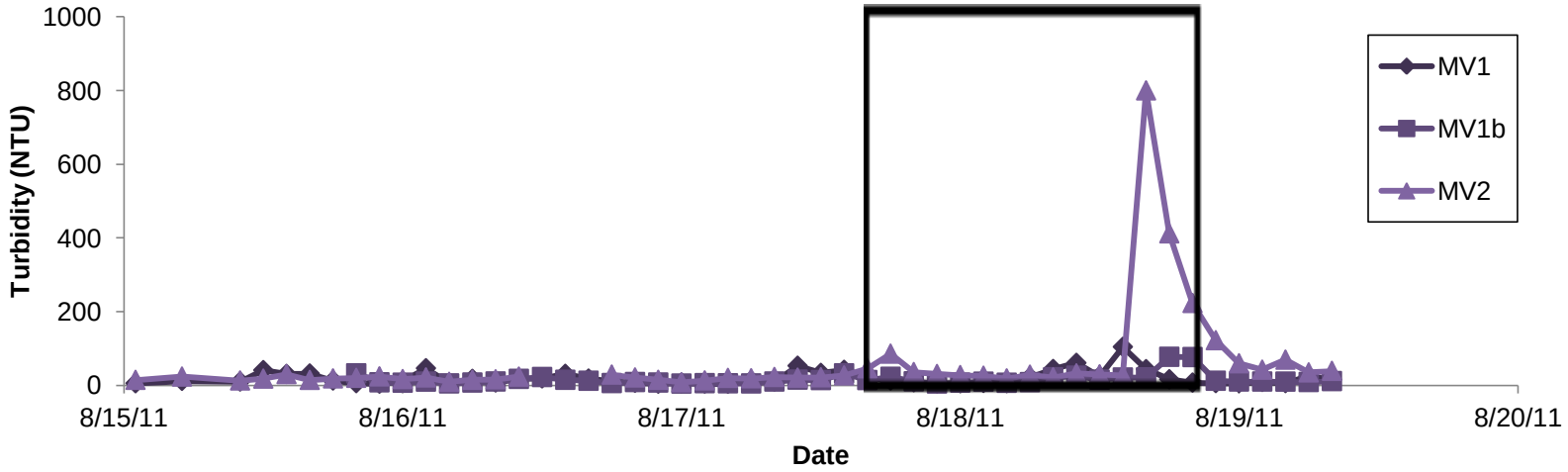

Figure 4.25: Turbidity time series for MV (box indicates period 2), Study 2

In order to use turbidity as a sign of impact, turbidity concentrations were compared to cattle presence. The cattle density method that was chosen was best correlated with the TSS concentrations found in Cattle Density and Pollutant Concentrations in Results. Because turbidity and TSS are closely related, the method in the TSS calculations is used. The time series graphs for the mentioned zones and studies graphed with turbidity concentrations can be found in figures 4.26-4.29.

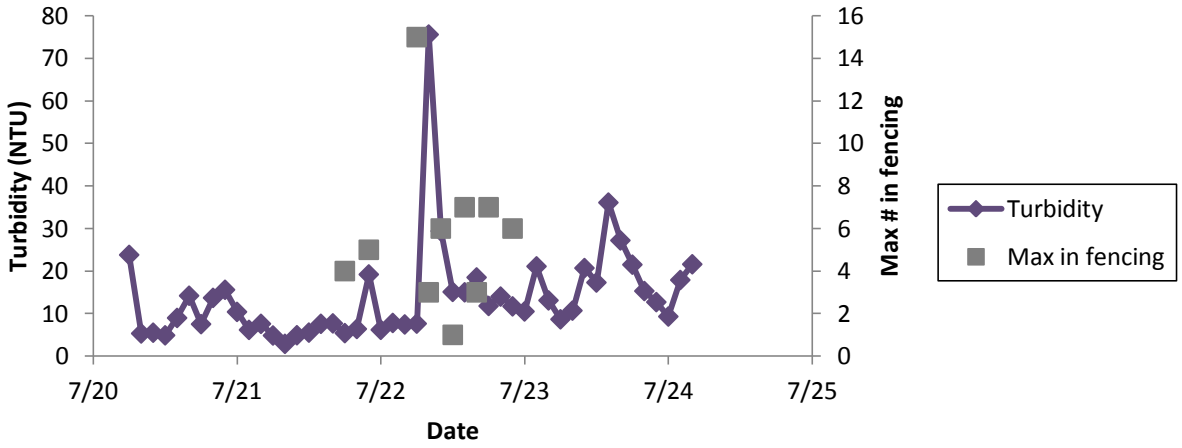

Figure 4.26: Zone 2 turbidity and maximum number of cattle in fencing, Study 1

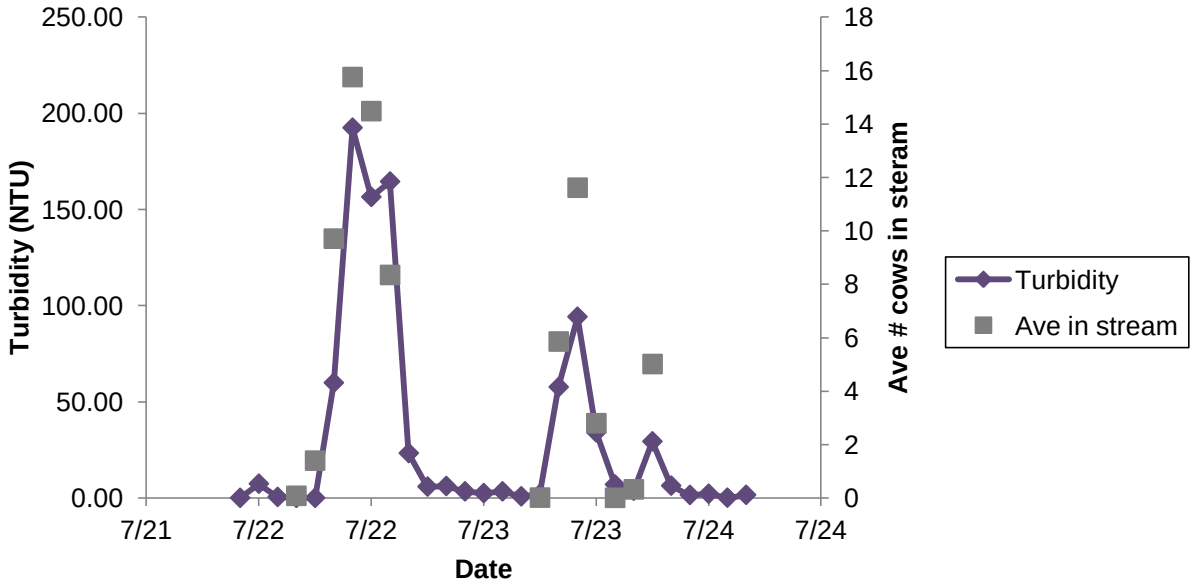

Figure 4.27: Zone 3 turbidity and average number of cattle in stream, Study 1

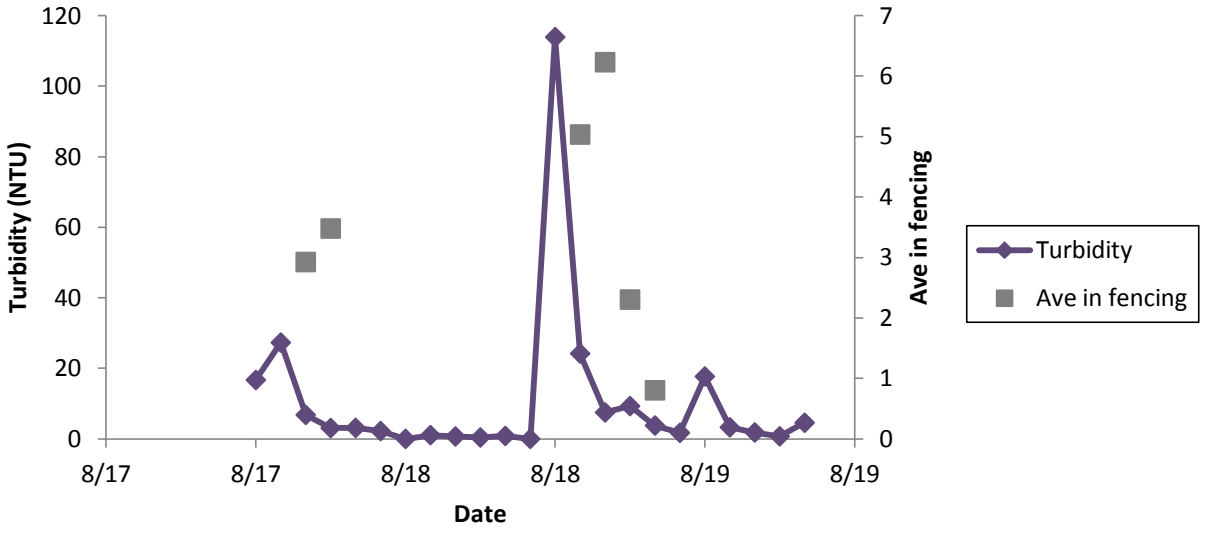

Figure 4.28: Zone 3 turbidity and average number of cattle in fencing, Study 2

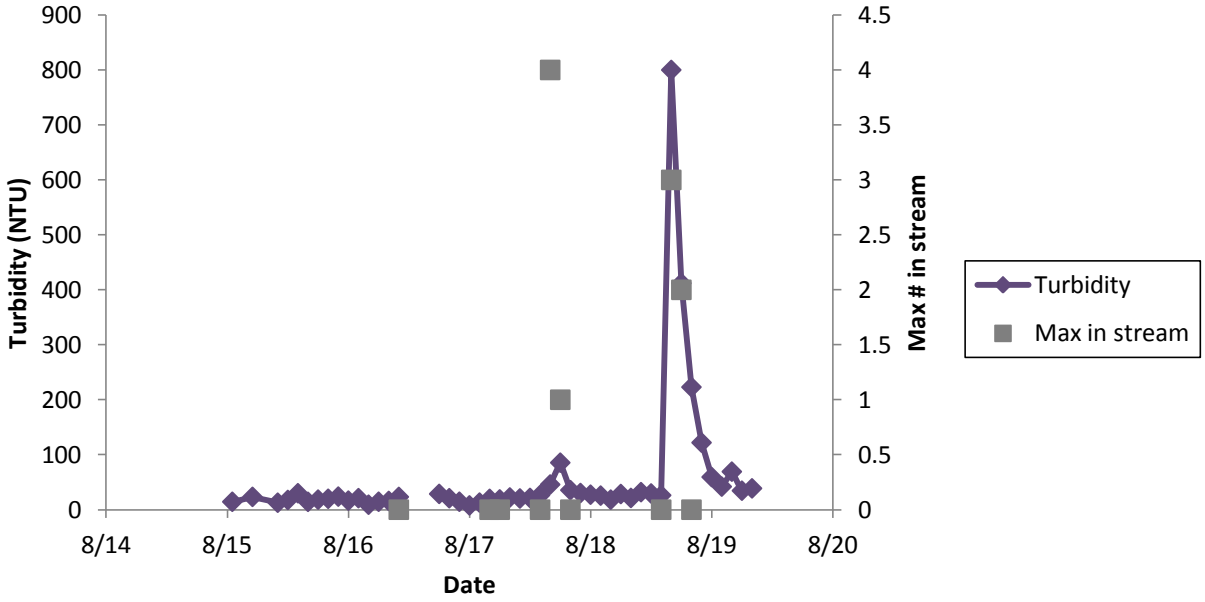

Figure 4.29: Zone 4 turbidity and maximum number of cattle in stream, Study 2

As seen in the figures 4.26-4.29, there was a consistent pattern that when there were cattle in the stream or fencing, concentrations increased. It also appears that when the cattle density reaches approximately three in stream or in fencing, concentrations tend to increase.

Note that just because cattle went above the three cattle approximation, does not mean that turbidity concentrations increased as seen in figure 4.29. The density methods mentioned were

also the density method with the greatest correlation, and the correlations were not highly significant with low R^2 values. There may have been more cattle present that were not represented in these density methods.

However, in figure 4.27, the relationship between cattle and turbidity were very close. Figure 4.27 represented zone 3, which also had the highest R^2 relationships for bacteria and TSS. The high correlation could be because the bed material of this zone was more mobile and increases at smaller amounts of cattle movement.

Once a level of turbidity was established, it will be important to educate the public that looking at the stream at one point of time is not necessarily representative of an event. A stream might naturally be cloudy at baseline levels, so seeing it at one point in time does not necessarily mean that there are cattle present. There are many reasons that a stream may have high turbidity, and cattle are just one possible cause.

4.9 Storm Concentrations

Storm samples were also collected as part of this research study. In order to compare the intensity of cattle influence on water quality, the loads from the flash studies were compared with those of several storms. Ten storms throughout 2010 and 2011 were sampled. The storms chosen to compare with the flash grazing study were storms III, V, IX, and X. These were chosen because they had clear baselines and peaks. MV2 was also chosen as the site to compare concentrations because only the permanent ISCOs take storm samples. MV1 and CR1 are upstream of the flash grazing, and CM is not in place during storm events. Therefore, MV2 and CR3 are remaining, and CR3 does not have any clear peak impacts due to cattle presence in the flash grazing study. During Study 2, MV2 has a clear peak in TSS but not in any other pollutant. Thus, only TSS can be compared because all of the other water quality parameters do not show increases above a baseline level. The graphs of the chosen storms with TSS and flow can be found in Appendix D. Also, several characteristics of the storms are shown in table 4.15.

Table 4.15: Storm dates, intensities, rainfall amounts, and duration

Event	Date	Rainfall (in)	Duration (hr)	Intensity (in/hr)
Storm III	7/13/10-7/14/10	1.79	22	0.08
Storm V	9/30/10-10/1/10	2.59	23	0.11
Storm IX	9/5/11-9/6/11	1.62	14	0.12
Storm X	10/12/2011	0.90	15	0.06

Note that the rainfall amounts for storms V and X came from sister stations on Silver Creek (SL3) near Singers Glen, Virginia due to lack of data at the Mountain Valley Road weather station.

Because the comparison is based on loads, the first step was to define a baseline level so only the peaks can be counted for total load. For the flash grazing study, the baseline was relatively easy to define because the concentrations have been consistently level throughout the study. The stable concentrations were then averaged to determine a baseline level. The start of the peak was clearly defined from the time series graph of the data. After the peak, when concentrations returned to the baseline levels, calculations stopped. However, not all concentrations returned to a baseline level after the peak, so loads can only be based on the collected data, thus not counting the total load of the event.

Storm loads were figured the same way by selecting a baseline concentrations and taking the load on everything above baseline. With the storms, few samples were collected, and it was more difficult to create a baseline. For all of the graphs, there are no two or more points before the maximum value that is stable enough to be considered baseline. Therefore, loads started for each storm at the first sample. Also, the graphs show that there are few to no points that level off after the peak values, so for storms III, V, and X, all of the samples were used to create a load. Storm IX load was calculated from the beginning until 6 September 11 8:30 because after this point there was a break in the samples until 6 September 11 15:30. The concentrations from this point onward in time appear to be at a steady level as well.

Using the corresponding year stage-discharge graphs, the level recorded by the ISCO was converted to flow. Because level was taken every five minutes, it was averaged over the same time period that samples were collected. For example, if the ISCO was programmed to take one hour composites in each bottle, the corresponding levels within that hour were averaged to find one volume. Then, total load was calculated as follows:

$$\text{Load}\left(\frac{\text{mg}}{\text{bottle}}\right) = \text{TSS}\left(\frac{\text{mg}}{\text{L}}\right) * \text{Flow}\left(\frac{\text{m}^3}{\text{s}}\right) * \left(\frac{1000\ (\text{L})}{(\text{m}^3)}\right) * \text{Time}\left(\frac{\text{s}}{\text{bottle}}\right) \quad (2)$$

The loads for each bottle were then summed and converted to kilograms. Table 4.16 shows the total loads and percentages for each storm and the flash grazing event during Study 2.

Table 4.16 Storm and flash grazing Study 2 TSS loads and percentage of storm load compared to flash grazing Study 2 load

Event	TSS (kg)	(kg/hour)	Storm Load as % of Study 2
Storm III	863	39	289%
Storm V	3497	152	1170%
Storm IX	336	24	112%
Storm X	286	19	96%
Study 2	299	17	-

Table 4.16 also shows the load per hour to normalize all the events. Normalizing the events did not change the results greatly as Storm IX and X have comparable loads to the flash grazing event. Storm III's total load is about three times greater than the flash grazing event, but the normalizing makes it about twice as large as the Study 2 load. Storm V for the total load and normalized load has a much greater load than the flash grazing event at approximately 12 times greater.

