

ARMORED STANCHION CATTLE WATER ACCESS EFFECTS ON *E. COLI*, SUSPENDED  
SEDIMENT, AND NUTRIENT LOADING TO SPRING CREEKS

by

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A thesis submitted in partial fulfillment  
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of

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July 2008

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## ABSTRACT

Livestock grazing activities contribute to impairment of 5,200 miles of Montana streams. Implementation of most water quality improvement efforts addressing this issue is voluntary. Thus, it is important to present land owners with simple, cost effective approaches to mitigate water quality impairment. An armored stanchion (AS) water access was designed, implemented, and tested on Thompson and Story Creeks near Belgrade, MT. Riparian fencing was constructed to allow access at a water gap where the AS was constructed. The AS allows animals to access spring creek water to drink but does not allow them to enter the stream. An AS was constructed adjacent to a traditional (TRAD) water access on each stream for comparison. Water quality impairment was quantified downstream of each access with and without animals actively using the accesses. Instantaneous loads of *E. coli*, suspended sediment concentration (SSC), total Kjeldahl nitrogen (TKN), nitrate (NO<sub>3</sub>), total phosphorus (TP), and orthophosphate (PO<sub>4</sub>) were evaluated using Kruskal Wallis procedures. Contaminant loading from the AS access was not significantly greater than loading from the control with or without animals present. The Story Site did not consistently produce significant differences for the TRAD access with animals present versus absent under the different analysis approaches employed. Results at the Thompson Site produced significant differences for *E. coli*, TKN, and TP for the TRAD access when animals were present versus absent from the access. Estimates were made of percentage of time cattle occupied the Thompson TRAD access. These estimates facilitated calculation of daily loads attributed to animals actively using the access. For *E. coli* the load was 6.0 E9 CFU per day, 425.9 g per day for TKN, and 53.1 g per day for TP. These results indicate the AS access can reduce water quality impacts from cattle, compared to traditional access methods.

## INTRODUCTION

Non-point source pollution is the cause of 90 percent of documented water quality impairment in Montana and grazing activities contribute to impairment of 5,200 miles of stream (MTDEQ, 2006a; MTDEQ, 2007). Livestock contribute to surface water quality impairment through physical impacts to stream banks and through deposition of feces in and adjacent to stream networks (Belsky et al., 1999; Byers et al., 2005; Line et al., 2000; Owens et al., 1996). Runoff of animal waste conveys pathogens and nutrients to streams. Downstream, these contaminants pose risks to human and livestock health and contribute to eutrophication (Goolsby et al., 1999; Oliver et al., 2005). The current management approach for mitigating nonpoint source pollution is through the process of defining allowable total maximum daily loads (TMDLs). During the TMDL planning process, pollutant loads are attributed to different land uses, and reduction targets are set. However, unlike point sources, nonpoint source pollution mitigation is voluntary for landowners. For this reason, cost effective, “low tech” best management practices (BMPs) are an essential part of meeting water quality improvement goals. The armored stanchion (AS) cattle water access point that was designed, built, and assessed for this study is an attempt to improve water quality through cost effective means that livestock producers can quickly adapt to their operations.

The AS water access is implemented in conjunction with riparian fencing and allows access to surface water in a controlled manner using panels suspended over the edge of the water. Cattle can reach the water to drink, but cannot fully enter the water.

This reduces deposition of feces directly into the stream. This system is limited to installation in locations where stream stage fluctuations are minimal, ideally less than 30 cm during the season cattle are using the access. If higher stage fluctuation occurs when animals are not using the access, panels over the stream could be removed to avoid inhibiting high flows. It is also most applicable in locations which are neither highly entrenched nor require steep stream approaches. Spring creeks tend to have relatively stable discharge, which was the primary reason spring fed streams were selected for this study. Irrigation conveyances which provide livestock water access often have stable stage and may be appropriate for AS installation to mitigate livestock related water quality impairments.

### Objectives

The objective of this study was to compare fecal bacteria, nutrient, and sediment water quality impairments by two groups of cattle, each group having access to either the AS water access or the TRAD surface water access.

## LITERATURE REVIEW

Evaluations of livestock nonpoint source impacts on lotic environments appear in the literature as early as 1918 (Duce, 1918), and sufficient research had been done by the 1980's to elicit review articles on bacteria, sediment, and nutrient impacts to surface water from livestock (Crane et al., 1983; Kauffman and Krueger, 1984). Riparian areas provide water, succulent forage, and shade, inducing cattle to spend five to 30 times more time in riparian areas than would be predicted by surface area percentage alone (Belsky et al., 1999). Byers et al. (2005) conducted a study between the months of May and August and found that cattle spent four to ten percent of time in riparian areas with some variation between pastures explained by distribution of shade. In addition to distribution of shade, Marlow and Pogacnik (1986) also cited the point where cattle are initially released into a pasture, changing forage quality in different parts of the pasture over the season, and insect activity as factors affecting cattle distribution patterns within pastures.

Gary et al. (1983) noted that 6.7 to 10.5 percent of defecations and 6.3 to 9.0 percent of urinations were deposited directly in the stream. These studies indicate that time cattle spend in riparian areas varies based on a number of factors, but that direct deposition of feces into a stream can be expected when cattle have access to it. Feces and urine deposited directly into the stream results in 100 percent of contaminants in the waste being loaded to the stream network. Waste deposited in adjacent upland areas can pose a threat to water quality but requires overland flow or soil matrix flow to

transport contaminants to the stream. With passage of time between deposition and transport, waste is subject to environmental conditions which can decrease concentrations of nitrogen and pathogens (Larsen et al., 1994; Nader et al., 1998; Oliver et al., 2005; Olson et al., 1999).

#### Sediment from Nonpoint Source Livestock Grazing

Negative impacts to channel structure and increased sediment loading to surface water from nonpoint source grazing have been illustrated by numerous studies (Belsky et al., 1999). Heavily grazed riparian areas can exhibit loss of woody and herbaceous riparian vegetation and accelerated bank erosion, resulting in increased width/depth ratios and increased solar radiation reaching the stream. This causes stream temperatures to increase and diminishes aquatic habitat quality, but these factors can be reversed under light to moderate grazing management (Clary, 1999; Kauffman and Krueger, 1984). In a livestock exclusion study by Line (2003), total suspended solid (TSS) concentration increased through a pasture reach by 299 percent pre-exclusion versus 35.3 percent after livestock exclusion ( $P < 0.0001$ ). Owens et al. (1996) found discharge weighted sediment concentration decreases of 57 percent (1,980 to 870 mg l<sup>-1</sup>) after the stream corridor was fenced to exclude livestock. In a study by Carline and Walsh (2007), installation of hardened water crossings and bank stabilization in conjunction with riparian fencing resulted in a 47 to 87 percent reduction in suspended sediments. Cattle behavior was influenced through provision of off-stream water in a study by Sheffield et

al. (1997), where a 51 percent reduction of time cattle spent in the riparian area resulted in an 89 percent reduction in TSS (132 to 14 mg l<sup>-1</sup>). Lyons et al. (2000) examined stream response to intensive rotational grazing (IRG), grassy buffers, woody buffers, and continuous grazing along 23 trout stream reaches in Wisconsin, to compare physical and biological response to different riparian land uses. The authors concluded that reaches with IRG and grassy buffers performed similarly and had significantly less bank erosion and fine sediment in channel than reaches with woody buffers and continuous grazing.

#### Bacteria from Nonpoint Source Livestock Grazing

Fecal waste from cattle can contain pathogens which pose health risks to livestock and human users downstream when fecal pollution is introduced to surface water (Oliver et al., 2005; Olson et al., 2004). A diverse range of pathogens can originate from fecal pollution. Each pathogen has a different quantification method, making the use of a general indicator of fecal pollution an attractive prospect (Gleeson, 1997). The USEPA supports the use of fecal indicator bacteria for quantification of fecal pollution and in 1986 the agency issued a recommendation for use of *E. coli* as the preferred indicator in fresh water systems (USEPA, 2002). *E. coli* inhabit the lower intestine of warm blooded animals and are deposited in the feces of gulls, waterfowl, deer, elk and livestock (Field and Samadpour, 2007; Gleeson, 1997). Crane et al. (1983) reviewed results from eight nonpoint source livestock grazing studies which reported

fecal indicator bacteria concentrations associated with grazed pastures ranging up to two orders of magnitude greater than fecal indicator bacteria concentrations associated with ungrazed pastures. A study of agricultural versus “pristine” watersheds in Finland indicated median presumptive *E. coli* concentrations two orders of magnitude higher in agricultural watersheds (Niemi, 1991). Line (2003) observed a significant decrease in fecal indicator inputs to surface water of more than 75 percent after exclusion of livestock and Sheffield (1997) observed concentration decreases of 70 to 99 percent with a 51 percent reduction of time cattle spent in the riparian area. Crane et al. (1983) noted the portion of bacteria applied in manure to pastures which was lost to surface water varied from 0.007 to 23 percent, dependent on manure application method, soil type, and time from application to runoff event.

When feces deposition occurs in drier environments away from surface water, solar radiation, temperature, moisture, predation, pH, and nutrient availability act on pathogens and fecal indicator bacteria in the feces, diminishing numbers of viable organisms. Olson et al. (1999) found that *Giardia* cysts were noninfective within two weeks at 25 °C in soil, water, and feces. Cysts survived longer at four degrees C however, remaining infective for up to seven weeks in soil. *Cryptosporidium* oocysts were more resilient, remaining infective at -4 °C and 4 °C for over 12 weeks in water and soil, but the rate of degradation increased at 25 °C. Wang (1996) found that *E. coli* persisted in dairy cattle fecal deposits for up to seven, eight, and ten weeks at 37 °C, 22 °C, and 5 °C, respectively. Meays (2005) found that intensity of solar radiation had a

significant effect on *E. coli* survival, with the lowest survival rate in the 100 percent solar radiation treatment and increasing survival with increased shading. However, crusting on the surface of fecal deposits can create a protected microcosm which allows bacteria to survive for extended periods, providing reservoirs for potential contamination during subsequent overland flow events (Oliver et al., 2005). Collins and Rutherford (2004) present a model for transport of *E. coli* from pastoral land to stream networks. The authors include discussion of overland flow from seepage areas where ground-water meets the surface. Overland flow from these areas can convey feces deposited on them to surface water, even in the absence of a precipitation event.

Once fecal bacteria enters the drainage network, it is either transported downstream or deposited in sediment where it can be stored for resuspension during subsequent disturbance events. Stephenson and Rychert (1982) found *E. coli* concentrations in sediment ranging from two to 760 times higher than in the overlying water. Muirhead et al. (2004) sampled *E. coli* concentrations in sediment associated with an artificial flood study and documented concentrations orders of magnitude greater in fine sediment than in rocky substrate. An initial artificial flood event elevated *E. coli* concentration in the water column by two orders of magnitude from  $10^2$  CFU per 100 ml to  $10^4$  CFU per 100 ml but the magnitude of the concentration spikes decreased by approximately 55 percent for each of two subsequent flood events, indicating depletion of *E. coli* stored in sediment.

### Nutrients from Nonpoint Source Livestock Grazing

The mass of feces and urine produced by cattle and nutrient content of the waste are dependent on intake and digestibility of forage and environmental conditions (Nader et al., 1998). Range cattle produce from 14 to 22 kg day<sup>-1</sup> of urine and 13 to 33 kg day<sup>-1</sup> of feces. For every thousand kg of live animal mass, beef cattle excrete 0.37 kg of total Kjeldahl nitrogen (TKN), 0.09 kg of ammonia nitrogen (NH<sub>4</sub>-N), and 0.10 kg of total phosphorus (TP) day<sup>-1</sup> (Nader et al., 1998). Proximity of feces deposition to the stream network and whether direct deposition into the stream is possible are key factors in assessing nutrient loading to streams associated with grazing (Nader et al., 1998). Exclusion of cattle from a riparian corridor in North Carolina resulted in a significant decrease of 78 and 76 percent for in-stream TKN and TP concentrations, respectively (Line et al., 2000). In a study where off-stream water was provided, Sheffield et al. (1997) found that cattle used off-stream water 92 percent of the time, which resulted in decreases of 54 and 81 percent, respectively, for total nitrogen and TP in-stream. Neither Line nor Sheffield detected significant reductions in soluble nutrients associated with implementation of riparian improvement BMPs.

Soluble nutrient concentrations and dynamics can be significantly affected by uptake associated with aquatic vegetation. In a nutrient spiraling review by Ensign and Doyle (2006), the median travel distance before uptake of NO<sub>3</sub> and PO<sub>4</sub> by aquatic plants was 236 m and 96 m, respectively. Mulholland (2004) found that nutrient concentrations in mountain streams were significantly different between seasons,

partially as a result of vegetation uptake dynamics. In another study by Mulholland et al. (2006), in-stream nitrate concentrations were shown to fluctuate diurnally. These fluctuations were correlated to the amount of light reaching the stream, with higher in-stream nitrate concentrations corresponding to times with less light reaching the stream.

When riparian pastures are not in use, they act as vegetative buffers between grazed pastures and the stream network. In the absence of precipitation, riparian buffers serve to preclude feces deposition directly into streams. When overland flow occurs, riparian buffers can intercept and filter out sediment and nutrients and reduce loading to the stream network (Fajardo et al., 2001; Lim et al., 1998). When urine and feces deposition is isolated from the stream network, nitrogen can be volatilized, reducing the magnitude of potential subsequent pollution. Stewart (1970) reported that 85 to 90 percent of nitrogen deposited with urine on dry soil was lost to volatilization. Loss rates were lower when deposition occurred on wet soil. Nitrogen loss of about 50 percent is a typical value used under ambient conditions (Nader et al., 1998).

This study was undertaken to assess the potential to reduce loading of *E. coli*, SSC, and nutrients from cattle to surface water through implementation of an AS water access and riparian fencing. The null hypothesis was that the contaminant load difference between upstream and downstream sample points for animals present versus animals absent from the TRAD access would be equal to that for the AS access.

## MATERIALS AND METHODS

Study Sites and Design

Two sites were selected based on identification of cooperative landowners with active grazing on their property. Pastures were selected as close to the top of watersheds as possible, where cattle were using spring-fed creeks for water. Spring creeks were selected due to their relatively small fluctuations in stage and reduced potential for ice formation, which could cause problems with infrastructure. Pastures near the top of watersheds were selected to minimize background variability in water quality from upstream land uses. Thompson Creek and Story Creek are both spring-fed systems which originate north of Belgrade, MT and flow into the East Gallatin River. This area is classified within the Gallatin hydrologic unit code (HUC: 10020008). Land use in this area is predominantly agricultural, with subdivisions encroaching from the south as Belgrade expands.

At both sites, an AS water access was constructed and a TRAD water access was laid out to facilitate comparison between the two access types. It was hypothesized that the animals using an AS access point would cause less impairment to the water quality of the stream. Thus, the AS was located upstream from the TRAD access at both sites to improve resolution of AS data. Water access locations were selected based on previously preferred cattle access points. Presumably this would maximize cattle affinity for sites and would restrict animal activity to previously impacted areas. A combination

of permanent five strand barbed wire and temporary electric fence was used to create separate pastures with access to the two water accesses.

### AS Access Design

The AS access is a modified water gap for cattle, installed in conjunction with fencing to exclude animals from the riparian corridor. The AS includes a fenced approach to the stream and fencing along the stream bank to prohibit animals from fully entering the water. A series of fence braces are installed perpendicular to the shoreline with one post at the bank and the brace extending away from the channel approximately 1.7 m (Figures 1 and 2). Redwood 2x6" (40 x 85 mm) lumber is bolted to the front of the posts, flush with the bottom of the channel. Redwood is also bolted to the back side of the posts at a higher elevation to create a step for cattle to approach the water. At the Thompson and Story Sites, this single step effectively provided livestock access to the water over the range of stage change observed during the study. The surface under the braces was installed just above the elevation of bankfull stage to minimize obstruction of water dispersion onto the floodplain in case of flooding. Sites with steep approaches were not selected for AS installation, but some additional slope could have been accommodated with another step installed by mounting boards on the back line of posts. The surface of the access was underlain with geotextile material or cobble as a base, and road mix was spread over the geotextile or cobble to accommodate animal traffic. Standard 4x16 foot (1.2 x 4.9 m) cattle panels are bowed out over the stream and fastened between each set of braces. By suspending panels

over the water, potential to catch floating debris is minimized, reducing potential for problems with stream flow obstruction.

Stanchions at the Thompson Site were built with a 1.7 m (5.5 ft) inside width, which was sufficient for two animals to access the water simultaneously. Four stanchions were installed, which resulted in overall accommodation for eight animals at a time. Stanchion width was narrow enough that animals preferred to back out rather than turning around in the stall but the stanchion was sufficiently wide that animals could turn around if necessary. This increased animal access per unit of building material and seemed to reduce stress on animals. On one occasion at the Thompson Site, a dominant cow approached another cow in a stall. The less dominant cow turned around in the stall and was able to escape past the other cow head-first. If the animal had not been able to turn around, she may have bolted forward against the stanchion, causing higher stress and potentially damaging the infrastructure. For this reason, stanchion widths of approximately 1.7 meters are advisable.

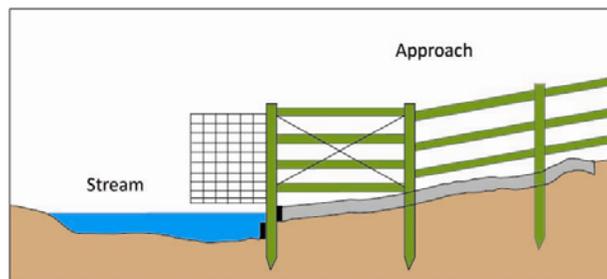


Figure 1. AS conceptual profile view.

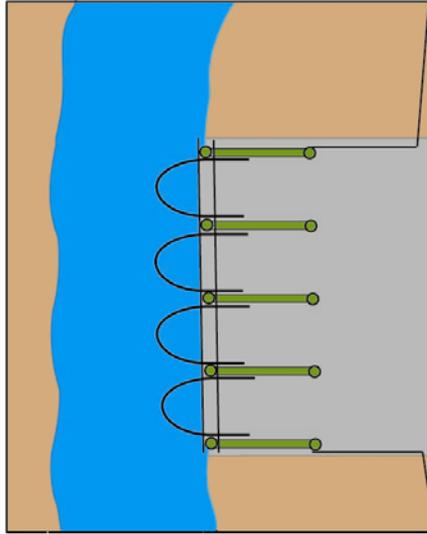


Figure 2. AS conceptual plan view.

### Thompson Site

Thompson Creek initiates in the vicinity of the Penwell Bridge road ( $45^{\circ} 48' 18''$ ,  $111^{\circ} 08' 45''$ ) and flows approximately 2.2 km (linear distance is only 1.2 km) through a neighboring pasture before entering the study pasture. The stream flows for 0.8 km through the study pasture with a sinuosity equal to two (Figure 3). Discharge during data collection ranged from approximately two to six cfs (Figure 4). Stream stage was monitored using a TruTrack stage recorder located between sample sites one and two, logging measurements every hour. Discharge was measured periodically with a Marsh-McBirney Flo-Mate at the culvert near sample site seven. Discharge was measured on five different days to develop a rating curve (Appendix A, Figure 12). The rating curve was used to estimate discharge for sample days when discharge was not directly measured. It was assumed that discharge did not change notably through the reach.

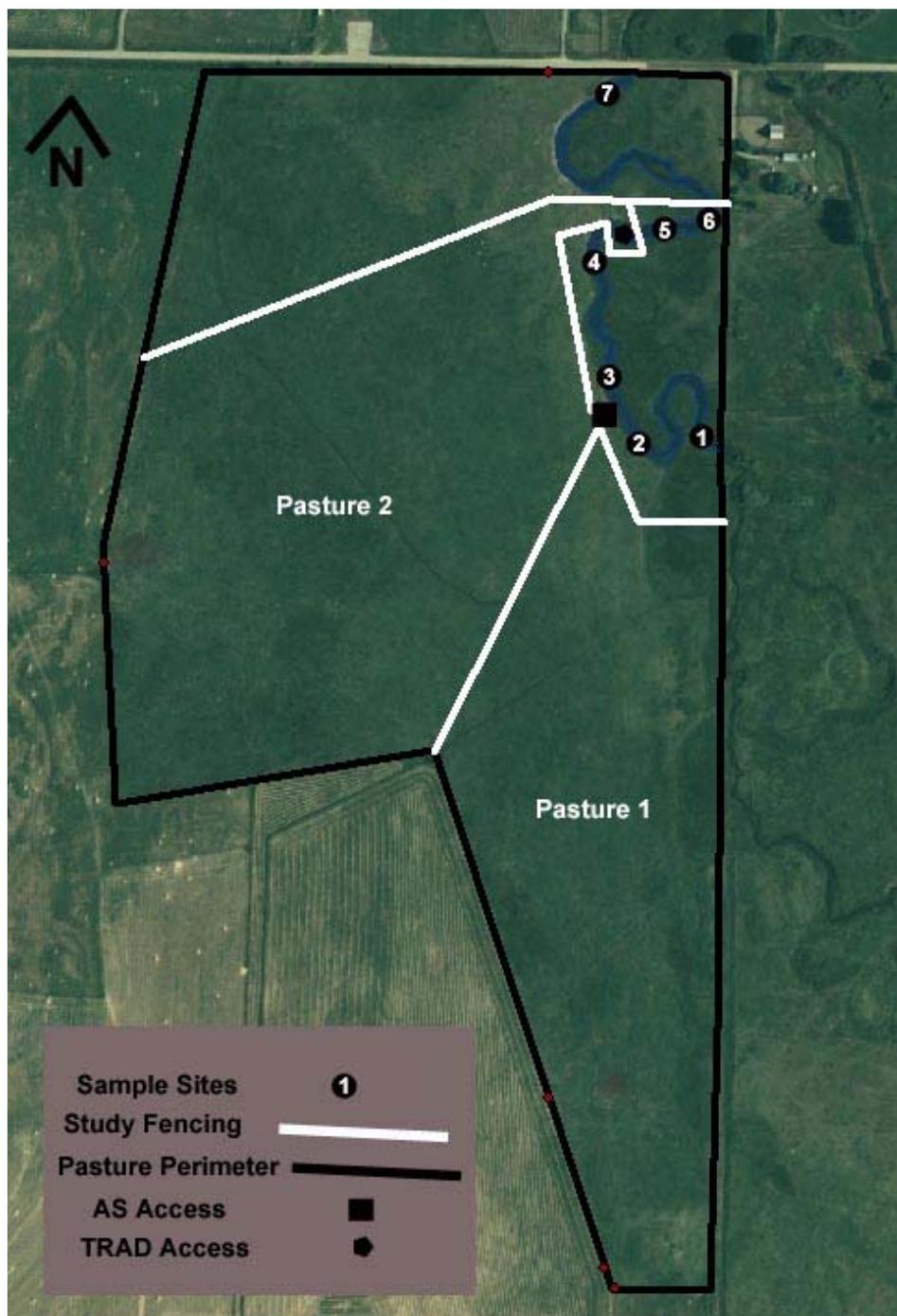


Figure 3. Thompson Site, Study Layout Map

The stream has a long history of grazing, according to the livestock producer (VanOrden, personal communication, 2007). It is relatively wide and shallow through the study reach, with widths ranging from two to 10 m. Flow is from south to north. The riparian area between sample site one and sample site six (Figure 3) was fenced to exclude cattle, except for at the AS and TRAD water access points. The AS access was 7.5 m wide and consisted of a graded approach and four stanchions at the edge of the water. Approximately 40 to 60 cattle in pasture 1 used the AS access for water during the study (Table 1, Figure 5). The TRAD access was approximately 10 m wide and gave animals access to the full width of the stream. Approximately 40 to 60 cattle in pasture 2 used the TRAD access for water during the study (Table 1, Figure 5). A selection of images showing the Thompson Site AS and TRAD accesses and livestock use of the watering accesses, is included in Figure 6.