In conclusion, Storms IX and X have comparable loads to that of a flash grazing event and storms III and V has much higher loads. Although the storms have approximately equal intensities, the rainfall amounts vary. Storm V with over 2.5 inches of rain had the greatest impact on load and showed an 1170% increase over the flash grazing study.

4.10 Weekly Grab Samples

The weekly grab samples collected during the spring, summer, and fall of 2010 and 2011 were used to compare changes in stream concentrations over these two summer seasons. During the fall of 2010, cattle were introduced to the pasture immediately upstream of CR1a where the cattle had free access to the stream. The pasture upstream of CR1a had no stream fencing and the stream in the pasture was the primary water source for the cattle. This change in land use is important to note when comparing pollutant concentrations between years.

Each site was evaluated comparing years as well as pairing upstream and downstream concentrations for each year. Each comparison was run for nutrients NH_4-N, PO_4-P, NO_3-N,

total nitrogen (TN), total phosphorus (TP), turbidity, TSS, *E.coli* bacteria counts, pH, and electrical conductivity (EC) in table 4.17. Little significant change in concentration of pH, EC, TN, and NO_3-N were found and can be seen in Appendix J.

Table 4.17: Statistical comparisons of water quality parameters (concentrations) of weekly grab samples from 2010 to 2011 and paired sites in 2010 and 2011

		Bacteria (MPN/100ml)	TSS (mg/L)	Turbidity (NTU)	pH	EC (µS)	NH_3-N (mg/L)	PO_4-N (mg/L)	NO_3-N (mg/L)	TN (mg/L)	TP (mg/L)
2010-2011	CR1a[2]	↑[1]	↑	↑	=	↓	-	=	=	=	=
	CR1b	↑	=	↑	=	↓	-	=	=	=	=
	CR2	↑	=	=	=	↓	-	=	=	=	=
	CR3	↑	=	=	=	↓	-	=	=	=	=
	MV1	=	↑	↑	=	=	-	↑	↓	↑	=
	MV2	=	↑	↑	=	=	-	↓	↓	↑	=
2010	CR1a-CR1b	=	=	=	=	=	=	=	=	=	↑
	CR1b-CR2	=	=	=	=	=	↓	↓	=	=	=
	CR2-CR3	=	=	=	=	=	=	↓	=	=	↓
	MV1-MV2	=	=	↓	=	=	↓	=	=	=	↓
2011	CR1a-CR1b	=	=	=	=	=	-	=	=	=	=
	CR1b-CR2	↓	=	=	=	=	-	=	=	=	=
	CR2-CR3	=	=	=	=	=	-	=	=	=	=
	MV1-MV2	↓	=	↓	=	=	-	=	=	=	=

[1] Statistical significance between 2010 and 2011 was found running a non-parametric Wilcox test with a Bonferroni correction. If 2010 and 2011 were found to be statistically dissimilar, a two-sample bootstrap was run to determine means and confidence intervals to determine increases and decreases. The last two groups of rows were found first using a non-parametric Friedman's test to determine significance among all the sites on Cub Run. If dissimilar, a pairwise Wilcox test with a Bonferroni correction was run to determine which pairs are not equal. A one-sample bootstrap was run using downstream minus upstream data.

Symbols in the table indicate the following:

↓ Statistical decrease from either 2010 to 2011 or upstream-to-downstream

↑ Statistical increase from either 2010 to 2011 or upstream-to-downstream

= Statistically equal from 2010 to 2011 or upstream-to-downstream

- No data

[2] CR1a is just upstream of the CR1 bridge; CR1b is same as flash grazing CR1

When comparing the 2010 to 2011 data, there is a significant increase in bacteria concentrations for all of the Cub Run sites. The increase could be due to the introduction of cattle upstream of CR1a in the last fall of 2010 and show that cattle have a significant influence on stream water quality within one season. Bacteria, unlike TSS and turbidity, show increases downstream as well. The mean differences from 2010 to 2011by subtracting upstream from downstream for the Cub Run sites are as follows in order of upstream to downstream: -3321, -6001, -1127, and -1174 MPN/100ml respectively. A negative mean difference indicates that downstream is greater than upstream. The increase in TSS and turbidity at CR1a could also be due to upstream cattle. Downstream sites may not show an increase due to settling.

The Cub Run sites also show a significant decrease in electrical conductivity from 2010 to 2011, which most likely cannot be explained from the introduction of cattle. In the literature review, cattle have been found to have little to no effect on the salinity of water. Cattle can, however, stir up bed material and rock that may have captured settled salts thus creating an increase in salinity and electrical conductivity.

Table 4.17 also shows that both MV sites have increases in TSS, turbidity, and TN in 2011. Mountain Valley Road tributary also had a strong cattle presence upstream that could contribute to the increase in sediment. However, the increase in bacteria did not change, but through the cutting back of banks and storm events, sediment could have become unsettled even when cattle were not present in the stream. The silty, mucky streambed of MV is mobile and can be suspended into the water column easily. The increase in total nitrogen may be from natural sources as the literature review notes that cattle have little influence on nitrogen concentrations. Although both these sites had increases in total nitrogen, both sites, however, had a decrease in NO_3-N and equal amounts of NH_3-N; therefore, there may have been sampling/laboratory error or another source of nitrogen causing the increase.

The last two groups of rows looks at the paired differences from upstream-to-downstream to determine what was occurring throughout the stream reach. In 2010, there were few changes except for nutrient decreases. The nutrient decreases do not show patterns in pollutants or sites. While 2010 had only changes in nutrients, 2011 had no significant changes except in bacteria and turbidity. The differences were found in sites that were closest to the upstream cattle influence. Although the free access cattle upstream of the study site may have contributed to the increases in concentrations at the upstream stations, the free access cattle

upstream may not have significant influence on concentrations of stations further downstream of the immediate influence.

When analyzing the paired data sets for 2010 and 2011 there are no significant differences between the CREP zone (CR1-CR2) and the flash grazing zones (CR2-CR3). Although there were noticeable increases during the immediate impact of cattle, there were no noticeable long-term impacts of flash grazing when analyzing weekly grab samples.

The only common significance for the MV tributary for both years was the decrease in turbidity from MV1 to MV2. The cattle influence upstream of MV1 was present during both years, and there were no major changes upstream on MV. The decrease in turbidity from MV1 to MV2 could largely be due to stream characteristics. MV1 was also placed in a stream bend that was consistently covered by sediment due to deposition whereas while MV2 was downstream of a straight reach segment lined with tall grasses.

4.11 Effects of CREP Zone

Although this project focuses on the effects of cattle on water quality, it is also important to compare the cattle affected streams to a stream that has not directly been impacted by cattle. CREP fencing was installed to keep animals out and to help establish a vegetative buffer between the cattle and the stream. Because the opportunities for inputs such as direct cattle or overland flow are reduced or eliminated, concentrations of pollutants not influenced from groundwater flow should decrease or attenuate downstream. The CREP zone for this project was located between sites CR1 and CR2. Using the long-term weekly samples and the short-term intensive, flash grazing samples, a comprehensive understanding of the effects of the CREP zone was found.

Table 4.18 shows the percent reductions for TSS, Bacteria, NO_3-N, and PO_4-P as well as the mean concentration difference between CR1 and CR2. Where table 4.18 includes the average of both years, table 4.19 shows the years separated to show any possible changes from 2010 and 2011 such as the upstream cattle introduction influence. Table 4.20 shows the statistical significance of the pollutant concentrations for both of the flash grazing studies.

Table 4.18: Mean percent and reductions of pollutant (concentration) from CR1 to CR2 (CREP zone)

	Study 1		Study 2		Weekly	
Pollutant	Mean reduction[1]	Mean percent[2]	Mean reduction	Mean percent	Mean reduction	Mean percent
TSS (mg/L)	19.1	53%	5.4	25%	-1.7	-58%
Bacteria (MPN/100ml)	5920	61%	3228	74%	2639	37%
NO_3-N (mg/L)	0.48	15%	-0.26	-19%	0.14	3%
PO_4-P (mg/L)	0.00041	7%	0.00047	11%	0.00103	24%

[1] Mean reduction in concentration from CR1 to CR2
[2] Mean percent reduction in concentrations from CR1 to CR2

Table 4.19: Statistically significant comparisons of pollutant concentrations from CR1-CR2 for 2010 and 2011 weekly grab sample data

	Bacteria	TSS	Turbidity	PO_4	NO_3	NH_3	TN	TP
2010	=[1]	↑	=	↓	=	↓	=	=
2011	↓	=	↓	↓	=	-	=	=

[1] Symbols in the table indicate the following:
↓ Statistical decrease from upstream-to-downstream
↑ Statistical increase from upstream-to-downstream
= Statistically equal from upstream-to-downstream
- No data

Table 4.20: Statistically significant comparisons of pollutant concentrations from CR1-CR2 for both flash grazing studies

	Bacteria	TSS	Turbidity	PO_4	NO_3	NH_3	TN	TP
Study 1	↓[1]	↓	↓	↓	↓	↓	↓	↓
Study 2	↓	↓	↓	=	=	-	=	=

[1] Symbols in the table indicate the following:
↓ Statistical decrease from upstream-to-downstream
↑ Statistical increase from upstream-to-downstream
= Statistically equal from upstream-to-downstream
- No data

As seen in tables 4.18 – 4.20, overall concentrations of pollutants decreased through the CREP zone with the exception of 2010 weekly TSS and Study 2 NO_3. Table 4.18 shows that nutrients did not have a large difference whereas the TSS and bacteria counts had a noticeable difference. The weekly data were not found to have a significant difference in nutrients with the exception of NH_3-N during 2010 (table 4.19). Bacteria, turbidity, and PO_4 did experience decreases during 2011, which could also be due to the cattle upstream. The additional free-access cattle could promote higher concentrations at the inlet which attenuate and settle downstream to CR2.

Although the TSS weekly grab sample data shows an increase in concentration of 58%, the concentration difference is only 1.7 mg/L (table 4.18). Table 4.19 shows that 2010 had a statistical increase in the weekly TSS data; however, a concentration of 1.7 mg/L is not a noticeable change of sediment. Even though 58% appears to be a large increase, the scale of the difference is quite small.

Table 4.20 shows that all Study 1 pollutant concentrations significantly decreased. Study 2 found no changes in nutrients and deceases in concentrations in bacteria, TSS, and turbidity.

5 Discussion and Conclusions

The main objective of this research was to assess the impact of short-term cattle grazing on stream water quality parameters. Storm samples, weekly grab samples, and two short-term (flash) grazing events were studied to evaluate the impact of cattle on in-stream concentrations of *E. coli*, sediment, and nutrients. Flash grazing is defined as short-term, high-density grazing. This research focuses on the impact of pasture cattle within the riparian zone of exclusion fencing on streams in the Shenandoah Valley in Virginia.

Storm and weekly grab samples were collected during the summer and fall of 2010 and 2011, and flash grazing studies were sampled during July 2011 (Study 1) and August 2011 (Study 2). The flash grazing studies was split into three periods: baseline (1), cattle access to the riparian zone (2), and post cattle access (3). Eight automatic water samplers collected stream subsamples every 15 minutes for 2-hour composite samples. Upstream-to-downstream samplers created zones within the riparian area (table 3.3). Cattle were tracked and counted using hunting cameras in order to quantify their presence.

Data from the flash grazing studies were statistically analyzed comparing the differences between periods as well as upstream/downstream changes, using non-parametric tests in the R statistics package. Study 1 showed many significant changes in pollutant concentrations such as increases between periods 1 and 3 as well as increases in paired samples from period 1 to period 2. Few changes in nitrogen concentrations were found throughout the study. Study 2 did not provide results as clear as Study 1. For example, Study 2 had about equal increases and decreases when comparing periods 1 and 3 and periods 1 and 2. However, the paired sites FM to CM saw significant changes across all the pollutants during period 2. Few other increases in paired pollutant concentrations were found in bacteria and TSS. The only significant changes in TP and TN were found in the paired sides FM to CM during period 2.

To determine any significant changes that were consistent across both flash grazing studies, tables 4.9-4.12 were combined into tables 4.21 and 4.22. When table 4.9 for Study 1 and table 4.11 for Study 2 had the same symbol, that symbol was placed in table 4.21. Similarly, when table 4.10 for Study 1 and table 4.12 for Study 2 agree, the symbol was placed in table 4.22.

Table 4.21: Statistical summary between periods of pollutant concentrations for Studies 1 and 2

		Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1,3	CR2b	=[2]	↑				
	CR3		=	=	=	=	=
	CM		=		=	=	=
	FW[1]		↑		=	=	=
Period 1,2	CR2	-	-	-	-	-	-
	CR2b				=		
	CR3			=			=
	CM				=		=
	FW		↑		=		=

[1] FW = flow weight of MV2 and CR3
[2] Symbols in the table indicate the following:
↓ Statistically significant decrease from period-to-period
↑ Statistically significant increase from period-to-period
= Statistically equal from period-to-period
- Study 1 or Study 2 did not have sufficient data
( ) Study 1 and Study 2 statistical analyzes do not agree

Table 4.21 shows that there were many consistencies, or equals, with nutrients; therefore, short-term cattle influence did not appear to have significant influence on nutrient concentrations in streams. Bacteria concentrations appeared to have the most fluctuation with only one similar symbol (CR2b period 1 and 3) in both studies.

Table 4.22 shows more similarities between both the studies than table 4.21. The most prominent similarity in table 4.21 is both studies showed increases in pollutants from FW to CM during the cattle access, period 2. CR2-CR2b also had many similarities with mostly equal symbols. Overall, table 4.21 indicates that the most prominent changes were found in zone 3, just upstream of the CM site. However, other sites and zones did not have as clear common symbols or results between both studies. Therefore, cattle may have had a significant impact at zone 3 but not in the other zones.

Table 4.22: Statistical summary of paired sites of pollutant concentrations for Studies 1 and 2

		Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1	CR2-CR2b	-[2]	-	-	-	-	-
	CR2b-CR3	↓		=	=		=
	FW[1]-CM	↑	↑			=	=
	MV1b-MV2	-	-	-	-	-	-
Period 2	CR2-CR2b				=		=
	CR2b-CR3		=	=	=	=	=
	FW-CM	↑	↑	↑	↑	↑	↑
	MV1b-MV2	-	-	-	-	-	-

[1] FW = flow weight of MV2 and CR3
[2] Symbols in the table indicate the following:
↓ Statistically significant decrease from period-to-period
↑ Statistically significant increase from period-to-period
= Statistically equal from period-to-period
- Study 1 or Study 2 did not have sufficient data
( ) Study 1 and Study 2 statistical analyzes do not agree

Determining the time it takes for peak concentrations of TSS and *E. coli* to return to a baseline condition can help in understanding the differences between unrestricted free cattle access and flash grazing events. Results show that many of the peak concentrations did not have time to return to baseline, but the peaks that experienced a 100% recovery, returned to baseline within one day.

Turbidity was used as an indicator of cattle impact on water quality because it can easily be seen by the naked eye. Although each zone varied, as a general rule, turbidity increased when cattle were present in the stream zone. Approximately three or more cows would cause an increase above baseline.

Storm loads were compared with flash grazing loads to help understand the impact of short-term cattle access on water quality. Results show that low intensity storms generally had comparable impact to a flash grazing event at the MV2 site with the exception of Storms III and V with rainfall intensities of 1.8 in/hr and 2.6 in/hr respectively.

The weekly grab samples were used to assess any pollutant concentration changes in the system from 2010 to 2011. These samples were statistically analyzed comparing year-to-year as well as upstream/downstream variation. Results show that there are significant increases in

E. coli and significant decreases in EC for the Cub Run sites with a few statistical differences in TSS and turbidity. The increases in bacteria could be due to the unrestricted cattle access upstream of CR in the late fall of 2010. There were no significant long-term changes in pollutant concentrations from the CREP zone to the flash grazing riparian zones. Therefore, flash grazing may not have a significant impact beyond the initial impact.

In order to understand the impact of cattle on water quality, it is important to understand how the system would react in a non-cattle impacted setting represented in this project by the CREP zone. Overall, pollutant concentrations decreased within the CREP zone from CR1-CR2 and experienced attenuation of bacteria both long-term and short-term impact.