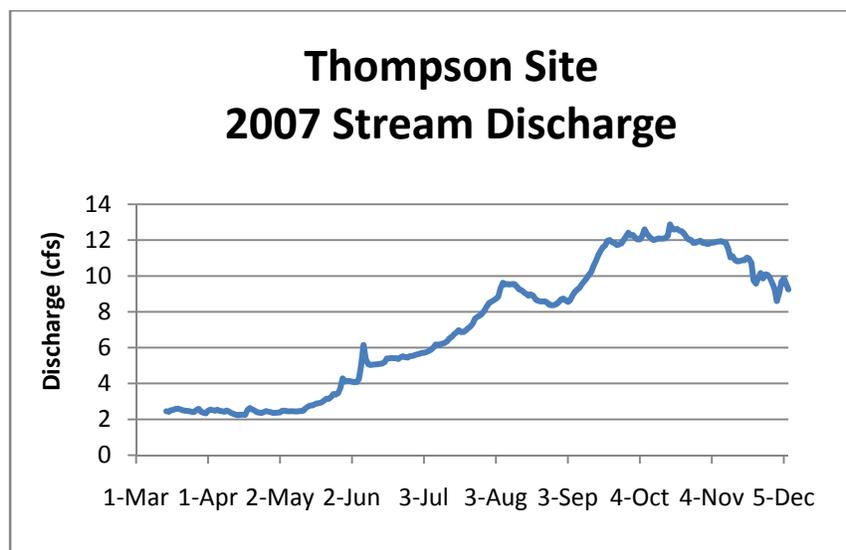


Figure 4. Thompson Site 2007 hydrograph (see Table 12 in appendix for the rating curve).

Table 1. Livestock stocking rate ranges for pastures at Thompson and Story Sites.

Pasture Stocking Rate cow/calf pairs ha <sup>-1</sup>							
Pasture	Pasture Size (ha)	March	April	May	June	July	August
Thompson Pasture 1 (AS)	14	2.9 - 3.6	2.9 - 3.6	2.9 - 3.6	2.9 - 3.6	-	-
Thompson Pasture 2 (TRAD)	17.7	2.3 - 2.8	2.3 - 2.8	2.3 - 2.8	2.3 - 2.8	-	-
Story Pasture 1 (AS)	10.5	0.6 - 1.0	0.6 - 1.0	0.6 - 1.0	0.6 - 1.0	0.6 - 1.0	2.9 - 3.8
Story Pasture 2 (TRAD)	40	0.2 - 0.3	0.2 - 0.3	0.2 - 0.3	0.8 - 1.0	0.8 - 1.0	0.8 - 1.0

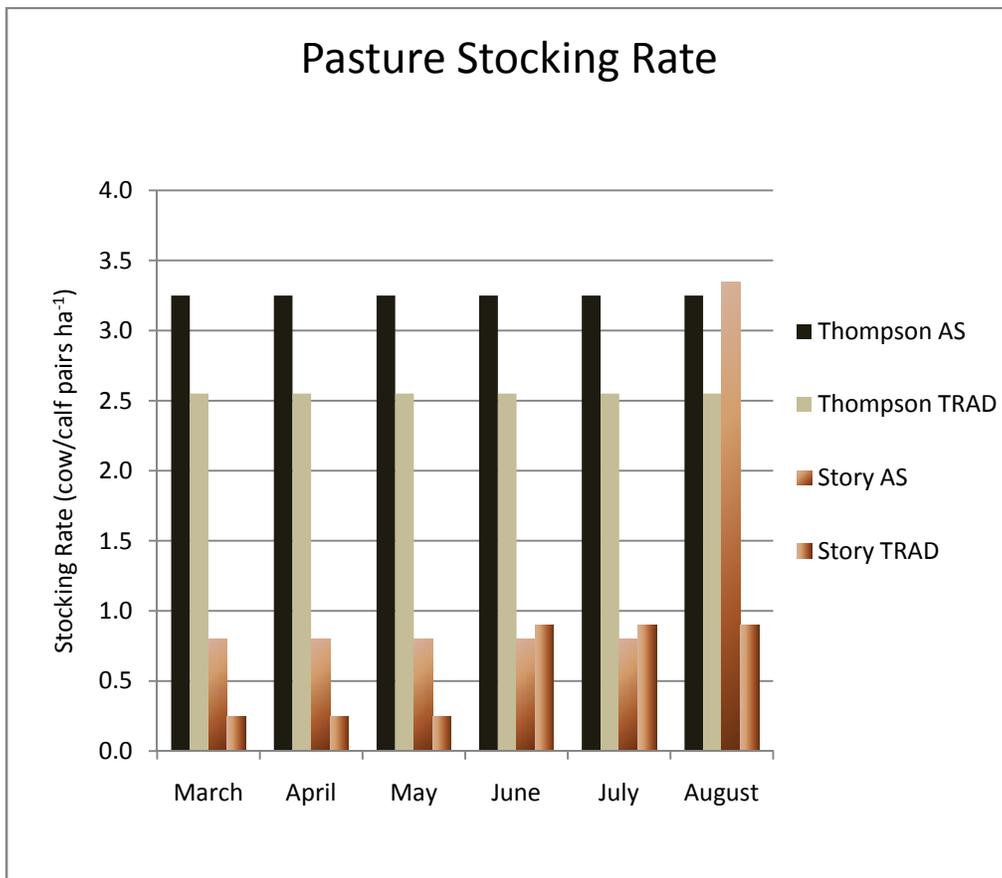


Figure 5. Livestock average stocking rates for pastures at Thompson and Story Sites.



Figure 6. Thompson Site AS access. Top Left: AS access. Top Right: Cow using AS access.. Bottom Left: TRAD access. Bottom Right: Cattle using TRAD access.

### Story Site

Story Creek initiates adjacent to Swamp Road partially from borrow pits associated with the historic railroad grade ( $45^{\circ} 49' 51''$ ,  $111^{\circ} 12' 04''$ ). The study reach was located immediately below the headwaters, with a linear distance of 0.4 km and a stream length of 0.5 km (Figure 7). Discharge during data collection ranged from nearly zero to approximately eight cfs, and was influenced by an irrigation checkdam upstream (Figure 8). Stream stage was monitored using a TruTrack stage recorder located

between sample sites four and five, logging measurements every hour. Discharge was measured periodically with a Marsh-McBirney Flo-Mate, within one meter of the TruTrack. Discharge was measured on five different days to develop a rating curve (Appendix A, Figure 13). The rating curve was used to estimate discharge for sample days when discharge was not directly measured. It was assumed that discharge did not change notably through the reach.

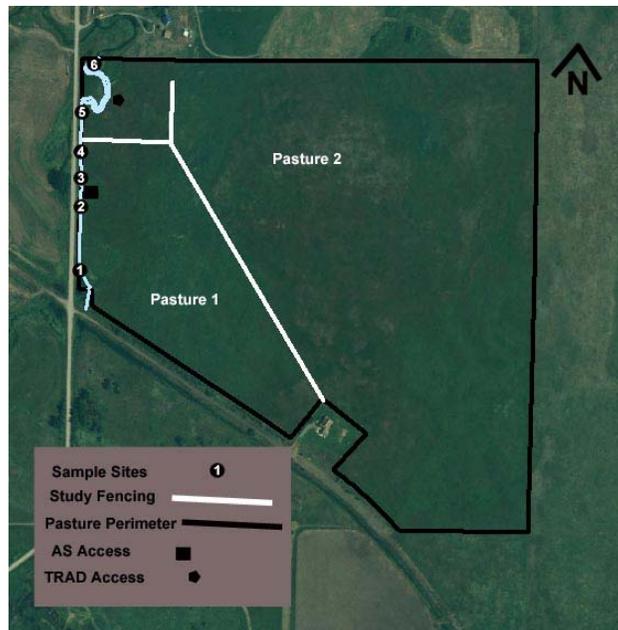


Figure 7. Story Site, Study Layout Map

The stream through the study reach has three distinct zones. The first segment is upstream from sample site 1 and is approximately 30 m long with widths ranging from two to five m. It is degraded from previous cattle access, but cattle are completely excluded as a result of fencing associated with the study. The second segment is between sample sites one and five and is 290 meters long with widths ranging from 0.5 to 1.5 m. This reach is constrained to a narrow corridor between the west pasture

boundary fence and the Swamp Road grade. In the second section, the stream crosses under the fence into the pasture for approximately 15 meters, which is where the AS access was installed between sample sites 2 and 3. The third stream section is between sample sites 5 and 6 and runs through the northwest corner of the pasture for 176 meters. The third section is somewhat degraded, with widths ranging from two to four meters. Stanchion construction at the Story Site was similar to Thompson Site, with a few modifications. Cobble was used as a base layer rather than geotextile material, and stanchions were constructed with approximately 1.3 m internal widths (Figure 9).

Cattle in pasture 1 utilized the AS access for water during the study. The AS access was constructed with four stanchions, built with inside widths of 1.5 m. Animals were observed sharing the stanchions, but the width did not appear to be sufficient for two animals to comfortably access the water simultaneously. Pasture 1 was stocked with six to ten cattle between March and July, and thirty to forty cattle in August (Table 1, Figure 5). Six to ten of these cattle were Scottish Highlanders and the remaining animals were Black Angus. The Scottish Highlanders had horns approximately 30 cm long, which did not seem to impede the animal's ability to use the stanchions. Cattle in pasture 2 had full access to the 176 m section of stream in the northwest corner of the pasture during the study. Pasture 2 was stocked with six to ten cattle between March and May, and thirty to forty cattle between June and August (Table 1, Figure 5). A selection of images showing the Story Site AS access construction and use is included in Figure 9.