Overall, cattle access to the stream zone caused increases in *E.coli* and sediment. Zone 1 and 2 results were often inconsistent and did not appear to have any significant changes when cattle had access to the stream zone. In contrast, zone 3 and 4 showed several instances with statistically significant increases in all pollutants. The consistency in increases could be due to the nature of that particular stream section. The stream bed consists of silt particles and fewer cobbles compared to other parts of Cub Run. Cattle may like to congregate under the riparian trees because it has a better footing and provides lots of shade.

6 Limitations and Recommendations

There are several limitations associated with this project. For example, the entire stream riparian zone in this study was not under the camera surveillance. Due to the limited number of cameras, they were placed in areas that were suspected to have the greatest number of cattle. However, there may be large influences of cattle in the stream that were not captured and could help explain discrepancies in the data. Along with having more cameras, it is suggested that all the cameras be time-lapse. Motion-sensor cameras only take pictures when the sensor is triggered. However, there may be movement just outside the viewing area that is not recorded. Having all time-lapse cameras would give a comprehensive view of the entire stream riparian zone.

Also, in known high priority areas such as zone 3, several cameras were placed pointing in the same general area so that the entire zone was captured with video. However, this caused camera viewing areas to overlap. In future studies, it would be beneficial to place flags or other markers in the riparian zone that would not alter cattle movement but would clearly define which camera the cow will be counted towards. Similarly, cameras should be positioned in a way that

captured two different zones such as in position 7 in this study. Flags or other marking tools would also be helpful in creating specific boundaries of each zone. It is quite easy to define zones upstream and downstream of the ISCO, but the riparian bank area is harder to determine.

Counting cattle in the stream was easier for Cub Run since it is a wider stream with manicured riparian vegetation. In contrast, MV consisted of low flows and banks with very tall, thick grasses. The tall grasses create a difficulty when trying to define the presence of cattle in the stream versus just on the riparian area. There is especially an issue when the cow is further away from the camera and the view gets smaller. Solving this problem might include more cameras along the reach or again markers in the water that could help identify when a cow is in the water or not.

The results and conclusions established for this study only represent the characteristics of this site. Future studies on different cattle exclusion practices would be beneficial to get the overall effect of short term impact of cattle. In order to establish a comprehensive understanding of flash grazing, future studies need to establish the effects of cattle beyond the immediate impacts. For example, the cutting back of banks during flash grazing has the potential to cause an increase in sediment during times of higher flows. However, once enough evidence is established, flash grazing may be a beneficial management opportunity for farmers that are otherwise reluctant to implement cattle exclusion practices.

7 References

Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, J. L. Taraba, and R. S. Gates. 2004a. Effects of cattle grazing and BMPs on stream water quality. Trans. ASAE/CSAE.: 042131.

Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, J. L. Taraba, and R. S. Gates. 2004b. Influence of BMPs on cattle position preferences. Trans. ASAE/CSAE: 042182.

Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, E. S. Vanzant, and J. L. Taraba. 2005. Streambank erosion associated with grazing practices in the humid region. Trans. ASAE. 48(1):181-190.

Alison, G. 2007. Australia introduces virtual livestock fencing. Frontiers of Ecology and the Environ. 5(6):291.

Benham, B. L., Robbins, J.H., Brannan, K.M., Mostaghimi, S., Dillaha, T.A., Pease, J.W., Smith, E.P. 2005. Development of survey-like assessment tools to assess agricultural best management practice performance potential. Soil and Water Conserv. 60(5):251-259.

Bewsell, D. R., R. M. Monaghan, and G. Kaine. 2007. Adoption of stream fencing among dairy farmers in four New Zealand catchments. Environ. Manage. 40(2):201-209.

BLM. 2011. The Taylor Grazing Act. Casper, WY: U.S. Bureau of Land Management. Department of the Interior. Available at: http://www.blm.gov/wy/st/en/field_offices/Casper/range/taylor.1.html. Accessed 3 January 2011.

Brannan, K. M., R. M. Mostaghimi, T. A. Dillaha, C. D. Heatwole, M. L. Wolfe, M. Al-Smadi, S. Shah, and J. Miller. 2001. Big Otter River fecal coliform TMDL: a case study. ASAE Paper No. 01-2067.

Buckhouse, J. C., and G. F. Gifford. 1976. Water quality implications of cattle grazing on a semiarid watershed in southeastern Utah. Range Manage. 29(2):109-113.

Elmore, W., and J. B. Kauffman. 1994. Riparian and watershed systems: degradation and restoration. Soc. for Range Manage.: 212-231.

Embry, L. B., M. A. Hoelscher, R. C. Wahlstrom, C. W. Carlson, L. M. Krista, W. R. Brosz, G. F. Gastler, and O. E. Olson. 1959. Salinity and livestock water quality. South Dakota Agricultural Experimental Station Bulletin 481.

Follett, R. F. J.L. Hatfield. 2001. Nitrogen in the environment: sources, problems and management. 2nd ed. San Diego, CA: Elsevier. 17-43.

Franklin, D. H., M. L. Cabrera, Byers H.L., M. M.K., A. J.G., D. E. Radcliffe, M. A. McCann, H. A. Kuykendall, C. S. Hoveland, and V. H. I. Calvert. 2009. Impact of water troughs on cattle use of riparian zones in the Georgia Piedmont in the United States. Anim. Sci.(87):2151-2159.

Frondorf, L. 2001. An investigation of the relationships between stream benthic macroinvertebrate assemblage conditions and their stressors. MS thesis. Blacksburg, VA: Virginia Tech, Department of Biological Systems Engineering.

Galeone, D. G., D. J. Low, and R. A. Brightbill. 2006. Effects of streambank fencing of near-stream pasture land on a small watershed in Lancaster County, Pennsylvania U.S. Geological Survey Fact Sheet 2006-3112.

Gary, H. L., S. R. Johnson, and S. L. Ponce. 1983. Cattle grazing impact on surface water quality in a Colorado front range stream. Soil and Water Conserv. 38(2):124-128.

Grandin, T. 2011. Essential topics in animal agriculture: what farmers need to know. Winter Forage Conference. Virginia Forage and Grassland Council.

Howell, J. M., C. M.S., and C. P.L. 1996. Effect of sediment particle size and temperature on fecal bacteria mortality rates and the fecal colifrom/fecal streptococci ratio. Environ. Qual. 25(6):1216-1220.

Hughes, A. H. 2008. The effects of cattle exclusion on stream structure and function. MS thesis. Blacksburg, VA: Virginia Tech, Department of Biological Sciences.

Hurley, M. A., and M. E. Roscoe. 1983. Automated statistical analysis of microbial enumeration by dilution series. Appl. Bacteriology. 55:159-164.

James, E., P. Kleinman, T. Veith, R. Stedman, and A. Sharpley. 2007. Phosphorus contributions from pastured dairy cattle to streams of the Cannonsville Watershed, New York. Soil and Water Conserv. 62(1):40-47.

Jarvie, H. P., P. M. Haygarthb, C. Neala, P. Butlerb, B. Smitha, P. S. Nadena, A. Joynesb, M. Neala, H. Wickhama, L. Armstronga, S. Harmana, and E. J. Palmer-Felgatea. 2008. Stream water chemistry and quality along an upland–lowland rural land-use continuum, southwest England. Hydrol. 350(3-4):215-231.

Johengen, T. H., A. M. Beeton, and D. W. Rice. 1989. Evaluating the effectiveness of best management practices to reduce agricultural nonpoint source pollution. Lake and Reserv. Manage. 5(1):63-70.

Larsen, R. E., J. R. Miner, J. C. Buckhouse, and J. A. Moore. 1994. Water-quality benefits of having cattle manure deposited away from streams. Bioresource Technol. 48(2):113-118.

Masters, A. L. 2002. Factors influencing the amount of time spend by cattle in streams:implications for TMDL development. MS thesis. Blacksburg, VA: Virginia Tech, Department of Biological Systems Engineering.

MDDNR. 2004. Freshwater benthic macroinvertebrates. Annapolis, Maryland.: Maryland Department of Natural Resources. Available at: http://www.dnr.state.md.us/streams/pdfs/benthic_macroinvertebrates.pdf. Accessed 3 January 2012.

Miller, J. D., D. Chanasyk, T. Curtis, T. Entz, and W. Willms. 2010. Influence of streambank fencing with a cattle crossing on riparian health and water quality of the Lower Little Bow River in Southern Alberta, Canada. Agr. Water Manage. 97(2):247-258.

Miner, J. R., J. C. Buckhouse, and J. A. Moore. 1992. Will a trough reduce the amount of time hay-fed livestock spend in the stream (and therefore improve water quality)? Rangelands 14(1):35-38.

Parsons, C. T., P. A. Momont, T. Delcurto, M. McInnis, and M. L. Porath. 2003. Cattle distribution patterns and vegetation use in mountain riparian areas. Range Manage. 56(4):334-341.

Peppler, M. C., and F. A. Fitzpatrick. 2006. Methods for monitoring the effects of grazing management on bank erosion and channel morphology, Fever River, Pioneer Farm, Wisconsin, 2004. Middleton, WA. United States Geological Survey. Available at: http://pubs.usgs.gov/fs/2005/3134/. Accessed 20 June 2011.

Platts, W. S., and R. L. Nelson. 1985. Streamside and upland vegetation use by cattle. Rangelands 7(1):5-7.

Reynaud, J. Y., B. Tessier, J. P. Auffret, S. Berne, M. De Batist, T. Marsset, and P. Walker. 2003. The offshore quaternary sediment bodies of the English Channel and its Western Approaches. Quaternary Sci 18(3-4):361-371.

Robillard, P. D., J. C. Clausen, E. G. Flaig, and D. M. Martin. 1992. Research needs and future vision for nonpoint source projects. Proceedings of the National RCWP Symposium on 10 Years of Controlling Agricultural Nonpoint Source Pollution: The RCWP Experience. United States Environmental Protection Agency.

Russell, J. 2010. GPS proves useful tool for Leopold Center grazing research. Iowa State University. Ames, Iowa. Available at http://www.leopold.iastate.edu/news/05-03-2010/gps-proves-useful-tool-leopold-center-grazing-research. Accessed 20 June 2011.

Scrimgeour, G. J., and S. Kendall. 2002. Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. Environ. Manage. 29(6):824-844.

Shukla, S. 2000. Impacts of best management practices on nitrogen discharge from a Virginia coastal plain watershed. PhD diss. Blacksburg, VA: Virginia Tech, Department of Biological Systems Engineering.

Soupir, M. L. 2003. Release and transport of bacteria and nutrients from livestock manure applied to pastureland. MS thesis. Blacksburg, VA: Virginia Tech, Department of Biological Systems Engineering.

Sweeney, B. W., and J. G. Blaine. 2007. Resurrecting the in-stream side of riparian forests. Journal of Contemporary Water Research & Education 136(1):17-27.

USEPA. 2003. National management measures to control agricultural sources of NPS pollution. United States Environmental Protection Agency. Washington, D.C. Available at: http://water.epa.gov/polwaste/nps/agriculture/agmm_index.cfm. Accessed 20 June 2011.

USEPA, 2008. What is a TMDL? Overview of Impaired Waters and Total Maximum Daily Loads Program. United States Environmental Protection Agency. Washington, D.C. Available at: http://www.epa.gov/owow/tmdl/overviewoftmdl.html. Accessed 20 January 2011.

VADCR. 2011. Virginia's Conservation Reserve Enhancement Program. Virginia Department of Conservation and Recreation. Richmond, Virginia. Available at: http://www.dcr.virginia.gov/soil_and_water/crep.shtml. Accessed 29 March 2011.

Vallentine, J. F. 1989. Range developments and improvements. 3rd ed., San Diego, CA. Brigham Young University Press.

Vesterby, M., and K. S. Krupa. 1997. Major uses of land in the United States. Statistical Bulletin No. 973. Washington, D.C.

Vidon, P., M. A. Campbell, and M. Gray. 2008. Unrestricted cattle access to streams and water quality in till landscape of the Midwest. Agr. Water Manage. 95(3):322-330.

Zeckoski, R., B. Benham, and C. Lunsford. 2007. Water quality and economic benefits of livestock exclusion from streams: experiences from Virginia. In Watershed Management to Meet Water Quality Standards and TMDLS (Total Maximum Daily Load) Proceedings. San Antonio, TX. ASABE No. 701P0207.

Appendix A. Stage-Discharge Curves

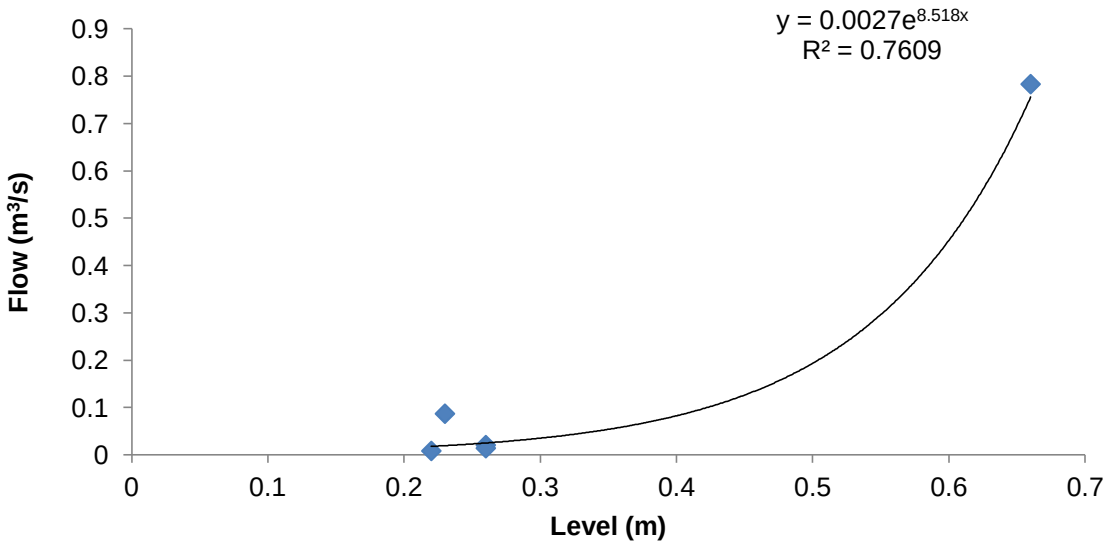

Figure A.1: CR1 2011 stage-discharge curve

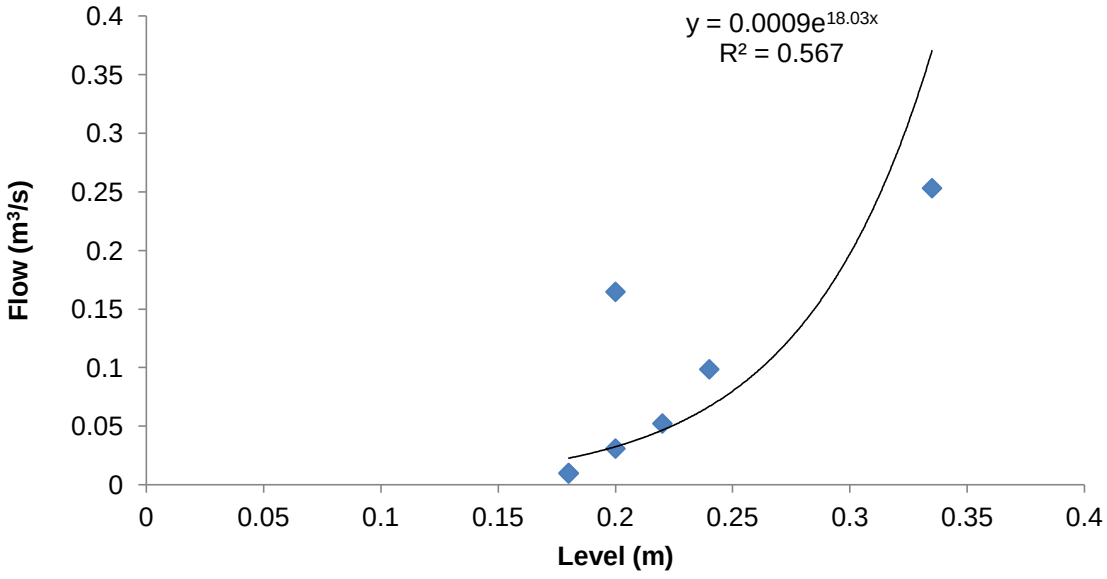

Figure A.2: CR3 2011 stage-discharge curve

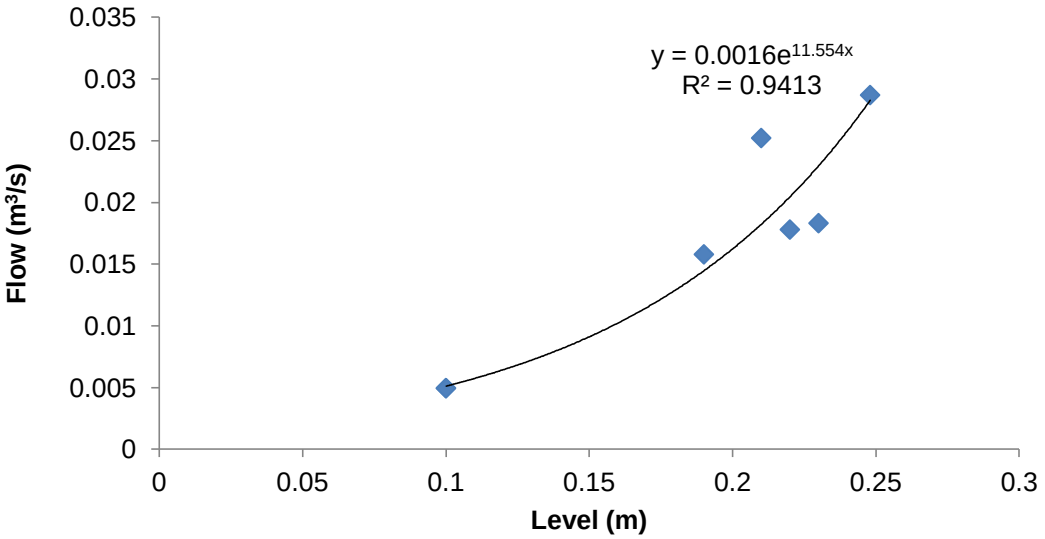

Figure A.3: MV1 2011 stage-discharge curve

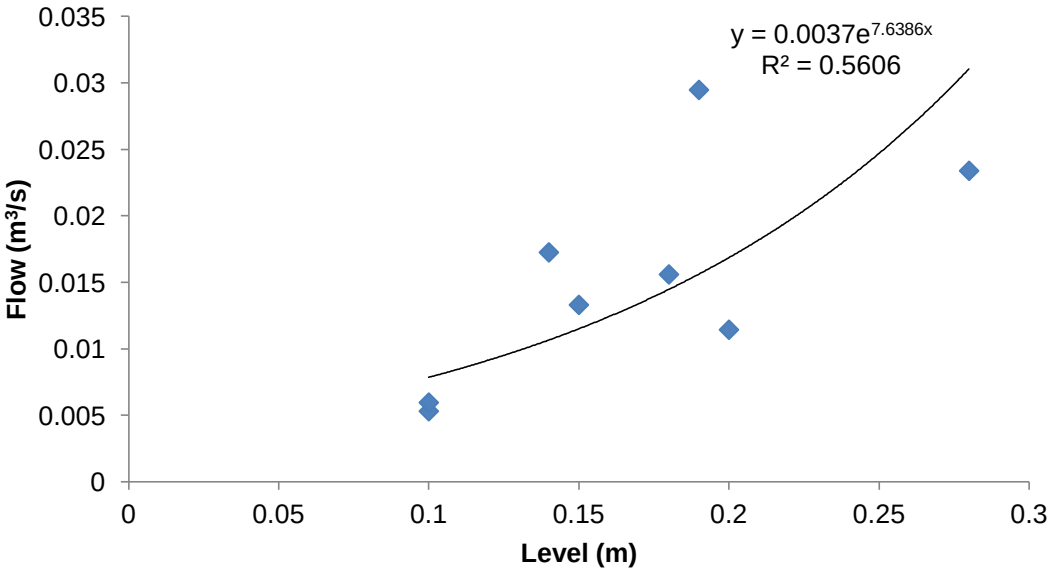

Figure A.4: MV2 2011 stage-discharge curve

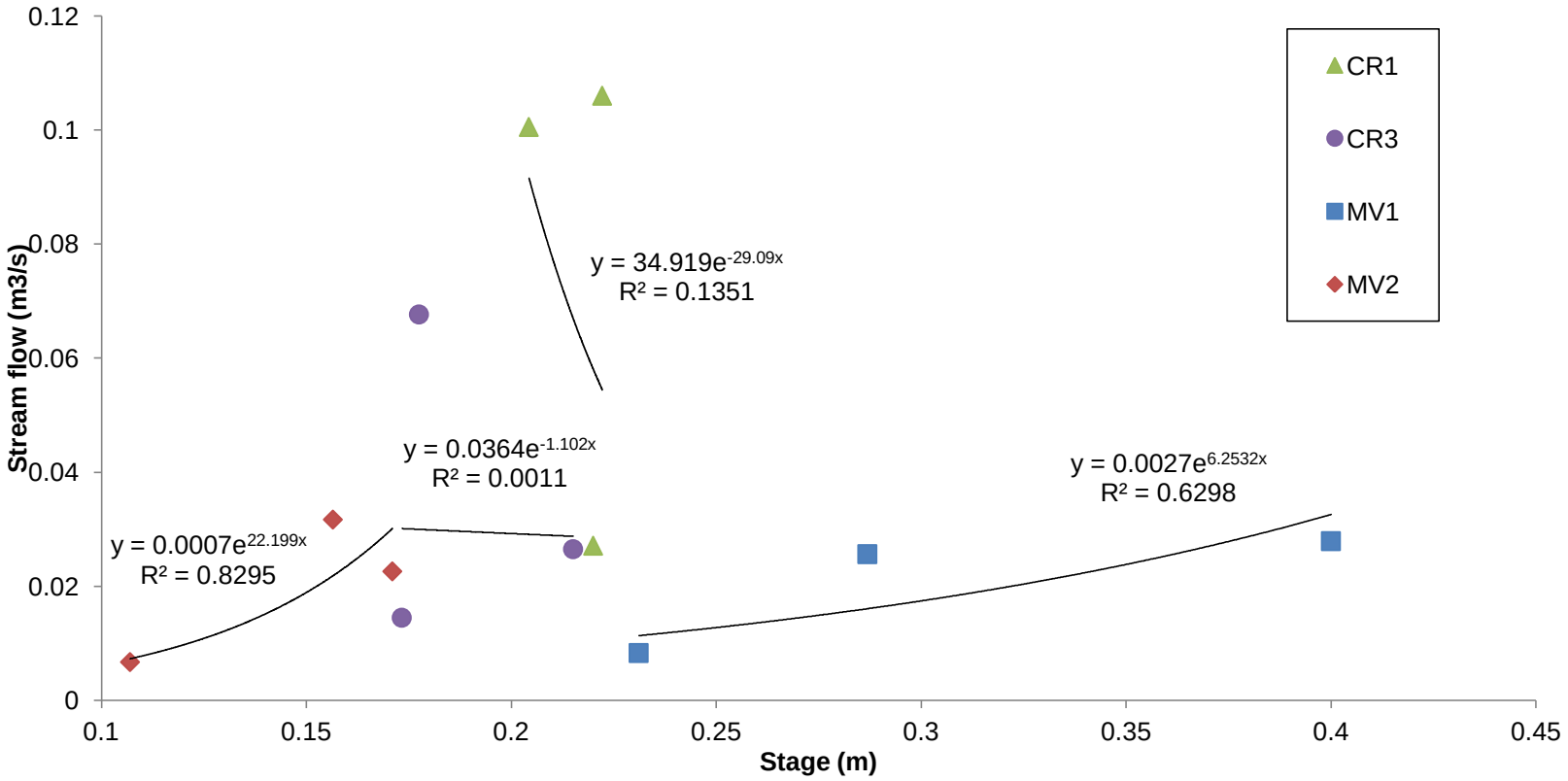

Figure A.5: 2010 stage-discharge curves for CR1, CR3, MV1, and MV2

Appendix B. R Statistical Code

This code has been written for the flash grazing study, but only the file and column heading names would be changed to match the years and sites of the weekly grab samples.

To test for normality:

```
y<-read.csv("Study1.Bacteria.csv")
attach(y)
shapiro.test(CR2.1)
shapiro.test(CR2b.1)
shapiro.test(CR3.1)
shapiro.test(CM.1)
shapiro.test(FW.1)
shapiro.test(MV1b.1)
shapiro.test(MV2.1)
shapiro.test(CR2.2)
shapiro.test(CR2b.2)
shapiro.test(CR3.2)
shapiro.test(CM.2)
shapiro.test(FW.2)
shapiro.test(MV1b.2)
shapiro.test(MV2.2)
shapiro.test(CR2.3)
shapiro.test(CR2b.3)
shapiro.test(CR3.3)
shapiro.test(CM.3)
shapiro.test(FW.3)
shapiro.test(MV1b.3)
shapiro.test(MV2.3)
```

To test for equal variance:

```
bartlett.test(CR2.1)
bartlett.test(CR2b.1)
bartlett.test(CR3.1)
bartlett.test(CM.1)
bartlett.test(FW.1)
bartlett.test(MV1b.1)
bartlett.test(MV2.1)
bartlett.test(CR2.2)
bartlett.test(CR2b.2)
bartlett.test(CR3.2)
bartlett.test(CM.2)
bartlett.test(FW.2)
bartlett.test(MV1b.2)
bartlett.test(MV2.2)
```

```
bartlett.test(CR2.3)
bartlett.test(CR2b.3)
bartlett.test(CR3.3)
bartlett.test(CM.3)
bartlett.test(FW.3)
bartlett.test(MV1b.3)
bartlett.test(MV2.3)
```

To compare period-to-period:

```
wilcox.test(CR2.1, CR2.3)
wilcox.test(CR2b.1, CR2b.3)
wilcox.test(CR3.1, CR3.3)
wilcox.test(CM.1, CM.3)
wilcox.test(FW.1, FW.3)
wilcox.test(MV1b.1, MV2.3)
wilcox.test(MV2.1, MV2.3)
wilcox.test(CR2.1, CR2.2)
wilcox.test(CR2b.1, CR2b.2)
wilcox.test(CR3.1, CR3.2)
wilcox.test(CM.1, CM.2)
wilcox.test(FW.1, FW.2)
wilcox.test(MV1b.1, MV1b.2)
wilcox.test(MV2.1, MV2.2)
```

To compare site-to-site:

```
friedman.test(Bacteria, Site, Date.time)
pairwise.wilcox.test(Bacteria, Site, p.adj='bonferroni', paired=T)
```

In Study 2 where groups had different lengths and could not be compared as a whole:

```
wilcox.test(CR2.1, CR2b.1, p.adj='bonferroni', paired=T)
wilcox.test(CR2b.1, CR3.1, p.adj='bonferroni', paired=T)
wilcox.test(FW.1, CM.1, p.adj='bonferroni', paired=T)
wilcox.test(MV1b.1, MV2.1, p.adj='bonferroni', paired=T)
wilcox.test(CR2.2, CR2b.2, p.adj='bonferroni', paired=T)
wilcox.test(CR2b.2, CR3.2, p.adj='bonferroni', paired=T)
wilcox.test(FW.2, CM.2, p.adj='bonferroni', paired=T)
wilcox.test(MV1b.2, MV2.2, p.adj='bonferroni', paired=T)
```

To find the mean and confidence intervals of two unpaired data sets:

```
y<-read.csv("Study1.Bacteria.csv")
attach(y)
M=10000
alpha=0.05
bootmean.two=function(CR2b.ln1,CR2b.ln3,M,alpha){
N1=length(CR2b.ln1)
```

```
N2=length(CR2b.ln3)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CR2b.ln1,N1,replace=TRUE)
RS2=sample(CR2b.ln3,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(CR2b.ln1,CR2b.ln3,M=10000, alpha=0.05)
bootmean.two=function(CM.ln1,CM.ln3,M,alpha){
N1=length(CM.ln1)
N2=length(CM.ln3)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CM.ln1,N1,replace=TRUE)
RS2=sample(CM.ln3,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(CM.ln1,CM.ln3,M=10000, alpha=0.05)
bootmean.two=function(FW.ln1,FW.ln3,M,alpha){
N1=length(FW.ln1)
N2=length(FW.ln3)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(FW.ln1,N1,replace=TRUE)
RS2=sample(FW.ln3,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
```

```
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(FW.ln1,FW.ln3,M=10000, alpha=0.05)
bootmean.two=function(CR2b.ln1,CR2b.ln2,M,alpha){
N1=length(CR2b.ln1)
N2=length(CR2b.ln2)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CR2b.ln1,N1,replace=TRUE)
RS2=sample(CR2b.ln2,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(CR2b.ln1,CR2b.ln2,M=10000, alpha=0.05)
bootmean.two=function(CM.ln1,CM.ln2,M,alpha){
N1=length(CM.ln1)
N2=length(CM.ln2)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CM.ln1,N1,replace=TRUE)
RS2=sample(CM.ln2,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
```

```
}
bootmean.two(CM.ln1,CM.ln2,M=10000, alpha=0.05)
bootmean.two=function(FW.ln1,FW.ln2,M,alpha){
N1=length(FW.ln1)
N2=length(FW.ln2)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(FW.ln1,N1,replace=TRUE)
RS2=sample(FW.ln2,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(FW.ln1,FW.ln2,M=10000, alpha=0.05)
bootmean.two=function(CR2.ln1,CR2.ln2,M,alpha){
N1=length(CR2.ln1)
N2=length(CR2.ln2)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CR2.ln1,N1,replace=TRUE)
RS2=sample(CR2.ln2,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(CR2.ln1,CR2.ln2,M=10000, alpha=0.05)
bootmean.two=function(CR3.ln1,CR3.ln2,M,alpha){
N1=length(CR3.ln1)
N2=length(CR3.ln2)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CR3.ln1,N1,replace=TRUE)
```

```
RS2=sample(CR3.ln2,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(CR3.ln1,CR3.ln2,M=10000, alpha=0.05)
bootmean.two=function(CR3.ln1,CR3.ln3,M,alpha){
N1=length(CR3.ln1)
N2=length(CR3.ln3)
Med=rep(NA,M)
for(i in 1:M){
RS1=sample(CR3.ln1,N1,replace=TRUE)
RS2=sample(CR3.ln3,N2,replace=TRUE)
mean.RS1<-mean(RS1, na.rm=T)
mean.RS2<-mean(RS2, na.rm=T)
diffRS1.RS2<-(mean.RS1-mean.RS2)
Med[i]=diffRS1.RS2
}
Iterations<-sum(!is.na(Med))
Boot.est<-mean(Med, na.rm=T)
Lower<-quantile(Med, probs=alpha/2, na.rm=T)
Upper<-quantile(Med, probs=(1-alpha/2), na.rm=T)
Boot.se<-sd(Med, na.rm=T)
return(data.frame(Lower, Boot.est, Upper, Boot.se, Iterations))
}
bootmean.two(CR3.ln1,CR3.ln3,M=10000, alpha=0.05)
```

To find the mean and confidence intervals of a paired data set:

```
Zone2.ln1<-CR3.ln1-CR2b.ln1
Zone3.ln1<-CM.ln1-FW.ln1
Zone4.ln1<-MV2.ln1-MV1b.ln1
Zone2.ln2<-CR3.ln2-CR2b.ln2
Zone3.ln2<-CM.ln1-FW.ln1
Zone4.ln2<-MV2.ln2-MV1b.ln2
b<-Zone2.ln1[!is.na(Zone2.ln1)]
c<-Zone3.ln1[!is.na(Zone3.ln1)]
e<-Zone4.ln1[!is.na(Zone4.ln1)]
f<-Zone2.ln2[!is.na(Zone2.ln2)]
g<-Zone3.ln2[!is.na(Zone3.ln2)]
```

```
z<-Zone4.ln2[!is.na(Zone4.ln2)]
n<-10000
alpha<-0.05
ymean<-numeric(n)
for (i in 1:n) {
ymean[i]<-mean(sample(b, replace=T))
}
quantile(ymean, probs=c(0.025, 0.975), na.rm=T)
mean(b)
ymean<-numeric(n)
for (i in 1:n) {
ymean[i]<-mean(sample(c, replace=T))
}
quantile(ymean, probs=c(0.025, 0.975), na.rm=T)
mean(c)
ymean<-numeric(n)
for (i in 1:n) {
ymean[i]<-mean(sample(e, replace=T))
}
quantile(ymean, probs=c(0.025, 0.975), na.rm=T)
mean(e)
ymean<-numeric(n)
for (i in 1:n) {
ymean[i]<-mean(sample(f, replace=T))
}
quantile(ymean, probs=c(0.025, 0.975), na.rm=T)
mean(f)
ymean<-numeric(n)
for (i in 1:n) {
ymean[i]<-mean(sample(g, replace=T))
}
quantile(ymean, probs=c(0.025, 0.975), na.rm=T)
mean(g)
ymean<-numeric(n)
for (i in 1:n) {
ymean[i]<-mean(sample(z, replace=T))
}
quantile(ymean, probs=c(0.025, 0.975), na.rm=T)
mean(z)
```