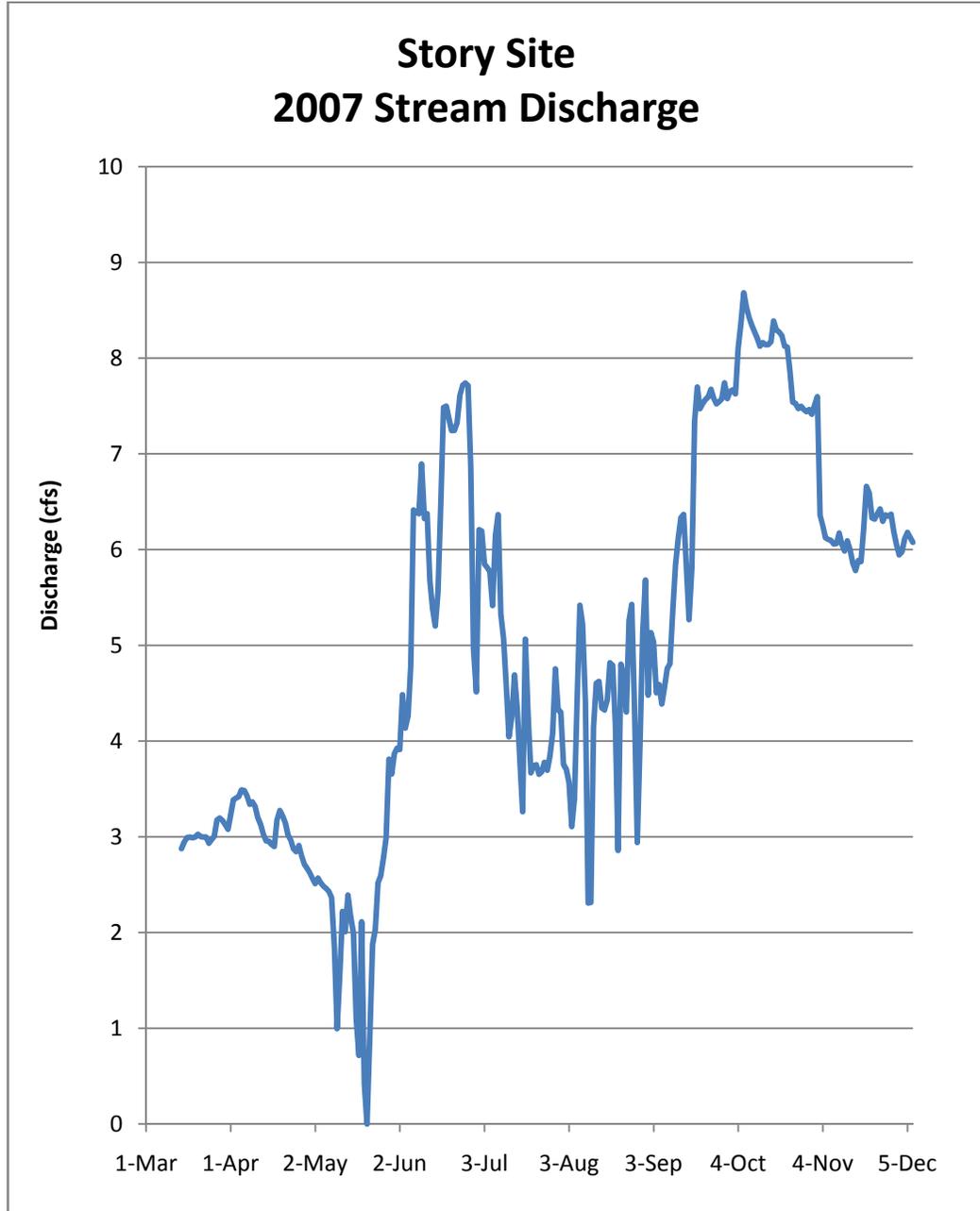


Figure 8. Story Site 2007 hydrograph (see Table 13 in appendix for the rating curve).



Figure 9. Story Site AS access. Top Left: Access just after earthwork. Top Right: Installation of chicken wire to stabilize substrate. Middle Left: Cobbles over chicken wire. Middle Right: Redwood step to stabilize bank. Bottom Left: AS completed. Bottom Right: Scottish Highlander using AS.

Sampling

Stream water samples were collected between March 7<sup>th</sup> and June 18<sup>th</sup> at the Thompson Site, and between March 7<sup>th</sup> and August 29<sup>th</sup> at the Story Site. Bacteria and sediment were collected for every sampling event, and sampling for nutrients was conducted roughly every second visit (see Tables 11 and 12, appendix). On each sampling occasion, samples were collected upstream and downstream of each reach, representing influent and effluent concentrations. The upstream value (influent) of each parameter was subtracted from the corresponding downstream value (effluent) of the parameter and the difference was multiplied by discharge to calculate the instantaneous load difference attributed to the reach. Sampling was conducted for each water access point when animals were actively using the access and when they were in the pasture but not using the access. The sampling strategy produced five factor levels which are depicted in Table 2.

Table 2. Factor levels defined by study reach and presence versus absence of animals. (CONT = control, AS = armored stanchion access, TRAD = traditional access, A = absent, P = present)

Thompson		Story	
Animals		Animals	
Absent	Present	Absent	Present
CONT_A = Site 2 - Site 1	NA	CONT_A = Site 2 - Site 1	NA
AS_A = Site 3 - Site 2	AS_P = Site 3 - Site 2	AS_A = Site 3 - Site 2	AS_P = Site 3 - Site 2
TRAD_A = Site 5 - Site 4	TRAD_P = Site 5 - Site 4	TRAD_A = Site 6 - Site 5	TRAD_P = Site 6 - Site 5

Sampling with animals present was initiated by an animal entering the access point and the sample was considered an “animal present” sample if at least one animal

remained in the access for enough time for the fastest velocity water to reach the sample location. This was approximately thirty seconds for both accesses at the Thompson Site and the AS access at the Story Site. Six minutes was required for water to travel through the TRAD access reach at the Story Site. Travel times were determined by introducing surface debris to the stream and measuring the time required for the fastest materials to reach the downstream sample location on the day of sampling.

Sampling was width integrated by collecting subsamples from three locations across the channel. This was accomplished with a bottle on an extendable golf ball retriever to avoid disturbing the bottom of the channel. Width integrated sampling was conducted to compensate for the possibility that full lateral mixing of contaminants introduced to the stream by livestock using the accesses may not have occurred before water reached the downstream sample location. Sampling was also depth integrated at sample sites deeper than 20 cm. For *E. coli*, a 3 ml aliquot was withdrawn from each of the three subsamples from across the stream width. These aliquots were placed in plastic bottles provided by Micrology Laboratories (ML). For SSC, the three subsamples were mixed streamside into a single quart mason jar for evaluation as a composite sample. Soluble nutrient samples were collected by thoroughly mixing composite SSC samples and extracting 60 ml of sample with a syringe. These subsamples were filtered in the field with 0.2  $\mu\text{m}$  Fisher syringe filters and dispensed into three 20 ml high-density polyethylene (HDPE) scintillation vials. Samples for TKN and TP were collected by thoroughly mixing composite SSC samples and pouring off 250 ml into plastic bottles

provided by Energy Laboratories. These samples were preserved in the field with sulfuric acid to reduce pH below 2.

### Sample Analysis

#### SSC

SSC samples were refrigerated upon return to the MSU lab until processing. SSC was determined by filtration and drying with methods modified from standard methods (APHA, 1995). Sample volumes ranged from 500 to 1000 ml and were filtered in their entirety through Whatman 2  $\mu\text{m}$  glass fiber filters, using Buchner Funnels. Filter papers were dried at 103°C prior to filtering for starting weights, and filter papers with sediment were dried for two hours before measurement of ending weights. Hot weights were measured for filters 10 seconds after removal from the oven. Blanks were run for each set of samples to account for changes in filter weight from the filtration process. Weight change of blanks was subtracted from weight change of each filter. The reporting limit for the method is 10 mg l<sup>-1</sup>.

#### *E. coli*

Water samples for *E. coli* were transported to the MSU lab in bottles provided by ML with pre-dispensed Coliscan enumeration media. In the MSU lab, samples were poured into treated Petri dishes which cause the media to solidify to a slant. Samples were incubated 36 to 48 hours at 32°C  $\pm$  2°C. At the end of incubation, Petri dishes were placed on a light table and digitally photographed. Photos were evaluated for *E.*

*coli* by differentiating the colors of halos surrounding colonies, as directed by ML methods. The reporting limit was 1 CFU per 3 ml, which occurred when at least three colonies appeared collectively in the triplicate 3 ml subsamples. *E. coli* numbers are reported as CFU per 3 ml. These numbers can be converted to the more typical reporting of CFU per 100 ml by multiplying by 33. This conversion was not performed to avoid misrepresenting the detection resolution of the method.

#### TKN and TP

Particulate nutrient samples were transported on ice to the MSU lab and refrigerated until shipment to Energy Laboratories in Billings, MT. Samples were shipped to allow analysis within the 28 day holding time. Energy Laboratories analyzed samples for TKN and TP using methods E351.2 and E365.1, respectively (USEPA, 1993a; USEPA, 1993b). The reporting limit was  $0.5 \text{ mg l}^{-1}$  for TKN-N and  $0.01 \text{ mg l}^{-1}$  for TP-P.

#### NO<sub>3</sub> and PO<sub>4</sub>

Soluble nutrient samples were transported on ice to the MSU lab and refrigerated until analysis. Anions including chloride ( $\text{Cl}^-$ ), nitrite ( $\text{NO}_2^-$ ), nitrate ( $\text{NO}_3^-$ ), phosphate ( $\text{PO}_4^{3-}$ ), and sulfate ( $\text{SO}_4^{2-}$ ) were measured by ion-exchange chromatography (IC). Analysis was performed using a Metrohm IC equipped with an ASUPP-5, 250 x 4.0 mm column (Metrohm Corp., Herisau, Switzerland). A 100  $\mu\text{L}$  injection volume was chosen for low-level detection of anions. The analytical detection limit for  $\text{NO}_3^-$  and

$\text{PO}_4^{3-}$  was  $5 \mu\text{g l}^{-1}$ . Standards prepared from reagent-grade salts were routinely checked against certified Alltech or Fluka brand standards during every IC run.

### Statistical Methods

All statistics were conducted using R software version 2.7.0 available through the Comprehensive R Archive Network (CRAN). A significance level of 0.05 was used for all analyses. Statistical analyses were conducted on differences in instantaneous load entering versus exiting a reach. Instantaneous loads were reported as CFU *E. coli*  $\text{day}^{-1}$ , kg SSC  $\text{day}^{-1}$ , and g of nutrients  $\text{day}^{-1}$ . These units were selected to be consistent with units in the literature and to be easily interpretable. The units do not imply that instantaneous loads are constant over the course of a day.

Two different approaches were taken for statistical analysis. The first approach was to compare instantaneous load differences for the two access types specifically associated with animals actively using the accesses. This approach is referred to as the FACT2 approach because it reduced the data to only two factor levels for comparison. This was accomplished by subtracting instantaneous load differences with animals absent from instantaneous load differences with animals present (Table 3).

Table 3. Factor levels under the FACT2 analysis approach.

Thompson		Story	
AS Reach	TRAD Reach	AS Reach	TRAD Reach
AS_P - AS_A	TRAD_P - TRAD_A	AS_P - AS_A	TRAD_P - TRAD_A

The FACT2 analysis did not include the CONT reach because animals were never present in the CONT reach. This analysis resulted in reduction of sample size because only data for individual days with samples representing animals presence and absence was used. This was the most conservative way to analyze the data because, by adjusting load differences with animals present using load differences with animals absent, the reach specific water quality background effects were removed. This analysis procedure served to isolate effects of cattle use within the accesses.