Appendix C. Statistical Means and Confidence Intervals

Table C.1: Means and confidence intervals for statistical comparisons that found dissimilar results, Weekly Sampling

			Bacteria (MPN/100ml)	TSS (mg/L)	Turbidity (NTU)	EC (µS)	NH_3 (mg/L)	PO_4 (mg/L)	NO_3 (mg/L)	TN (mg/L)	TP (mg/L)
CR1a	2010-2011	Mean	-3321[2]	-1.8	-2.3	111					
		2.5%	-4327	-2.7	-3.6	68					
		97.5%	-2377	-1.0	-1.2	161					
CR1b	2010-2011	Mean	-6001	[1]	-1.2	104					
		2.5%	-13312		-2.9	69					
		97.5%	-2029		0.4	139					
CR2	2010-2011	Mean	-1127			108					
		2.5%	-1465			66					
		95.0%	-807			152					
CR3	2010-2011	Mean	-1174			98					
		2.5%	-3019			50					
		97.5%	-273			141					
MV1	2010-2011	Mean		-9.4	-80.5			-0.1229	-1.74	-1.00	-0.7158
		2.5%		-10.7	-161.9			-0.5690	-2.22	-1.56	-1.1440
		97.5%		-8.1	-17.9			0.1505	-1.32	-0.44	-0.3950
MV2	2010-2011	Mean		-22.4	-26.5			0.0397	-1.44		-0.0741
		2.5%		-24.4	-41.8			0.0023	-1.92		-0.0840
		97.5%		-20.0	-12.1			0.0856	-0.99		-0.0640
2010	CR1a-CR1b	Mean									0.0031
		2.5%									0.0012
		97.5%									0.0059
	CR1b-CR2	Mean					-0.007	-0.0010			-0.0014
		2.5%					-0.014	-0.0015			-0.0040
		97.5%					-0.003	-0.0005			0.0008
	CR2-CR3	Mean						-0.0010			

		2.5%				-0.0015	
		97.5%				-0.0005	
	MV1-MV2	Mean		-21.4	-0.182		-0.0240
		2.5%		-41.8	-0.325		-0.0447
		97.5%		-7.6	-0.080		-0.0060
	CR1a-CR1b	Mean					
		2.5%					
		97.5%					
	CR1b-CR2	Mean	-4540				
		2.5%	-11001				
2011		97.5%	-974				
	CR2-CR3	Mean					
		2.5%					
		97.5%					
	MV1-MV2	Mean	-17195	-74.5			
		2.5%	-30050	-142.2			
		97.5%	-8633	-18.2			

[1] ( ) Non-parametric tests found a similar ($p > 0.05$) comparison with no need to calculate means and confidence intervals
[2] Values were calculated by subtracting upstream from downstream. Thus a negative number indicates a decrease in concentration from upstream to downstream

Table C.2: Means and confidence intervals for statistical comparisons that found dissimilar results, Study 1

			Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1,3	CR2b	Mean	[1]	-8.1[2]	0.0010	-0.86	-0.041	-0.56
		2.5%		-12.0	0.0004	-1.33	-0.048	-0.86
		97.5%		-3.5	0.0015	-0.39	-0.035	-0.29
	CR3	Mean						
		2.5%						
		97.5%						
	CM	Mean			-0.0010			
		2.5%			-0.0018			
		97.5%			-0.0003			
	FW	Mean	270	-0.6	0.0000			
		2.5%	83	-1.1	0.0000			
		97.5%	530	-0.2	0.0000			
	CR2	Mean		5.5				
		2.5%		1.9				
		97.5%		9.2				
Period 1,2	CR2b	Mean	-970	-9.4	0.0007		-0.019	-0.06
		2.5%	-1604	-14.1	0.0003		-0.028	-0.44
		97.5%	-405	-4.4	0.0010		-0.012	0.33
	CR3	Mean	-980	-9.6			-0.008	
		2.5%	-1381	-17.6			-0.012	
		97.5%	-594	-2.1			-0.004	
	CM	Mean	-3787	-40.8	-0.0041		-0.035	
		2.5%	-5913	-68.0	-0.0086		-0.051	
		97.5%	-1676	-17.6	-0.0014		-0.024	
	FW	Mean	244	-0.5			-0.093	
		2.5%	57	-1.0			-0.132	
		97.5%	508	-0.1			-0.062	

Period 1	CR2-CR2b	Mean	-1181					
		2.5%	-1794					
		97.5%	-611					
	CR2b-CR3	Mean	-630				0.007	
		2.5%	-885				0.004	
		97.5%	-414				0.010	
	FW-CM	Mean	2903	6.6	0.0032	2.69		
		2.5%	1687	5.6	0.0028	2.18		
		97.5%	4247	7.6	0.0036	3.10		
Period 2	CR2-CR2b	Mean		12.0	-0.0009		0.009	
		2.5%		8.3	-0.0013		0.004	
		97.5%		16.2	-0.0006		0.014	
	CR2b-CR3	Mean						
		2.5%						
		97.5%						
	FW-CM	Mean	6945	46.5	0.0073	2.69	0.019	4.03
		2.5%	5256	23.8	0.0046	2.22	-0.013	3.52
		97.5%	8663	74.4	0.0116	3.09	0.058	4.60

[1] ( ) Non-parametric tests found a similar ($p > 0.05$) comparison with no need to calculate means and confidence intervals
[2] Values were calculated by subtracting upstream from downstream. Thus a negative number indicates a decrease in concentration.

Table C.3: Means and confidence intervals for statistical comparisons that found dissimilar result, Study 2

			Bacteria (MPN/100ml)	TSS (mg/L)	PO_4-P (mg/L)	NO_3-N (mg/L)	TP (mg/L)	TN (mg/L)
Period 1, 3	CR2b	Mean	[1]	-52.6[2]				
		2.5%		-102.8				
		97.5%		-15.2				
	CR3	Mean	-485					
		2.5%	-794					
		97.5%	-139					
	CM	Mean		-10.6				
		2.5%		-21.8				
		97.5%		-2.7				
	FW	Mean		-1.3				
		2.5%		-2.0				
		97.5%		-0.7				
	MV1b	Mean						
		2.5%						
		97.5%						
	MV2	Mean		-146.8		0.50		
		2.5%		-22.7		0.31		
		97.5%		-84.2		0.65		
Period 1, 2	CR2b	Mean	526					
		2.5%	382					
		97.5%	695					
	CR3	Mean	303			0.58		
		2.5%	201			0.30		
		97.5%	402			1.05		
	CM	Mean						
		2.5%						
		97.5%						
	FW	Mean	-1	-1.4		0.02		

		2.5%	-33	-3.5		0.01		
		97.5%	21	-0.2		0.03		
	MV1b	Mean		-36.6				
		2.5%		-66.1				
		97.5%		-11.8				
	MV2	Mean		-330.4				
		2.5%		-863.9	0.0018			
		97.5%		-27.1	0.0081			
	CR2b-CR3	Mean						
		2.5%						
		97.5%						
Period 1	FW-CM	Mean	1250	7.3				
		2.5%	984	6.6				
		97.5%	1531	7.9				
	MV1b-MV2	Mean		20.4				
		2.5%		8.6				
		97.5%		30.2				
	CR2-CR2b	Mean	-332					
		2.5%	-524					
		97.5%	-150					
	CR2b-CR3	Mean	-128					
		2.5%	-199					
		97.5%	-45					
Period 2	FW-CM	Mean	1695	18.4	0.0066	2.39	0.051	1.29
		2.5%	1066	8.1	0.0050	1.93	0.043	1.00
		97.5%	2589	35.8	0.0088	2.73	0.061	1.00
	MV1b-MV2	Mean		316.3				
		2.5%		29.4				
		97.5%		795.9				

[1] ( ) Non-parametric tests found a similar ($p > 0.05$) comparison with no need to calculate means and confidence intervals
[2] Values were calculated by subtracting upstream from downstream. Thus a negative number indicates a decrease in concentration

Appendix D. Storm TSS Time Series and Hydrographs

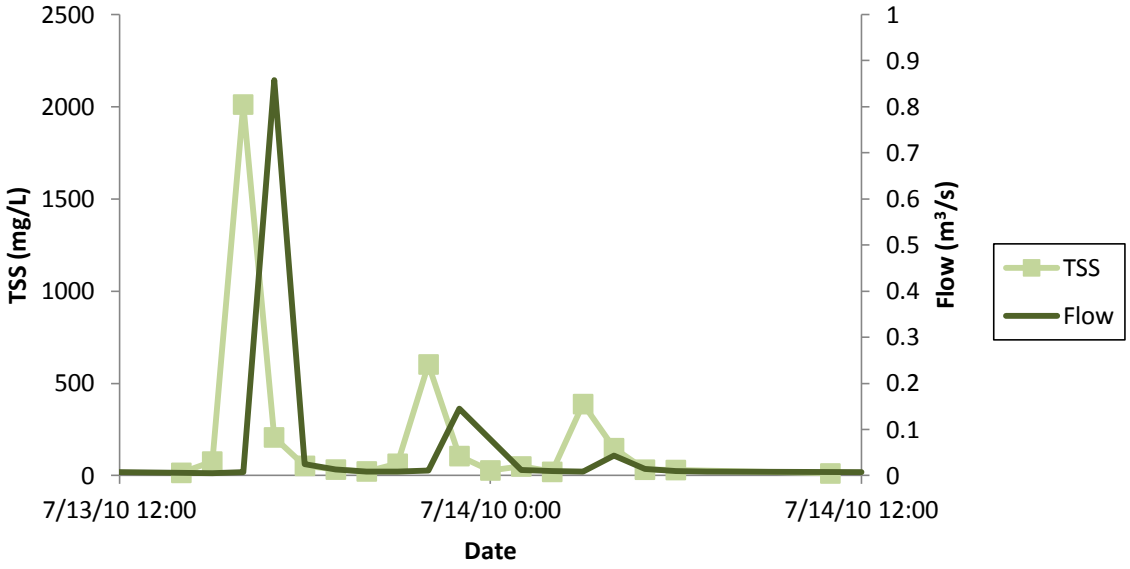

Figure D.1: Storm III TSS and flow for MV2

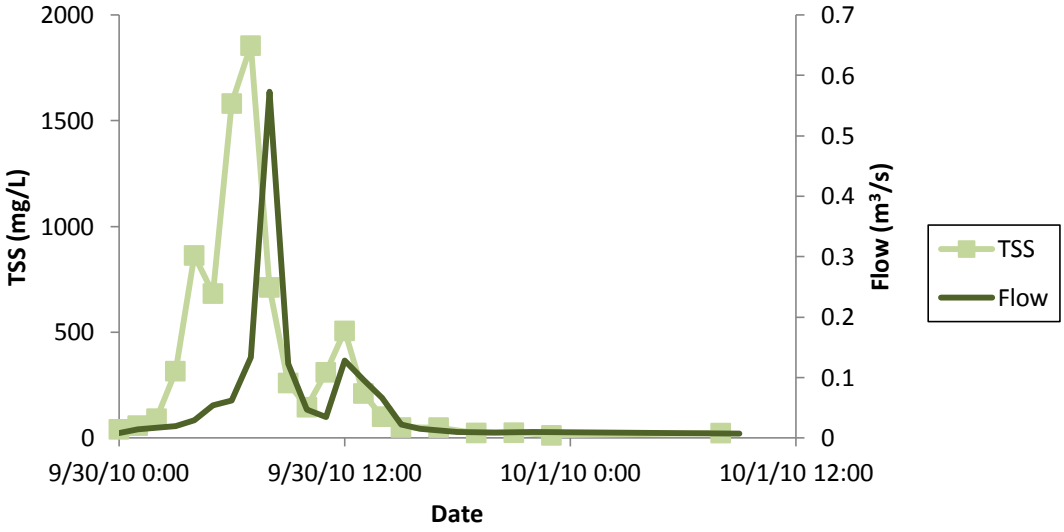

Figure D.2: Storm V TSS and flow for MV2

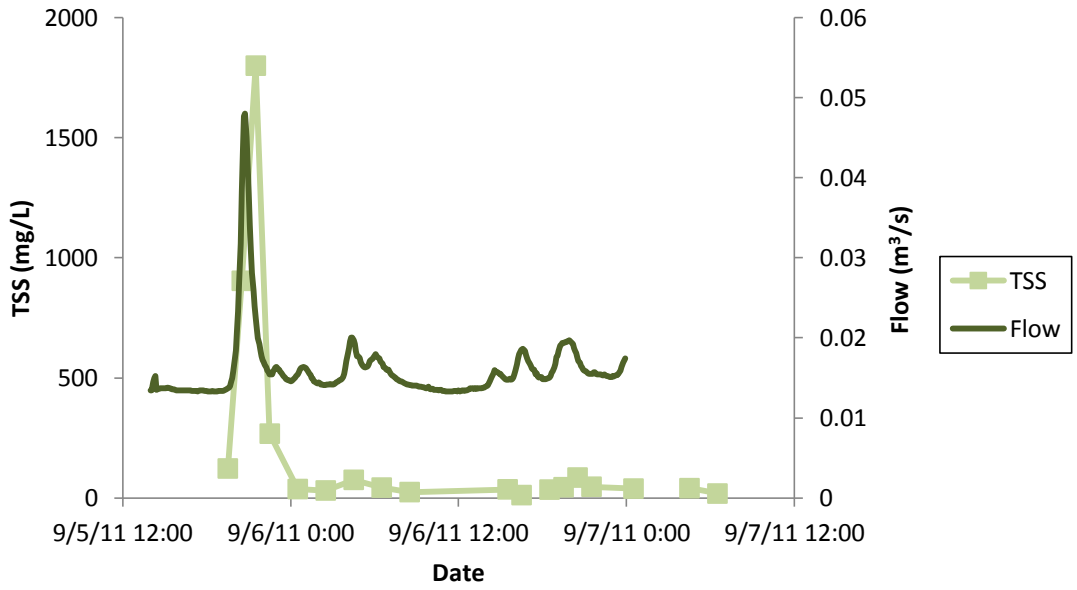

Figure D.3: Storm IX TSS and flow for MV2

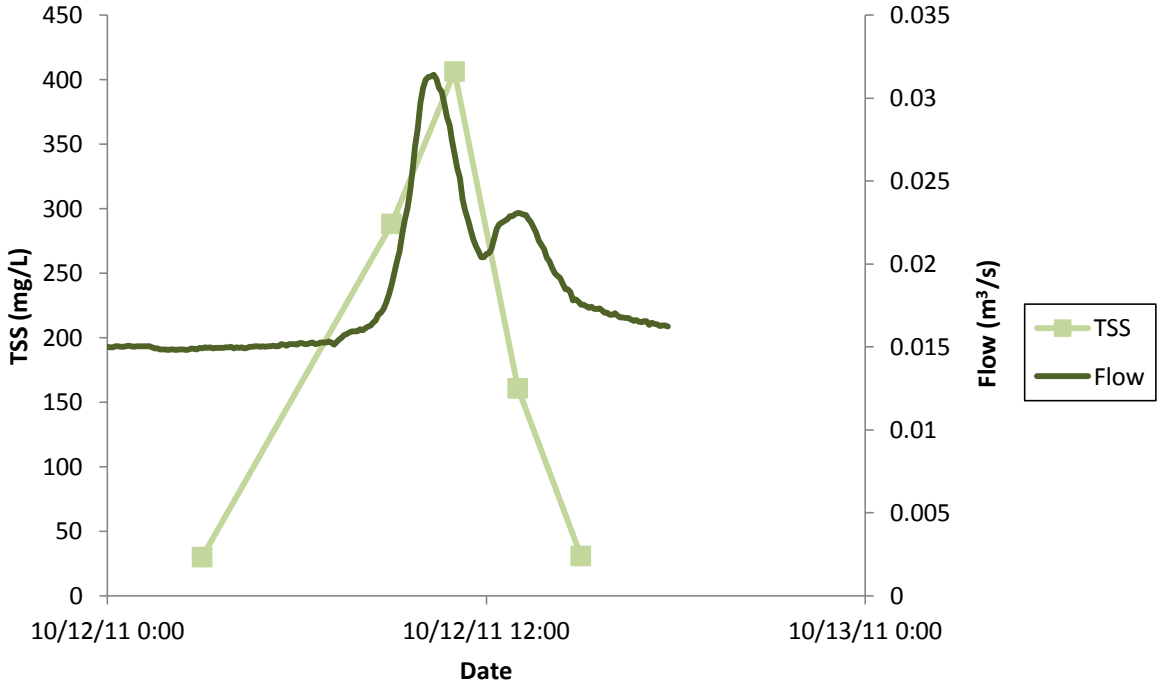

Figure D.4: Storm X TSS and flow for MV2

Appendix E. Comparing Manual and ISCO Samples

To compare any differences between the ISCO and manual grab samples, coincident samples were collected using both techniques twice during Study 2. Because the ISCO intake was located on a plate at the bottom of the stream, there was a greater potential for collecting bed load when compared to the grab samples that were collected mid-stream and mid-depth.

The comparison samples were analyzed for *E. coli*, TSS, pH, EC, and turbidity are represented in figures E.1-E.5. Because pH, EC, and turbidity appeared to be consistent across techniques, these constituents were not analyzed as rigorously as bacteria and TSS.

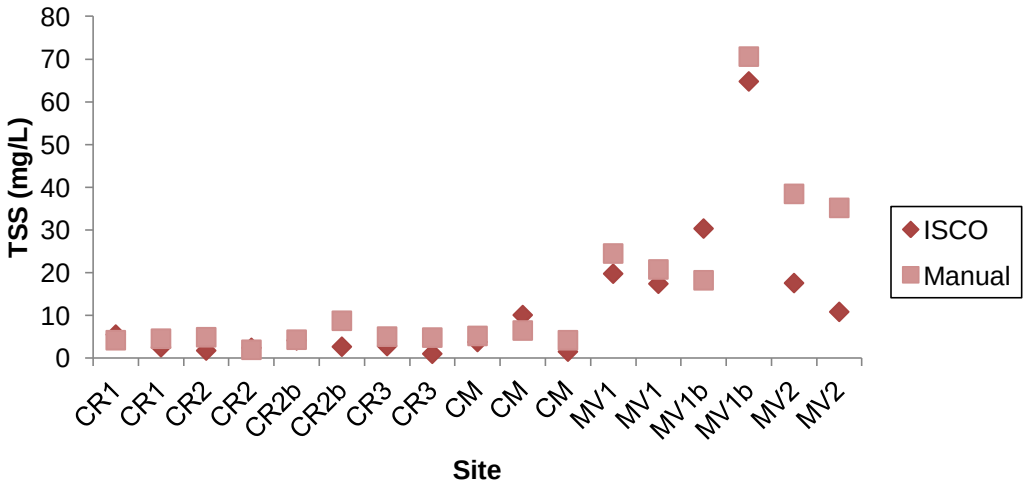

Figure E.1: Total suspended solids (TSS) for manual and ISCO grab samples by site

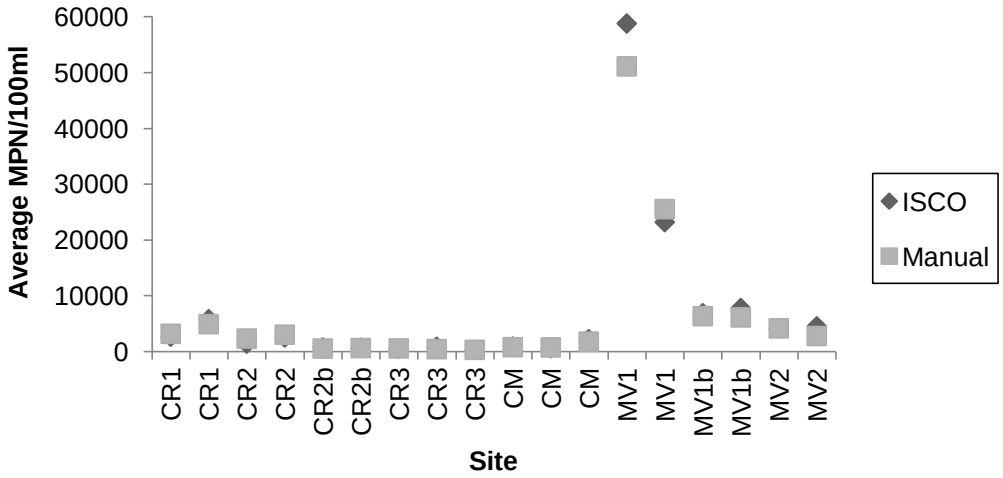

Figure E.2: *E. coli* bacteria for manual and ISCO grab samples by site

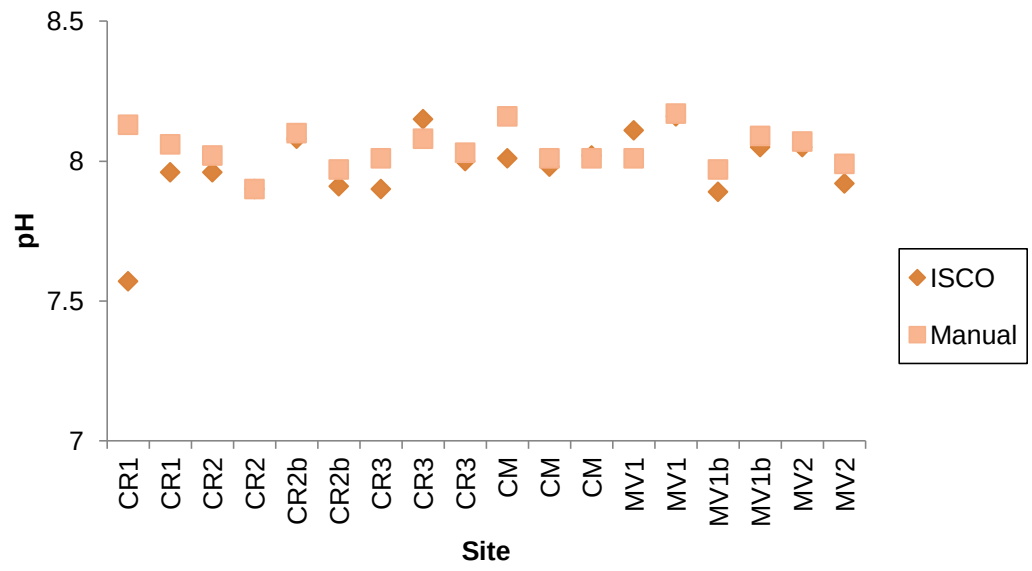

Figure E.3: pH for manual and ISCO grab samples by site

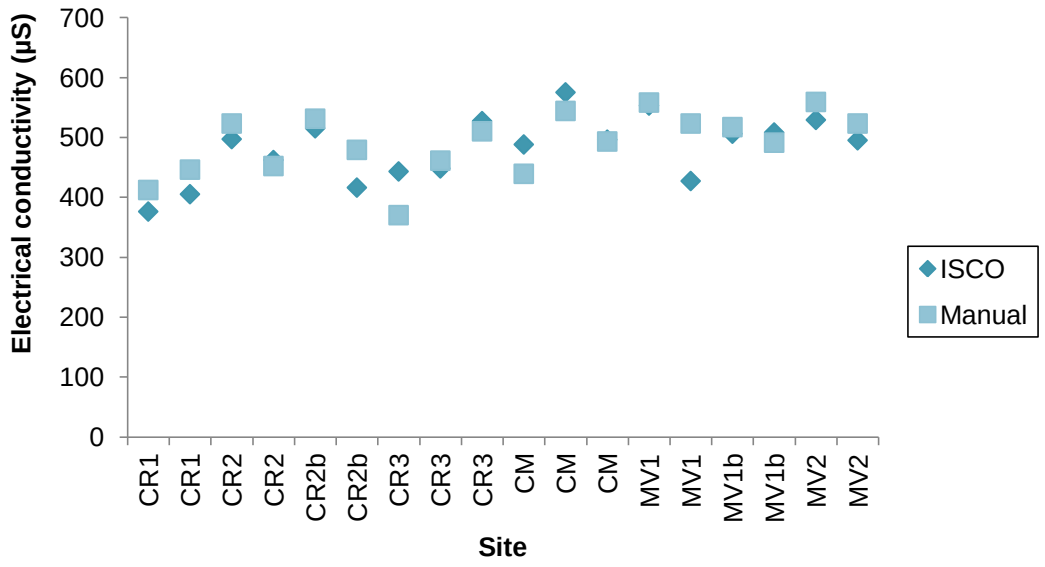

Figure E.4: Electrical conductivity (EC) for manual and ISCO grab samples by site

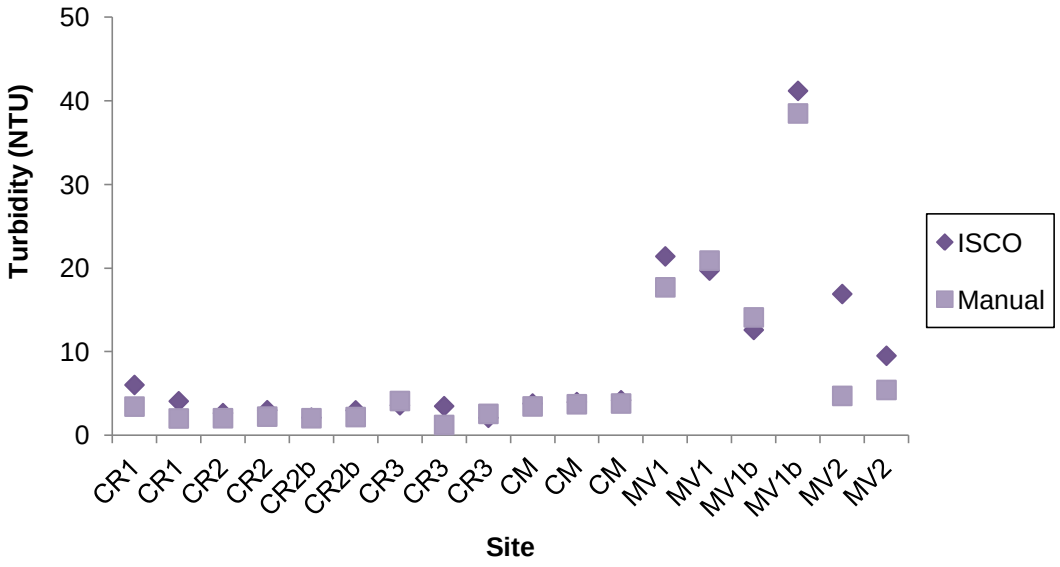

Figure E.5: Turbidity for manual and ISCO grab samples by site

First, the set was checked for normality using a Shapiro test in the R statistics package. Both the grab and ISCO samples were found to have a p-value of less than a confidence level of 95% or alpha of 5%. Therefore, a non-parametric Wilcox test was run with a result of a p-value of 0.8247. The samples for average most probable number (MPN) per 100 ml can be considered statistically similar. The bacteria boxplots of both the grab and ISCO samples have similar means, quartiles, and outlier values (fig. E.6).

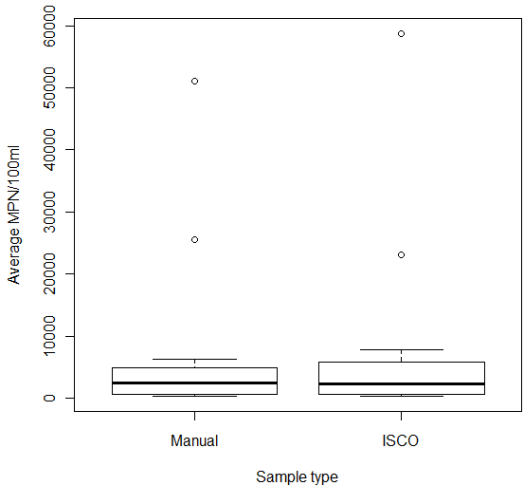

Figure E.6: Bacteria (*E. coli*) boxplot for manual and ISCO samples

When graphing bacteria for both sets of the data, the R^2 value is 0.989, which means, when graphed against each other, both have very close correlation and can be considered comparable (fig. E.7).

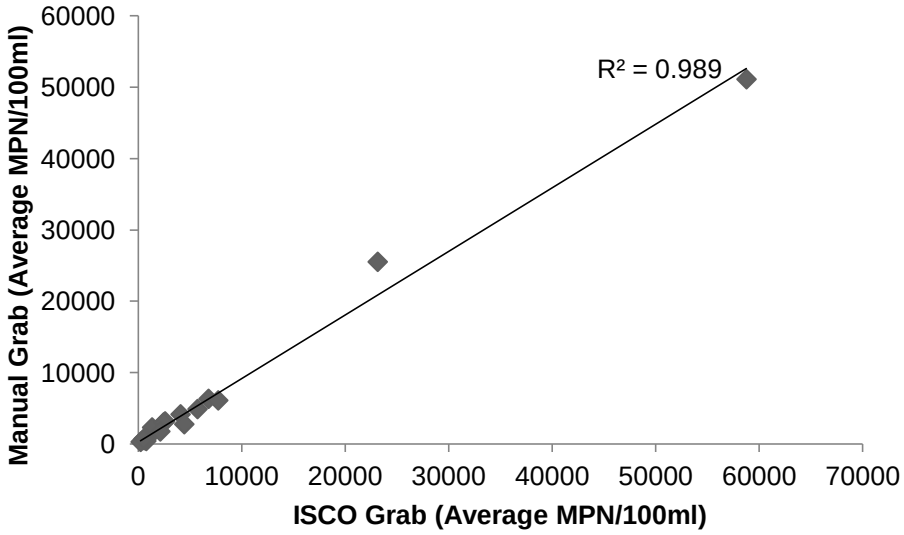

Figure E.7: Bacteria (*E. coli*) plot of manual versus ISCO samples

As in the bacteria, the boxplot of TSS also has similar mean, quartile, and outlier data (fig. E.8). However, when the grab and ISCO samples are graphed against each other with a one-to-one line, it can be seen that the ISCO samples over estimate total suspended solids as most of the points are below the line (fig.E.9). The difference in TSS may mean that there is an influence of bed load on the ISCO samples causing a higher TSS value than the manual grab samples. The R^2 value of 0.79 is not as significant as the bacteria but can still be considered acceptable. Therefore, although there are trace differences between the manual and ISCO grab samples, they can still be considered statistically similar. However, it is important to note that during times of heavy bed load such as storm events, there may not be as high of a correlation.

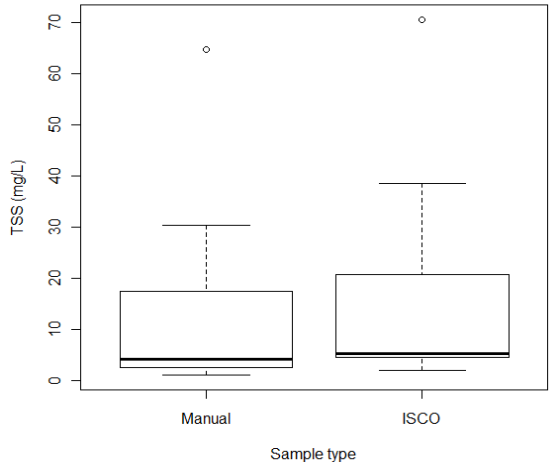

Figure E.8: TSS boxplot for manual and ISCO samples

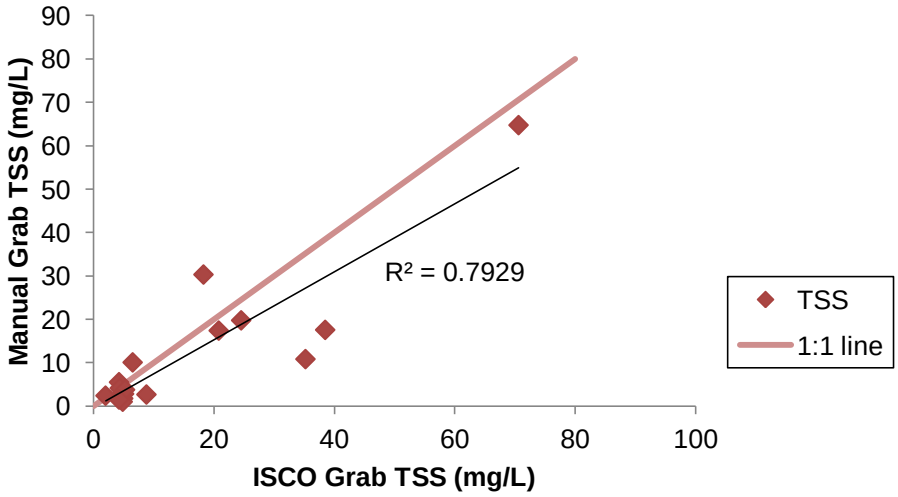

Figure E.9: TSS for manual versus ISCO samples and 1:1 line

Appendix F. QA/QC

A distilled water grab sample at each of the permanent ISCOs (MV1, MV2, CR1, and CR3) was taken in order to determine if there were any residual bacteria or sediment in the tubing and affecting stream water quality results. The data for these samples can be found in figures F.1-F.4.