The second approach was to make comparisons among the five factor level medians. Four pairwise comparisons were made (Tables 5 and 7). Comparisons were made between the control and each access reach with animals absent. Comparisons were also made within each access for animals present versus absent. This approach is referred to as the FACT5 approach because comparisons included all five factor levels (Table 4). This approach does not account for potential concerns with repeat measures that the FACT2 method does, but it allows for more specific examination of differences between factor levels.

Table 4. Factor levels under the FACT5 analysis approach. Animals are never present in the control reach, so that position in the table is labeled “not applicable” (NA).

Thompson		Story	
Animals		Animals	
Absent	Present	Absent	Present
CONT_A	NA	CONT_A	NA
AS_A	AS_P	AS_A	AS_P
TRAD_A	TRAD_P	TRAD_A	TRAD_P

In both the FACT2 and the FACT5 approaches, a multi-response permutation procedure (MRPP) was conducted first to determine whether significant differences were present among parameter median differences, with accounting for potential covariation between and among response variables. This analysis was conducted using MRPP code available in the “vegan” software package from CRAN. The MRPP analysis was conducted for Story and Thompson sites independently and was conducted on bacteria and sediment as one response group and the four nutrient species as a second response group. Sediment and bacteria were grouped because they were always sampled together and had larger sample sizes. Nutrients were grouped because they were sampled less often and had smaller sample sizes.

Not all datasets were normal or lent themselves to lambda transformations to normality, so nonparametric Kruskal Wallis tests were used. Under the FACT2 approach, Kruskal Wallis analysis was the final step to analyze for significant differences between the two factor level medians. Under the FACT5 approach, all five factor level medians were evaluated together to determine if any significant differences existed. If significant differences were found, Kruskal Wallis tests were used to conduct pair-wise comparisons between individual factor levels. P values from these comparisons were then adjusted, using the Bonferroni procedure for multiple comparisons. Four pair-wise comparisons were conducted, resulting in p values increasing by a multiple of four under the Bonferroni procedure. The increase in p value reduced power to detect significant differences.

## RESULTS

Thompson FACT2 Approach Results

Median concentration differences and instantaneous load differences between upstream and downstream locations are presented in Table 5. Concentration data is included for a frame of reference but all analysis was conducted on instantaneous load differences. Under the FACT2 approach, MRPP analysis indicated a significant difference (0.05 significance level) in the bacteria/sediment response group (delta = 0.014), but not in the nutrient response group (delta = 0.091). This initial test for presence of significant differences warranted further analysis of bacteria and sediment data but not the nutrient data.

Median instantaneous *E. coli* load difference attributed to animal presence in the AS access was zero CFU day<sup>-1</sup>. This was significantly less than the median instantaneous load difference of 9.4 E10 CFU day<sup>-1</sup> associated with animal presence in the TRAD access. P values for TKN, TP, and PO<sub>4</sub> are equal to the significance level at 0.05, which is the smallest p value possible for this test with a sample size of three. However, because the MRPP analysis did not suggest presence of significant differences in the nutrient response group, these differences are not reported as significant. Note that while only significantly greater *E. coli* load differences were attributed to the TRAD access versus the AS access, median differences for all parameters were greater for the TRAD access than the AS access.

Table 5. Median instantaneous load differences, concentration differences, sample sizes, and Kruskal Wallis p values for the FACT2 approach (Thompson Site). Values represent differences in instantaneous parameter loads specifically attributed to animals actively using the accesses.

(\* indicates a significant difference at a 0.05 significance level)

Thompson Medians (FACT2 Approach)						
Concentration Differences			Instantaneous Load Differences			
Parameter	AS	TRAD	Parameter	AS	TRAD	p value
SSC (mg l <sup>-1</sup> )	2 (n=8)	14 (n=9)	SSC (kg day <sup>-1</sup> )	10.9 (n=8)	80.7 (n=9)	0.178
<i>E. coli</i> [CFU (3 ml) <sup>-1</sup> ]	0 (n=8)	47 (n=9)	<i>E. coli</i> (CFU day <sup>-1</sup> )	0 (n=8)	9.4E+10 (n=9)	0.043*
TKN (mg l <sup>-1</sup> )	0.0 (n=3)	0.9 (n=3)	TKN (g day <sup>-1</sup> )	0 (n=3)	9522.8 (n=3)	0.050
NO <sub>3</sub> (mg l <sup>-1</sup> )	0.00 (n=3)	0.19 (n=3)	NO <sub>3</sub> (g day <sup>-1</sup> )	0 (n=3)	2349 (n=3)	0.127
TP (mg l <sup>-1</sup> )	-0.01 (n=3)	0.09 (n=3)	TP (g day <sup>-1</sup> )	-55.2 (n=3)	614.2 (n=3)	0.050
PO <sub>4</sub> (mg l <sup>-1</sup> )	0.01 (n=3)	0.06 (n=3)	PO <sub>4</sub> (g day <sup>-1</sup> )	72.26 (n=3)	386.2 (n=3)	0.050

#### Thompson FACT5 Approach Results

MRPP analysis indicated significant differences in both the bacteria/sediment response group (delta < 0.001) and the nutrient response group (delta = 0.002) at the Thompson Site under the FACT5 approach (0.05 significance level). This result prompted examination of differences among factor level medians for all parameters. Median differences are reported in Table 6. Concentration differences are included in the table for frame of reference but all analysis was conducted on instantaneous load differences. Kruskal Wallis analysis of the medians of the five factor levels for each response variable at the Thompson Site was conducted and p-values are included on box plots for each

parameter in Figure 10. Significant differences were detected among factor level medians for *E. coli*, SSC, TKN, and TP but not for NO<sub>3</sub> or PO<sub>4</sub>. Table 7 lists p values for subsequent pairwise analysis, comparing differences for the control to differences for each access with animals absent and comparing differences with animals present versus absent for each access. Neither access reach with animals absent was significantly different from the control for any parameter. For the AS reach, medians were not significantly different with animals present versus animals absent for any parameter. In fact, the difference in median concentration for above and below the reach with animals present in the AS access was lower than the difference with animals absent for four of the six parameters. However, in the TRAD access, instantaneous load differences of *E. coli*, TKN, and TP were significantly greater when animals were present versus absent. Instantaneous *E. coli* load difference increased by 8.0 E10 CFU day<sup>-1</sup>, TKN by 5679.2 g day<sup>-1</sup>, and TP by 708.3 g day<sup>-1</sup> when animals were using the TRAD access. The median SSC load difference in the TRAD access when animals were present was 180 kg day<sup>-1</sup> greater than when they were absent, but this difference was not significant (p value = 0.116). The TRAD access also showed an indication of elevated *E. coli* compared to the control, even when animals were not actively using the access, but the difference was not significant (p value = 0.052).

Table 6. Median concentration differences, instantaneous load differences, and associated sample sizes for CONT, AS, and TRAD reaches with and without animals present in the accesses at the Thompson Site under the FACT5 approach.

Thompson Site Factor Level Medians				
Reach	Animals Absent		Animals Present	
	Concentration Difference	Instantaneous Load Difference	Concentration Difference	Instantaneous Load Difference
SSC				
	$\text{mg l}^{-1}$	$\text{kg day}^{-1}$	$\text{mg l}^{-1}$	$\text{kg day}^{-1}$
CONT	5 (n=9)	29.2 (n=9)	NA	NA
AS	-6 (n=10)	-34.9 (n=10)	-2 (n=10)	-13.0 (n=10)
TRAD	4 (n=10)	40.4 (n=10)	34 (n=11)	220.6 (n=11)
<i>E. coli</i>				
	$\text{CFU (3 ml)}^{-1}$	$\text{CFU day}^{-1}$	$\text{CFU (3 ml)}^{-1}$	$\text{CFU day}^{-1}$
CONT	0 (n=9)	0 (n=9)	NA	NA
AS	1 (n=10)	1.0 E9 (n=10)	0 (n=10)	0 (n=10)
TRAD	7 (n=10)	2.0 E10 (n=10)	51 (n=11)	1.0 E11 (n=11)
TKN				
	$\text{mg l}^{-1}$	$\text{g day}^{-1}$	$\text{mg l}^{-1}$	$\text{g day}^{-1}$
CONT	0.0 (n=4)	0 (n=4)	NA	NA
AS	0.0 (n=4)	0 (n=4)	0.0 (n=4)	0 (n=4)
TRAD	0.0 (n=5)	0 (n=5)	0.9 (n=6)	5679.2 (n=6)
$\text{NO}_3$				
	$\text{mg l}^{-1}$	$\text{g day}^{-1}$	$\text{mg l}^{-1}$	$\text{g day}^{-1}$
CONT	-0.19 (n=6)	-1135.8 (n=6)	NA	NA
AS	0.00 (n=6)	0.00 (n=6)	-0.10 (n=5)	-551.4 (n=5)
TRAD	0.00 (n=7)	0.00 (n=7)	0.00 (n=7)	0 (n=7)
TP				
	$\text{mg l}^{-1}$	$\text{g day}^{-1}$	$\text{mg l}^{-1}$	$\text{g day}^{-1}$
CONT	0.01 (n=4)	36.1 (n=4)	NA	NA
AS	0.00 (n=4)	0 (n=4)	-0.01 (n=4)	-27.6 (n=4)
TRAD	-0.01 (n=5)	-58.4 (n=5)	0.09 (n=6)	649.9 (n=6)
$\text{PO}_4$				
	$\text{mg l}^{-1}$	$\text{g day}^{-1}$	$\text{mg l}^{-1}$	$\text{g day}^{-1}$
CONT	0.00 (n=6)	0 (n=6)	NA	NA
AS	0.01 (n=6)	30.2 (n=6)	-0.01 (n=5)	-58.4 (n=5)
TRAD	0.00 (n=7)	0 (n=7)	0.05 (n=7)	380.9 (n=7)