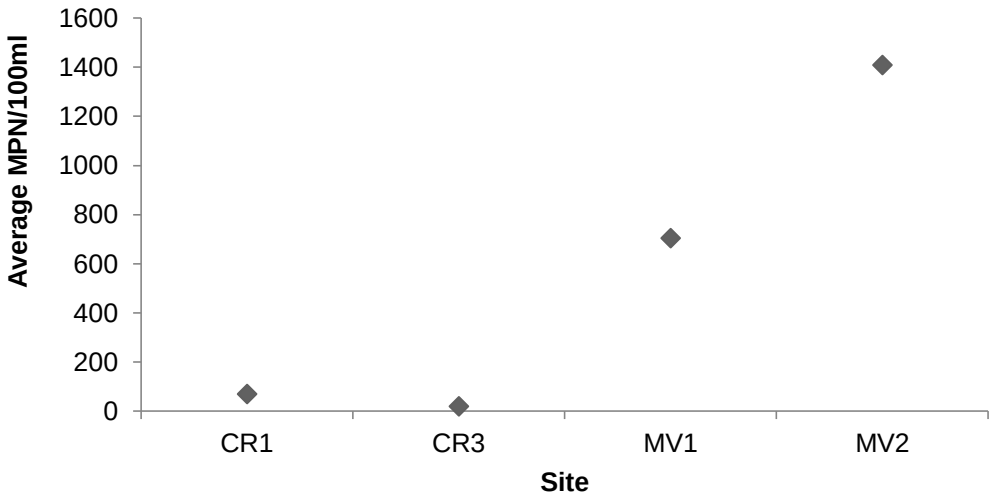

Figure F.1: *E. coli* bacteria for DI blanks by site

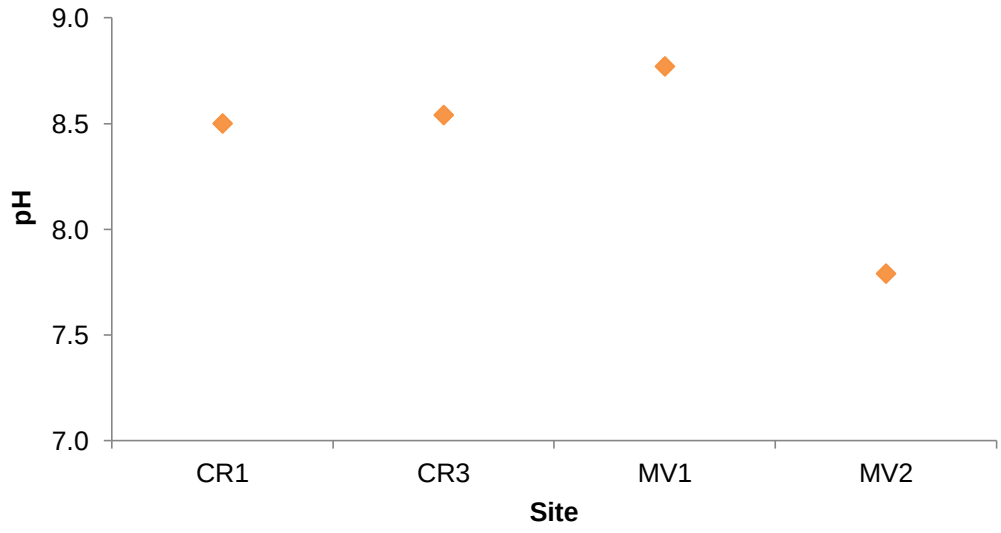

Figure F.2: pH for DI banks by site

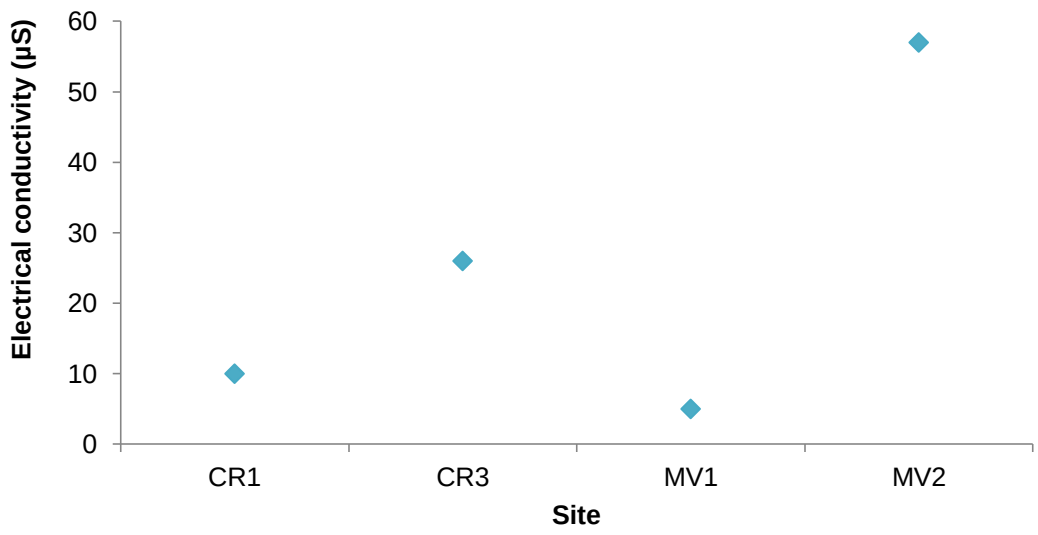

Figure F.3: Electrical conductivity (EC) for DI blanks by site

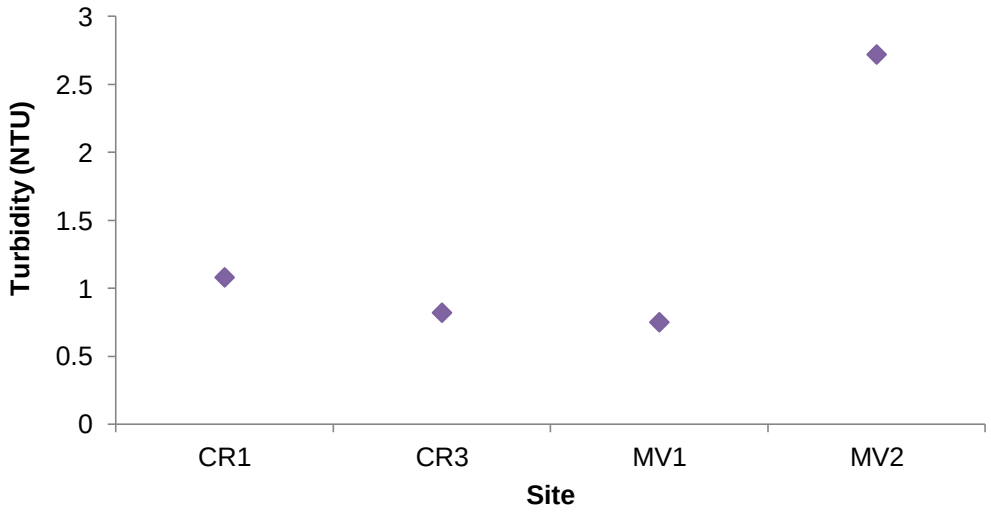

Figure F.4: Turbidity for DI blanks by site

When comparing the bacteria concentrations of these samples to the lowest concentration of a sample taken during Study 2 at the same site, the percentages are as follows: 5.3% for CR1, 14.9% for CR3, 25.6% for MV1, and 105.8% for MV2. This means that at site CR1, 5.3% of the lowest recorded bacteria value may be contributed to residual bacteria in the ISCO tubing and machine. This percentage is not significant for the Cub Run sites, but may be a source of interest for the Mountain Valley Road Tributary sites because the percentages are higher.

When comparing turbidity levels to the lowest sample value at the same site, the percentages are as follows: 23.9% for CR1, 29.6% for CR3, 19.2% for MV1, and 34.9% for MV2.

The DI blanks were only taken at one instance and is not representative of every sample throughout the study. It is a tool in order to understand the error involved with sampling. The previous percentages were based on only the lowest value in the study at each site, so as the concentrations increase, the percentages of influence will decrease. Then, the impact of the residual concentrations will be less significant.

Appendix G. Salt Tracer Results

The CREP zones and zones 1, 2, and 3 have the approximate travel times: 60 min, 80 min, 50 min, and 50 min, respectively. Mountain Valley Road Tributary has approximately a 45 min travel time from MV1 to MV2 (unpublished data, 2011. Blacksburg, VA: Virginia Tech, Department of Biological Systems Engineering). Because samples were a composite of two hours of stream sample and data were compared within each zone, no lags were applied when pairing upstream-to-downstream paired data sets. Comparing CR1 to CR2b would have a lag; however, samples were only tested from the upstream site of each zone to the downstream site.

Appendix H. Cattle Densities by Zone

Table H.1: Cattle counts and densities per date and time bottle for zone 1, Study 1

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
7/21/11 6:00	0	0	1	0.01	0.002	0.000	0	0
7/21/11 18:00	3	0.46	4	1.41	0.002	0.001	0.026	0.004
7/21/11 20:00	0	0	2	0.09	0.005	0.000	0	0
7/22/11 0:00	0	0	1	0.03	0.002	0.000	0	0
7/22/11 8:00	1	0.01	1	0.01	0.000	0.000	0.009	0.000
7/22/11 14:00	5	0.58	10	2	0.004	0.001	0.043	0.005
7/22/11 16:00	2	0.69	7	1.69	0.003	0.001	0.017	0.006
7/22/11 18:00	0	0	4	0.48	0.002	0.000	0	0
7/22/11 20:00	0	0	2	0.05	0.001	0.000	0	0
7/23/11 6:00	4	0.63	13	2.22	0.140	0.010	0.035	0.005
7/23/11 8:00	7	1.07	16	3.23	0.140	0.035	0.061	0.009
7/23/11 14:00	3	0.07	6	0.58	0.003	0.000	0.026	0.001
7/23/11 16:00	3	0.82	6	1.72	0.003	0.001	0.026	0.007
7/23/11 18:00	2	0.08	9	1.03	0.072	0.015	0.017	0.001
7/23/11 20:00	0	0	1	0.02	0.002	0.000	0	0
7/24/11 8:00	9	5.74	14	8.94	0.108	0.056	0.078	0.050
7/24/11 10:00	6	2.12	21	13	0.418	0.210	0.052	0.018
7/24/11 12:00	3	0.26	12	4.71	0.414	0.155	0.026	0.002
7/24/11 14:00	3	1.48	3	1.53	0.001	0.001	0.026	0.013
7/25/11 8:00	0	0	2	0.60	0.005	0.001	0	0
7/25/11 12:00	0	0	4	0.60	0.009	0.001	0	0
7/25/11 16:00	0	0	6	1.45	0.014	0.003	0	0

Table H.2: Cattle counts and densities per date and time bottle for zone 2, Study 1

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
7/21/11 18:00	2	0.33	4	0.95	0.005	0.001	0.043	0.007
7/21/11 22:00	1	0.01	5	0.04	0.018	0.000	0.063	0.001
7/22/11 6:00	5	0.11	15	0.79	0.018	0.001	0.106	0.002
7/22/11 8:00	3	0.98	3	0.98	0.002	0.001	0.073	0.024
7/22/11 8:00	2	0.33	6	0.46	0.005	0.000	0.049	0.008
7/22/11 10:00	1	0.15	1	0.15	0.001	0.000	0.024	0.004
7/22/11 12:00	3	0.47	7	1.37	0.011	0.002	0.064	0.010
7/22/11 14:00	1	0.10	3	0.30	0.004	0.000	0.021	0.002
7/22/11 16:00	3	0.54	7	1.68	0.022	0.005	0.125	0.027
7/22/11 18:00	3	0.13	6	0.33	0.022	0.001	0.188	0.008
7/22/11 22:00	0	0	3	0.13	0.011	0.000	0	0

Table H.3: Cattle counts and densities per date and time bottle for zone 3, Study 1

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
7/22/11 4:00	1	0.08	2	0.27	0.002	0.000	0.026	0.002
7/22/11 6:00	12	1.39	24	4.18	0.027	0.004	0.304	0.034
7/22/11 8:00	23	9.70	46	22.62	0.044	0.023	0.582	0.244
7/22/11 10:00	21	15.75	27	20.19	0.032	0.024	0.553	0.414
7/22/11 12:00	15	14.48	25	23.75	0.030	0.029	0.395	0.381
7/22/11 14:00	15	8.34	29	17.03	0.032	0.020	0.395	0.219
7/23/11 6:00	1	0.01	4	0.68	0.003	0.001	0.024	0.000
7/23/11 8:00	20	5.85	24	7.69	0.029	0.009	0.526	0.154
7/23/11 10:00	20	11.61	33	18.21	0.034	0.021	0.526	0.305
7/23/11 12:00	8	2.79	12	6.13	0.014	0.006	0.211	0.069
7/23/11 14:00	0	0	2	0.65	0.002	0.001	0	0
7/23/11 16:00	7	0.32	12	0.48	0.012	0.000	0.180	0.008
7/23/11 18:00	14	5.01	32	12.50	0.029	0.011	0.353	0.121

Table H.4: Cattle counts per date and time bottle for zone 4, Study 1

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)
7/22/11 8:00	0	0	1	0.21
7/22/11 14:00	0	0	1	0.30
7/23/11 6:00	0	0	1	0.68
7/23/11 10:00	0	0	1	0.21
7/23/11 12:00	0	0	2	0.21
7/23/11 18:00	1	0.02	4	1.39

Table H.5: Cattle counts and densities per date and time bottle for zone 1, Study 2

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
8/16/11 8:00	1	0.03	1	0.04	0	0.0000	0.009	0.000
8/16/11 8:00	7	0.59	17	2.18	0	0.001417	0.061	0.005
8/17/11 8:00	0	0	1	0.01	0	2.97E-05	0	0
8/17/11 10:00	0	0	2	0.60	0	0.00217	0	0
8/17/11 12:00	0	0	3	0.21	0	0.000743	0	0
8/17/11 14:00	0	0	3	0.08	0	0.000297	0	0
8/17/11 18:00	0	0	3	0.10	0	4.17E-05	0	0
8/18/11 6:00	3	0.34	3	0.80	0	0.000337	0.026	0.003
8/18/11 8:00	0	0	1	0.02	0	6.96E-06	0	0
8/18/11 6:00	0	0	1	0.34	0	0.000143	0	0
8/18/11 8:00	2	0.44	3	1.17	0	0.00052	0.017	0.004

Table H.6: Cattle counts and densities per date and time bottle for zone 2, Study 2

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
8/16/11 8:00	0	0	1	0.01	0.001	0.000	0	0
8/16/11 14:00	0	0	6	0.24	0.007	0.000	0	0
8/17/11 6:00	0	0	1	0.17	0.001	0.000	0	0
8/17/11 14:00	6	1.75	12	3.23	0.014	0.004	0.128	0.037
8/17/11 16:00	2	0.23	10	1.05	0.012	0.001	0.043	0.005
8/17/11 18:00	2	0.44	10	3.30	0.012	0.004	0.043	0.009
8/19/11 8:00	0	0	1	0.08	0.001	0.000	0	0

Table H.7: Cattle counts and densities per date and time bottle for zone 3, Study 2

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
8/16/11 14:00	6	0.93	15	2.93	0.02	0.003	0.16	0.024
8/17/11 16:00	6	0.9	15	3.48	0	0.003	0.12	0.022
8/17/11 18:00	14	3.09	23	5.03	0	0.006	0.37	0.080
8/18/11 14:00	14	3.20	23	6.23	0	0.007	0.37	0.082
8/18/11 16:00	3	0.31	16	2.30	0	0.002	0.05	0.006
8/18/11 18:00	1	0.07	7	0.80	0	0.001	0.02	0.001
8/18/11 20:00	0	0	6	0.36	0	0.000	0	0

Table H.8: Cattle counts and densities per date and time bottle for zone 4, Study 2