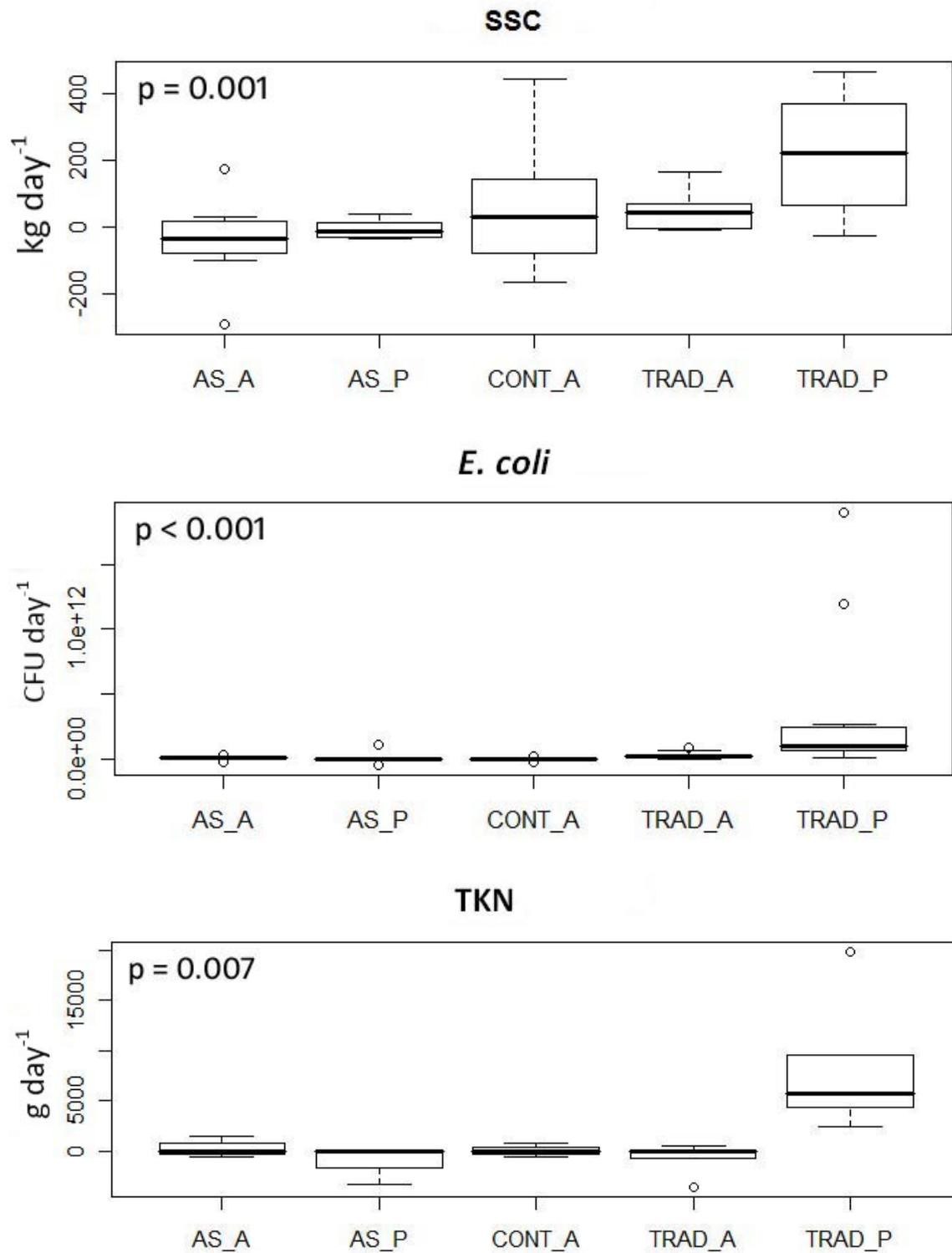


Figure 10. Box plots with Kruskal Wallis p values under the FACT5 approach (Thompson Site).

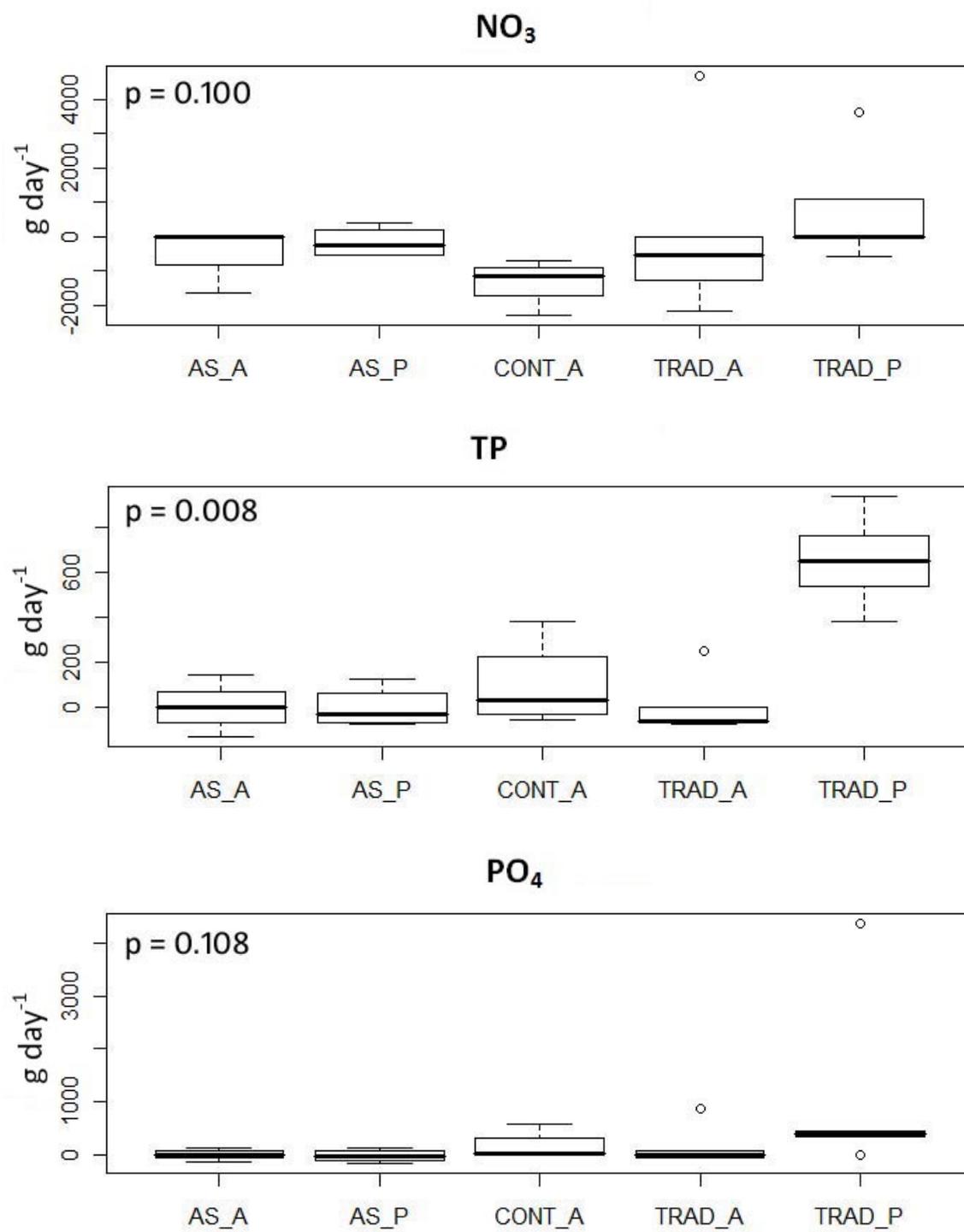


Figure 10. Continued.

Table 7. Estimated P values for pairwise comparisons under the FACT5 approach (Thompson Site). P values are adjusted up by a multiple of four according to the Bonferroni procedure for four multiple comparisons. Values greater than one are reported as one. NO<sub>3</sub> and PO<sub>4</sub> are not included because the Kruskal Wallis test found no significant differences between medians for these parameters. (\* indicates a significant difference at a 0.05 significance level)

Thompson Site				
Comparison	p values			
	SSC	<i>E. coli</i>	TKN	TP
CONT_A ↔ AS_A	1	1	1	1
CONT_A ↔ TRAD_A	1	0.052	1	0.704
AS_A ↔ AS_P	1	1	1	1
TRAD_A ↔ TRAD_P	0.116	0.028*	0.024*	0.024*

#### Story FACT2 Approach Results

Differences in median concentrations and instantaneous load differences are presented in Table 8. The MRPP analysis indicated a significant difference in the nutrient response group (delta = 0.037) but not in the bacteria/sediment response group (delta = 0.272). This initial test for presence of significant differences warranted further analysis of nutrient data but not bacteria and sediment data.

The median NO<sub>3</sub> load difference attributed to animal presence in the AS was -481.8 g day<sup>-1</sup>, which is significantly less than the median load difference of 3167.3 g day<sup>-1</sup> associated with the TRAD access. Differences for none of the other parameters were significantly different under the FACT2 approach. Median differences for all parameters at the TRAD access were greater than or equal to those for the AS access.

Table 8. Median instantaneous load differences, concentration differences, sample sizes, and Kruskal Wallis p values for the FACT2 approach (Story Site). These values represent differences in instantaneous parameter loads specifically attributed to animals actively using the accesses. (\* indicates a significant difference at a 0.05 significance level)

Story Medians (FACT2 Approach)						
Concentration Differences			Instantaneous Load Differences			
Parameter	AS	TRAD	Parameter	AS	TRAD	p value
SSC (mg l <sup>-1</sup> )	4 (n=14)	8 (n=15)	SSC (kg day <sup>-1</sup> )	42.8 (n=14)	78.2 (n=15)	0.257
<i>E. coli</i> [CFU (3 ml) <sup>-1</sup> ]	0 (n=14)	3 (n=15)	<i>E. coli</i> (CFU day <sup>-1</sup> )	0.0E+0 (n=14)	8.5E+9 (n=15)	0.315
TKN (mg l <sup>-1</sup> )	0.0 (n=6)	0.4 (n=6)	TKN (g day <sup>-1</sup> )	0 (n=6)	5466.5 (n=6)	0.097
NO <sub>3</sub> (mg l <sup>-1</sup> )	-0.08 (n=6)	0.27 (n=6)	NO <sub>3</sub> (g day <sup>-1</sup> )	-481.8 (n=6)	3167.3 (n=6)	0.01*
TP (mg l <sup>-1</sup> )	0.01 (n=6)	0.02 (n=6)	TP (g day <sup>-1</sup> )	52.0 (n=6)	294.2 (n=6)	0.092
PO <sub>4</sub> (mg l <sup>-1</sup> )	0.00 (n=6)	0.00 (n=6)	PO <sub>4</sub> (g day <sup>-1</sup> )	0 (n=6)	0 (n=6)	0.140

#### Story FACT5 Approach Results

MRPP analysis did not indicate any significant differences in either the bacteria/sediment response group (delta = 0.188) or the nutrient response group (delta = 0.198) at the Story Site under the FACT5 approach (0.05 significance level). This result did not warrant further analysis of any parameters for differences. Median differences are reported in Table 9. Concentration differences are given for frame of reference but analysis was conducted on instantaneous load differences.

While the MRPP did not warrant further investigation of any responses, a Kruskal Wallis analysis was performed and p values and box plots are included in Figure 11. Analysis did reveal differences among factor level medians for SSC. Table 10 lists p values for pair-wise analysis, comparing the control to each access with animals absent, and

Table 9. Differences in median SSC concentration, instantaneous SSC load differences, and associated sample sizes for CONT, AS, and TRAD reaches with and without animals present in the accesses at the Story Site under the FACT5 approach.

Story Site Factor Level Medians				
Reach	Animals Absent		Animals Present	
	Concentration Difference	Instantaneous Load Difference	Concentration Difference	Instantaneous Load Difference
SSC				
	mg l <sup>-1</sup>	kg day <sup>-1</sup>	mg l <sup>-1</sup>	kg day <sup>-1</sup>
CONT	1 (n=22)	5.8 (n=22)	NA	NA
AS	-2 (n=22)	-15.0 (n=22)	2 (n=17)	19.4 (n=17)
TRAD	2 (n=22)	20.3 (n=22)	11 (n=18)	128.2 (n=18)
<i>E. coli</i>				
	CFU (3 ml) <sup>-1</sup>	CFU day <sup>-1</sup>	CFU (3 ml) <sup>-1</sup>	CFU day <sup>-1</sup>
CONT	0 (n=22)	-2.0 E8 (n=22)	NA	NA
AS	0 (n=22)	2.0 E8 (n=22)	1 (n=17)	5.2 E9 (n=17)
TRAD	1 (n=22)	2.8 E9 (n=22)	3 (n=18)	1.2 E10 (n=18)
TKN				
	mg l <sup>-1</sup>	g day <sup>-1</sup>	mg l <sup>-1</sup>	g day <sup>-1</sup>
CONT	0.0 (n=7)	0 (n=7)	NA	NA
AS	0.0 (n=8)	0 (n=8)	0.0 (n=8)	0 (n=8)
TRAD	0.0 (n=7)	0 (n=7)	0.3 (n=9)	3819.3 (n=9)
NO <sub>3</sub>				
	mg l <sup>-1</sup>	g day <sup>-1</sup>	mg l <sup>-1</sup>	g day <sup>-1</sup>
CONT	-0.02 (n=10)	-254.1 (n=10)	NA	NA
AS	0.01 (n=11)	142.3 (n=11)	-0.01 (n=8)	-36.7 (n=8)
TRAD	-0.08 (n=10)	-758.6 (n=10)	0.00 (n=10)	24.6 (n=10)
TP				
	mg l <sup>-1</sup>	g day <sup>-1</sup>	mg l <sup>-1</sup>	g day <sup>-1</sup>
CONT	0.00 (n=7)	0 (n=7)	NA	NA
AS	0.00 (n=8)	0 (n=8)	0.00 (n=8)	0 (n=8)
TRAD	0.00 (n=7)	0 (n=7)	0.02 (n=9)	284.6 (n=9)
PO <sub>4</sub>				
	mg l <sup>-1</sup>	g day <sup>-1</sup>	mg l <sup>-1</sup>	g day <sup>-1</sup>
CONT	0.00 (n=10)	0 (n=10)	NA	NA
AS	0.00 (n=11)	0 (n=11)	0.00 (n=8)	0 (n=8)
TRAD	0.00 (n=10)	0 (n=10)	0.00 (n=10)	0 (n=10)

comparing animals present versus absent for each access. Neither access reach produced a median instantaneous SSC load difference significantly different from the control with animals absent. There was also no significant difference detected in SSC from the AS reach when animals were present versus animals absent. However, the SSC load difference from the TRAD access was significantly greater when animals were present than when animals were absent, but the MRPP test did not suggest this analysis was warranted, so these results must be interpreted cautiously.

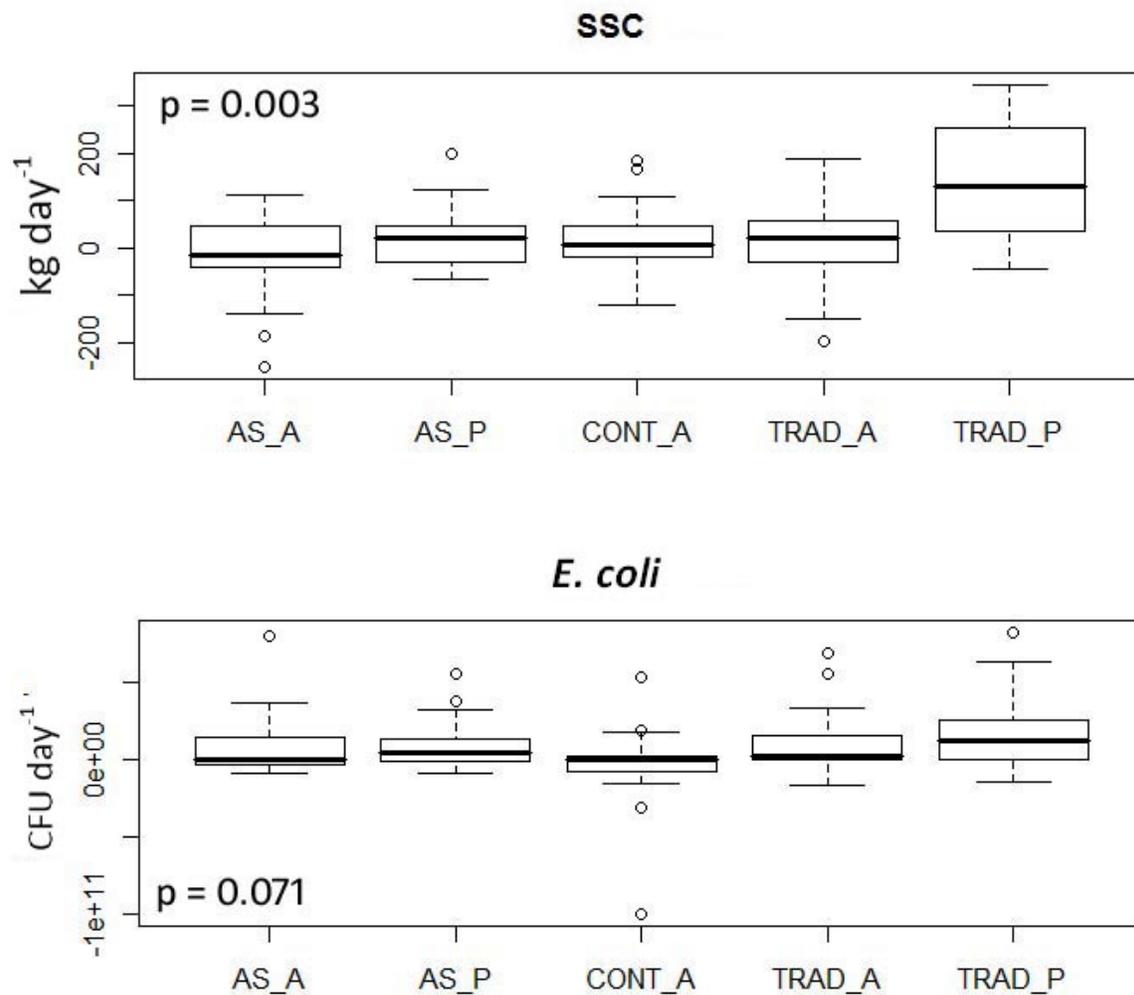


Figure 11. Box plots with Kruskal Wallis p values under the FACT5 approach (Story Site).

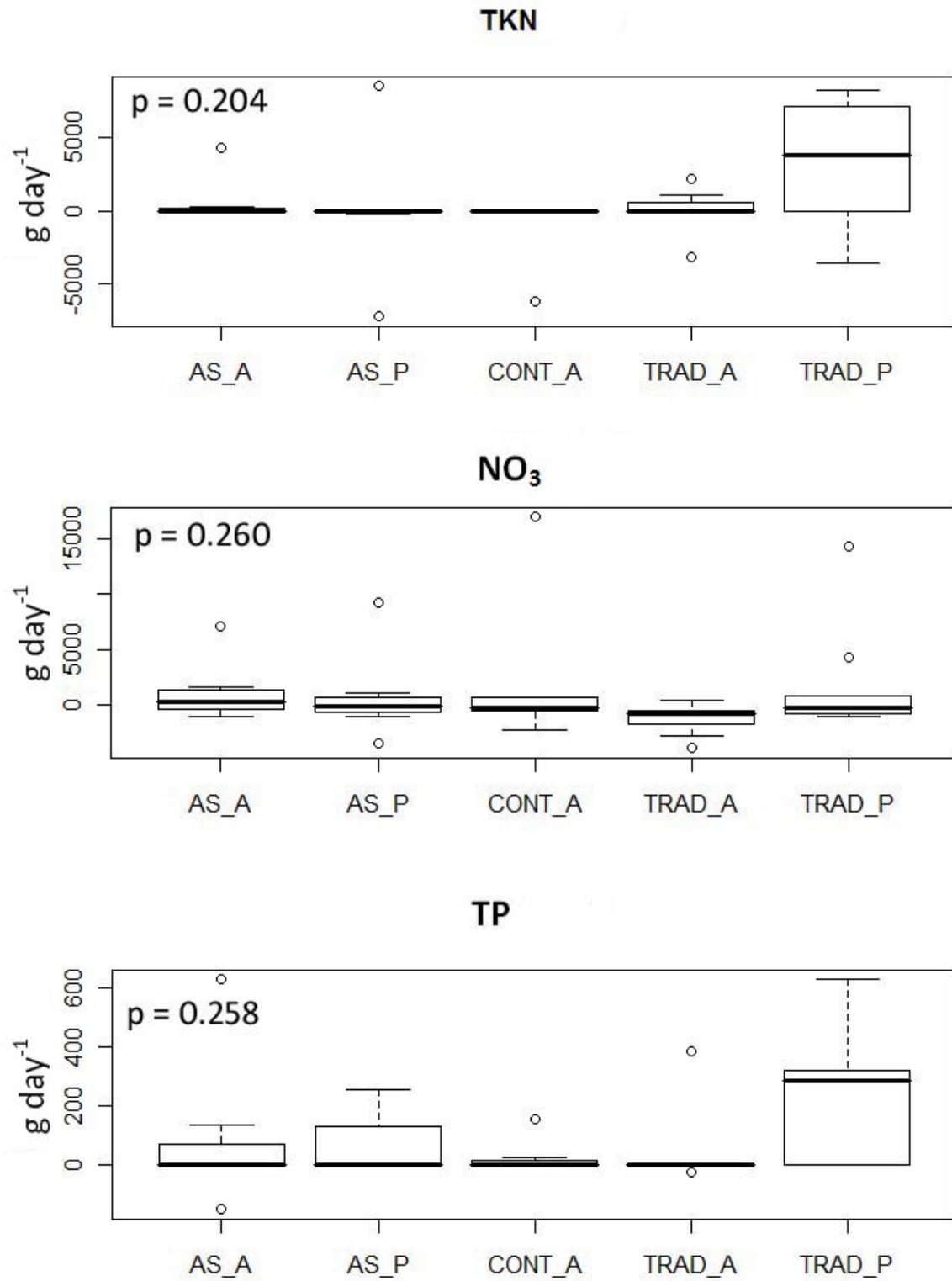


Figure 11. Continued.

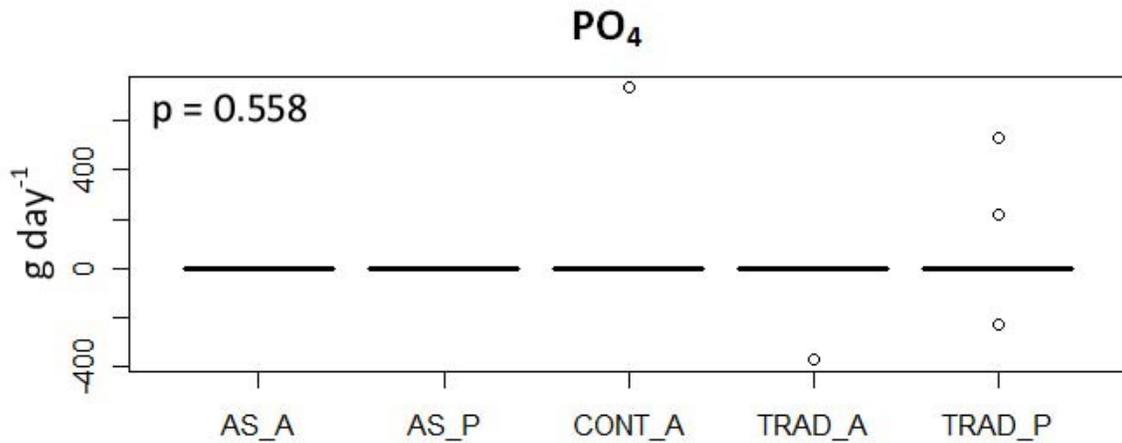


Figure 11. Continued.