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max fencing (#)	Ave fencing (#)	Max fencing/area (#/m^2)	Ave fencing/area (#/m^2)	Max stream/length (#/m)	Ave stream/length (#/m)
8/16/11 10:00	0	0	2	0.46	0.007	0.002	0	0
8/17/11 4:00	0	0	2	0.02	0	0.000	0	0
8/17/11 6:00	0	0	4	0.14	0	0.001	0	0
8/17/11 14:00	0	0	4	0.17	0	0.001	0	0
8/17/11 16:00	4	1.73	11	6.02	0	0.029	0.444	0.190
8/17/11 18:00	1	0.11	6	0.68	0	0.002	0.111	0.004
8/17/11 20:00	0	0	1	0.19	0	0.001	0	0
8/18/11 14:00	0	0	8	0.66	0	0.001	0	0
8/18/11 16:00	3	0.29	8	1.73	0	0.001	0.023	0.002
8/18/11 18:00	2	0.15	8	0.54	0	0.000	0.016	0.001
8/18/11 20:00	0	0	2	0.48	0	0.000	0	0

Table H.9: Number of cattle in stream upstream of MV1, Study 2

Date/Hr Bottle	Max stream (#)	Ave stream (#)
8/16/11 12:00	2	0.316667
8/16/11 16:00	2	0.033333
8/17/11 6:00	1	0.075
8/18/11 10:00	3	0.941667
8/18/11 14:00	5	0.966667
8/18/11 16:00	3	0.4
8/19/11 6:00	1	0.033613

Table H.10: Number of cattle in stream and near stream upstream of CR1, Study 2

Date/Hr Bottle	Max stream (#)	Ave stream (#)	Max near stream (#)	Ave near stream (#)
8/16/11 16:00	0	0	2	0.016667
8/17/11 6:00	0	0	3	0.041667
8/18/11 16:00	2	0.125	0	0

Appendix I. pH and EC Boxplots for Studies 1 and 2

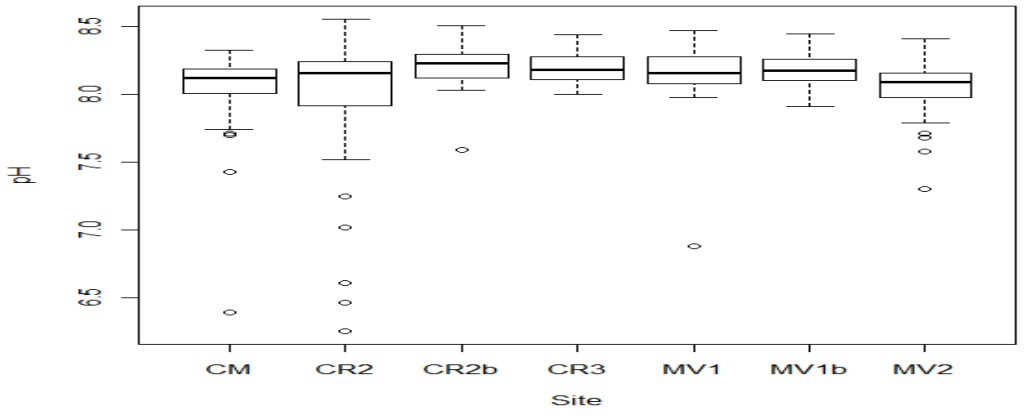

Figure I.1: pH by site, Study 1

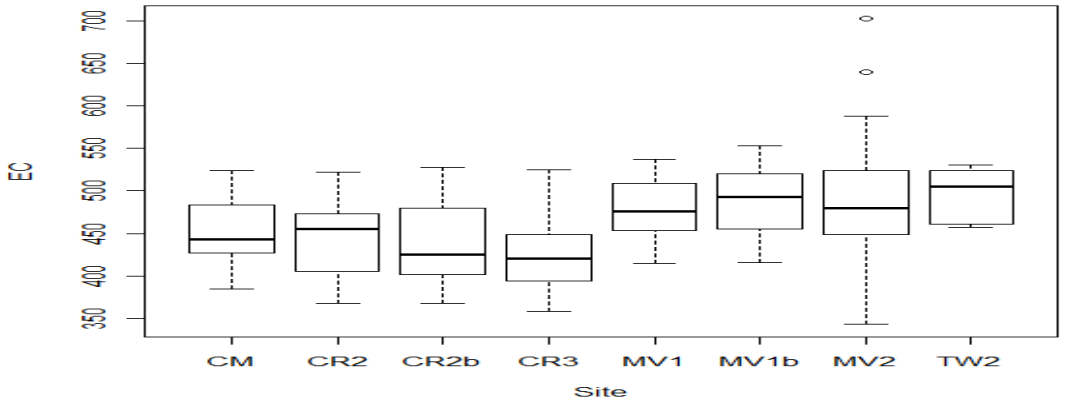

Figure I.2: Electrical conductivity (EC) by site, Study 1

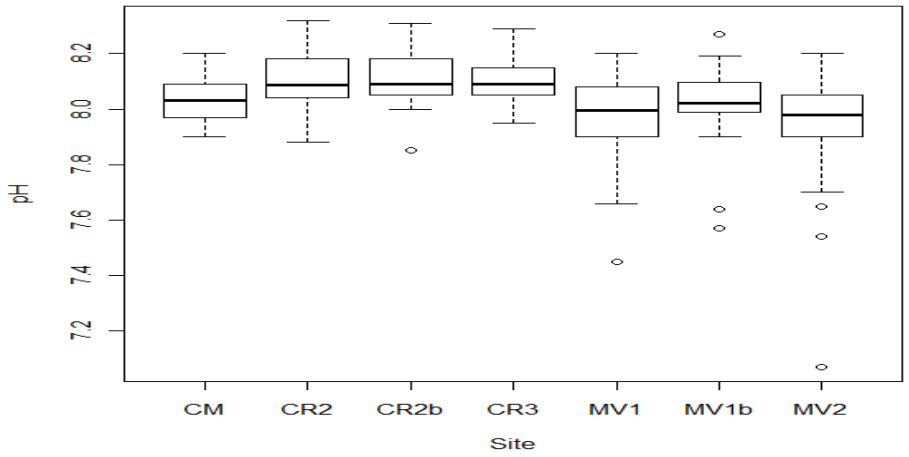

Figure I.3: pH boxplot by site, Study 2

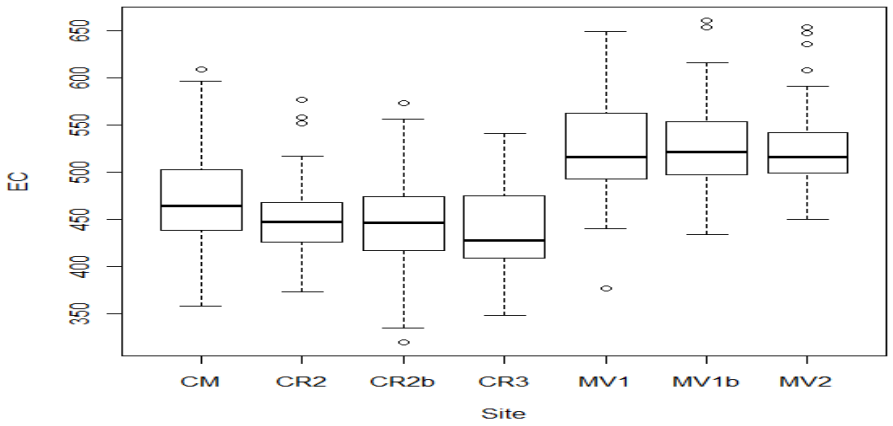

Figure I.4: Electrical conductivity (EC) boxplot by site, Study 2

Appendix J. pH, EC, NO_3-N, and TN Boxplots for Weekly Grab Samples

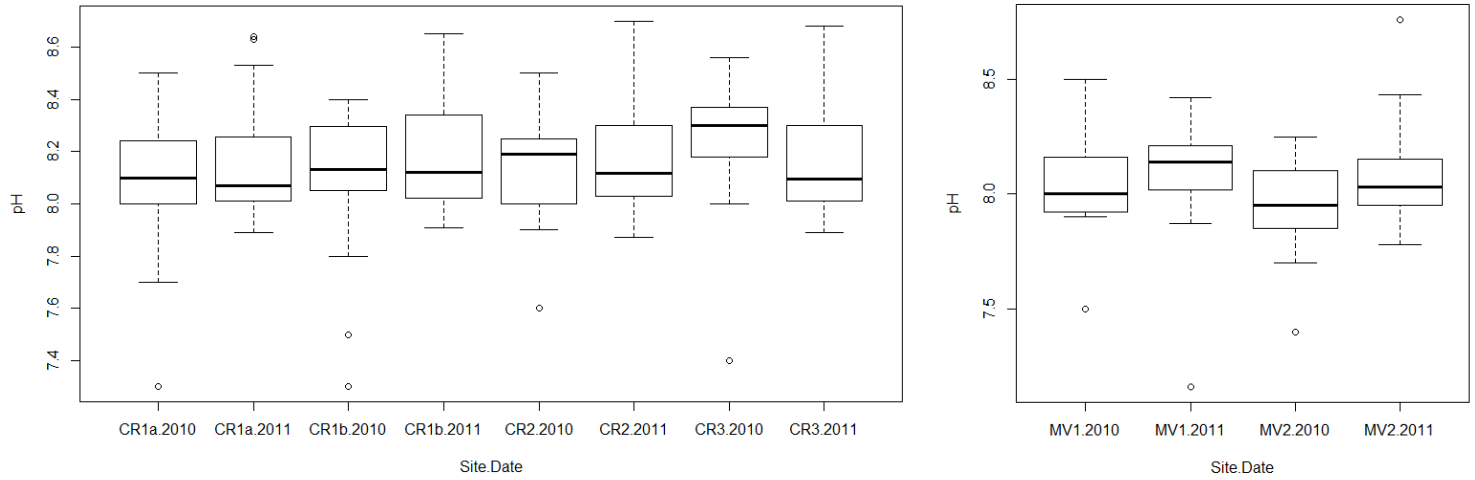

Figure I.5: Boxplots of pH for the weekly grab samples by site and year

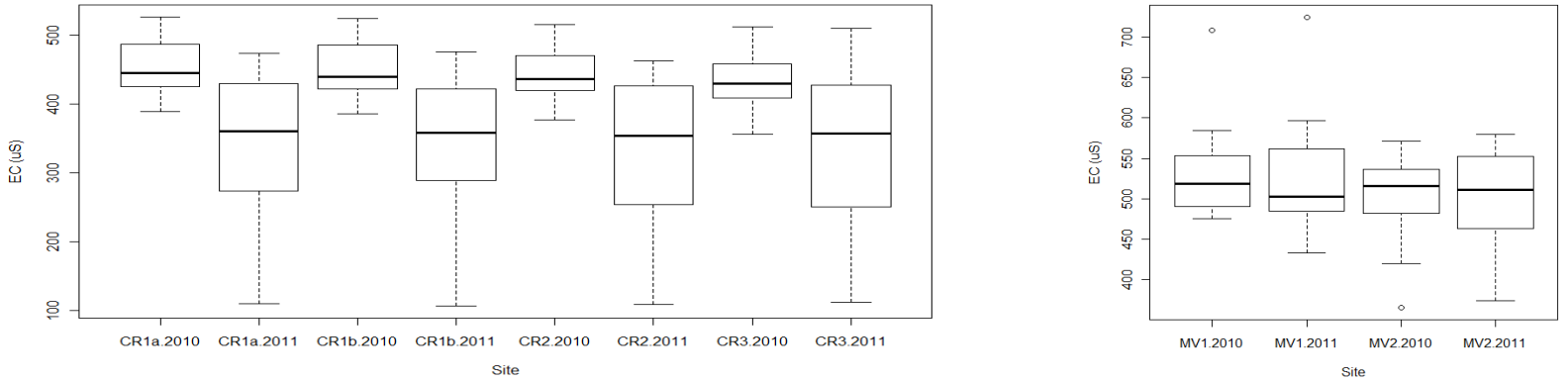

Figure I.6: Boxplots of electrical conductivity for the weekly grab samples by site and year

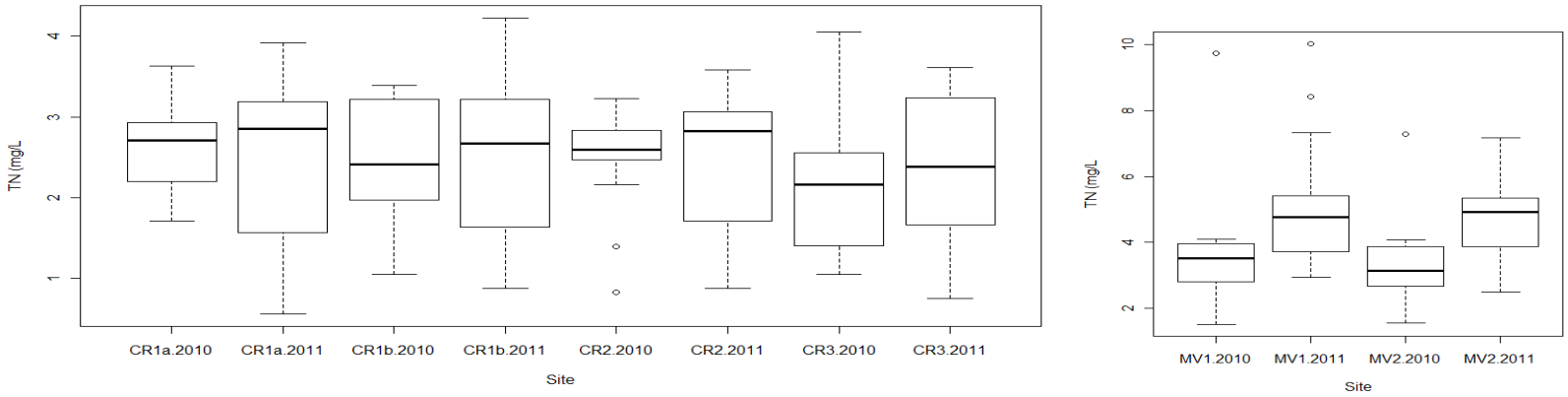

Figure I.7: Boxplots of total nitrogen for weekly grab samples by site and year

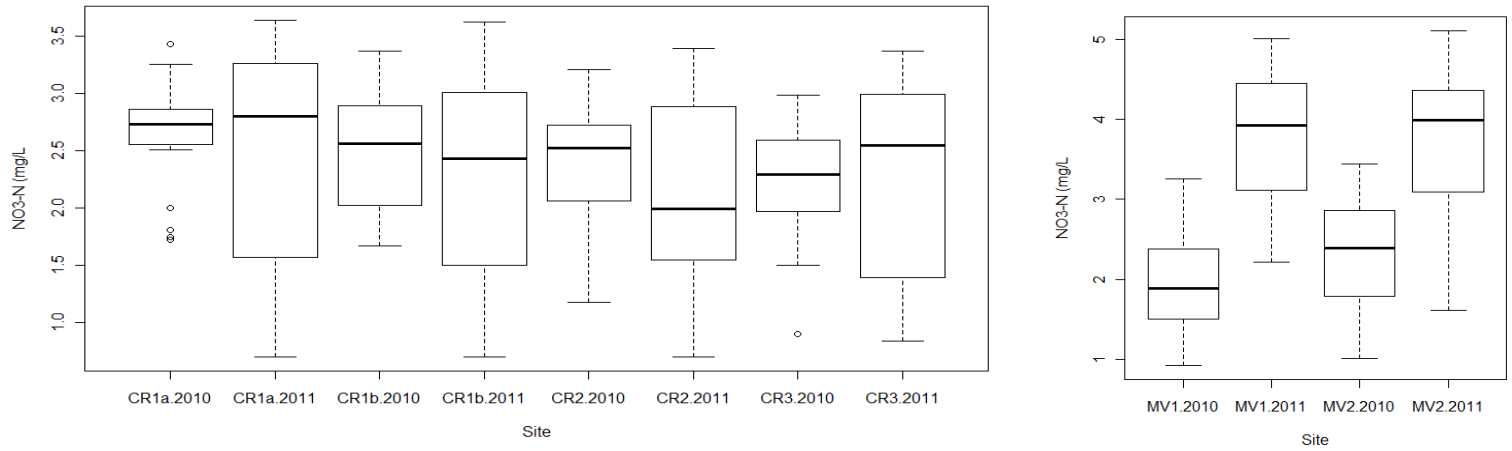

Figure I.8: Boxplots of NO_3-N for weekly grab samples by site and year