Table 10. Estimated P values for four pairwise comparisons of factor level medians under the FACT5 approach (Story Site). P values are adjusted up by a factor of four according to the Bonferroni procedure for multiple comparisons. Values greater than one are reported as one. Only SSC is analyzed because the Kruskal Wallis test found no significant differences between medians for the other parameters. (\* indicates a significant difference at a 0.05 significance level)

Story Site	
Comparison	p values SSC
CONT_A ↔ AS_A	1
CONT_A ↔ TRAD_A	1
AS_A ↔ AS_P	1
TRAD_A ↔ TRAD_P	0.014*

## DISCUSSION

Considerations for Interpretation of Results

The goal of this project was to implement and evaluate the concept that simple infrastructure could preclude livestock from depositing feces in or directly adjacent to the stream and that this would result in reduced contaminant loading to surface water. The concept of preventing animals from fully entering or turning around in the stream was the fundamental concept being tested and it is anticipated that a variety of physical methods could be used to meet these needs at other future sites. The basic design of the AS access at the two study sites was the same, but the sites were distinct in terms of channel form, animal stocking numbers, and the TRAD access. These differences precluded using the sites as replicates, and necessitated independent analysis of results for each site. Comparison of box plots for the Thompson Site with box plots for the Story Site reveals more pronounced loading for the TRAD access with animals present at the Thompson Site. The Thompson Site produced significant loading differences for *E. coli*, TKN, and TP with animals present in the TRAD access versus with animals absent. The *E. coli* difference was significant even under the conservative FACT2 analysis approach. The Story Site, however, did not show significant differences between any factor levels for any parameter under either analysis approach. The more pronounced response for the TRAD access at the Thompson Site could be partially explained by the greater number of cattle using the access and the higher stocking rate for the TRAD access

pasture compared to the TRAD access pasture at the Story Site. A higher sustained stocking rate for March through June could have resulted in sufficient manure deposition adjacent to the stream to produce the significant contaminant load findings. The number of cattle using the Story TRAD access approached that for the Thompson TRAD access for the months of June through August, but the stocking rate was less than half that of the Thompson TRAD access pasture. Even when the data from the Story Site in August was analyzed separately, significant differences for *E. coli* and sediment were not detected among factor levels at the Story Site (analysis not presented). More pronounced differences for the Thompson TRAD access may be partially explained by the confinement of impacts to a 10 m section of stream, with the sample location five m downstream. This focused impact and relatively short travel distance provided little opportunity for contaminants to dissipate before downstream sampling occurred. At the Story Site, the TRAD access was 176 m long, with the sample site at the downstream end of the access. Under these conditions, water exposed to cattle activity traveled an average distance of 88 m through the reach before being sampled. A longer travel distance provides more opportunity for contaminants to be dispersed, to be retained in transient storage, or to settle out (Kazezyilmaz-Alhan, 2008). This would result in lower concentrations at the sample site, making differences more difficult to detect.

It is necessary to consider fecal loading from waterfowl within the study reaches. Advances were made in the field of microbial source tracking to facilitate distinction of feces from waterfowl versus cattle, while this study was in progress (Field, personal

communication, 2007(Field, 2007; Field and Samadpour, 2007). Future studies could employ these methods to help differentiate fecal contamination sources. For the current study, sample sites were located as closely above and below each reach as possible to help isolate loading from the accesses. During the study, waterfowl were observed almost exclusively between access reaches, rather than directly in cattle access reaches. It was hypothesized that waterfowl *E. coli* inputs were removed when differences between influent and effluent concentrations were calculated.

Another consideration for evaluation of *E. coli* impacts was the high propensity for bacteria to be stored in sediment (Stephenson, 1982). It was hypothesized that *E. coli* from upstream sources could accumulate in sediment and be resuspended when cattle entered an access. This would result in *E. coli* loading being attributed to a water access, although the *E. coli* may have actually come from an upstream land use. This potential was minimized by selecting pastures as close to the top of watersheds as possible. Additionally, at the Thompson Site, a one-time sampling event was conducted to quantify *E. coli* in bottom sediment. Sampling was conducted in the CONT reach and below the AS and TRAD accesses. Eight locations were randomly selected within slow water environments for each of the three reaches. Sediment in a half meter square area was agitated and samples of the overlying water column were immediately collected for *E. coli* analysis. The median *E. coli* value below the AS access was not significantly different from the *E. coli* value associated with the control reach ( $p = 0.447$ ). The median *E. coli* value for samples collected below the TRAD access was significantly greater than

the median *E. coli* value associated with the control reach ( $p = 0.001$ ). This investigation indicated that *E. coli* concentration in sediment did not become significantly elevated until below the TRAD access. This supports the assertion that impacts measured from the Thompson TRAD access were attributed to use of that access and not to upstream land uses.

#### Translating Findings to Overall Loading Values

While median differences for four of the six parameters were greater for the TRAD access at the Thompson Site with animals absent than the CONT reach, these differences were not significant. For this reason, calculations of overall contaminant load reductions from AS installation should be based on the portion of time animals actively used an access. Overall percentage of time accesses were occupied was not quantified in this study. Sheffield et al. (1997) reported that individual cattle spent approximately 6.5 minutes per day in the stream drinking. These findings are a reasonable estimate, based on observations at the Thompson Site. It is also reasonable to estimate that three animals used an access at a time on average. Assuming Thompson pasture 2 was stocked with 50 cattle, with animals accessing the water three at a time for 6.5 minutes per day, the access would be occupied for 108 minutes each day. This means the access is occupied for 7.5 percent of the time on an average day. Based on these estimates, the daily load attributed to animals using the TRAD access at

the Thompson Site was  $6.0 \text{ E9 CFU day}^{-1}$  of *E. coli*,  $425.9 \text{ g day}^{-1}$  of TKN, and  $53.1 \text{ g day}^{-1}$  of TP.

The nutrient load numbers calculated above were compared to values derived from statistics in the literature regarding livestock waste production and deposition. Adopting an intermediate value from the range reported by Gary et al. (1983), it was assumed that eight percent of feces from livestock with access to TRAD accesses was deposited directly into the stream. Assuming each of the 50 cows in the pasture weigh 500 kg each (approximately 1100 lbs), and excretion values reported by Nader et al. (1998), approximately 740 g TKN and 200 g TP would be deposited into the stream per day in a TRAD setting. These crude estimates are relatively close to the load values calculated from study results.

### Implications

Outbreaks of food and waterborne illness and devastating eutrophication effects in the Gulf of Mexico underline the importance of limiting transmission of animal fecal waste to surface water (Goolsby et al., 1999; Oliver et al., 2005). For comparison to water quality standards, the load values calculated from the study were converted back to concentrations averaged over a day. Assuming a consistent discharge of three cfs, concentration increases attributed to animals using the Thompson TRAD access were 82 CFU *E. coli* per 100 ml,  $0.058 \text{ mg l}^{-1}$  TKN, and  $0.0072 \text{ mg l}^{-1}$  TP. The Montana water quality standard for *E. coli* states that “from April 1 through October 31, the geometric

mean number of *E. coli* may not exceed 126 colony forming units per 100 milliliters and 10% of the total samples may not exceed 252 colony forming units per 100 milliliters during any 30-day period” (MTDEQ, 2006b). The calculated average *E. coli* concentration attributed to the Thompson TRAD access was 82 CFU per 100 ml, which is less than the standard. Considering potential for cumulative effects and that loading occurs primarily in the day time, concentrations could easily approach or exceed the standard. The MTDEQ has classified Thompson Creek as B-1 stream within the Level 3 Ecoregion-Middle Rockies (MTDEQ, 2008). Draft numeric nutrient standards for aquatic life in this region are 0.40 mg l<sup>-1</sup> for TKN and 0.02 mg l<sup>-1</sup> for TP. The calculated average concentration contribution from 50 animals using a TRAD access is approximately 25 percent of the standard given a discharge of three cfs. Again, considering potential for cumulative watershed land use effects and focus of loading during the day time, TRAD accesses could result in nutrient concentrations approaching or exceeding standards.

#### Considerations for Implementation of AS Accesses

This study revealed significant loading of *E. coli*, SSC, TKN, and TP associated with TRAD accesses with animals present, but detected no impacts from the AS accesses. However, evaluation of water quality effects during precipitation events was not conducted. Feces is deposited adjacent to the stream when cattle use the AS access. With precipitation leading to runoff, some contaminants from this waste could be

transported to the stream. For this reason, off-stream water developments may provide more protection to water quality resources during heavy precipitation.

Another consideration is the amount of fencing the AS requires to be installed adjacent to the stream. Risk to infrastructure from flooding is an important concern. An AS should not be installed on streams where dramatic changes in stream stage are expected. Thompson and Story Creeks are spring fed and have relatively stable stages. At the Story Site, a stage monitoring station approximately 120 meters downstream from the AS access measured a stage range of 35 cm between March 14<sup>th</sup> and December 7<sup>th</sup> 2007. The channel at the stage monitoring site was narrower than at the AS site, indicating that 35 cm was a conservative, over-estimate of stage change at the AS. At the Thompson Site, a stage monitoring station approximately 220 m upstream from the AS access measured a stage range of 18 cm between March 14<sup>th</sup> and December 7<sup>th</sup>. Again, the channel was narrower at the stage monitoring site than at the AS site, indicating that 18 cm was a conservative, over-estimate of stage change at the AS site. At the Thompson Site, no debris was observed on the panels over the stream, indicating that flow did not reach the infrastructure during 2007. At the Story Site, debris was observed on the panels over the stream. Debris was approximately 15 cm above the bottom of the panels. However, infrastructure was not damaged and problems with flow diversion were not observed. At each site, the flat portion of the stream approach was installed just above bankfull stage elevation to reduce interference with flow during high flow conditions.

Low stage conditions are also a consideration for installation of AS accesses. At sites with extensive stage fluctuation, low discharge could result in water not moving through the stanchions, depriving animals of water. For this reason, it is important to determine the likely changes in stage at a proposed installation location. Ideally, sites should experience less than 30 cm of stage change during the season animals will be using the AS. A relatively straight section of bank is also required for installation. The Thompson AS had an overall length of approximately 7.5 meters.

Potential formation of ice at the edges of the stream needs to be considered if animals will use the AS access for water in the winter. The spring fed streams utilized in this study remain free from ice for all but the coldest days in the winter.

Locations should be chosen which remain as dry as possible. Seepage from the bank at the Thompson AS site resulted in muddy conditions which complicated installation. The seepage also resulted in the surface remaining moist; this condition may have reduced the rate of pathogen desiccation and ammonia volatilization (Stewart, 1970).

The number of cattle to be accommodated simultaneously must be considered when designing an AS access. If stanchions are constructed with a 1.7 m internal width, two 500 kg (1100 lbs) cattle can access the water at the same time. The four stanchion access installed at the Thompson Site could accommodate up to eight animals simultaneously. The livestock producer at the Thompson Site thought this would be sufficient access for his herd of approximately 100 head of cattle. At the Thompson Site,

Black Angus bulls, cows, calves, and horses successfully used the AS access. At the Story Site, Horned Schottish highlander cattle and Black Angus cattle and calves successfully used the AS access.

## CONCLUSION

Contaminant loading associated with the AS access was not significantly greater than that from the control reach for any parameter with or without animals present.

Significant contaminant loading from the TRAD accesses was detected. This indicates that the AS access can effectively mitigate water quality impairment while allowing animals access to surface water. Sampling for this study, however, was not conducted during precipitation events. Surface grading was implemented to minimize potential for overland flow to enter the AS area from higher ground. However, there is a precipitation intensity which would produce overland flow on the AS surface. With overland flow, contaminants from feces deposited on the access would be transported to the stream. For this reason, the AS is presented as a surface water access improvement option, but off-stream water is recommended as a preferred first alternative.

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APPENDICES

APPENDIX A

RATING CURVES

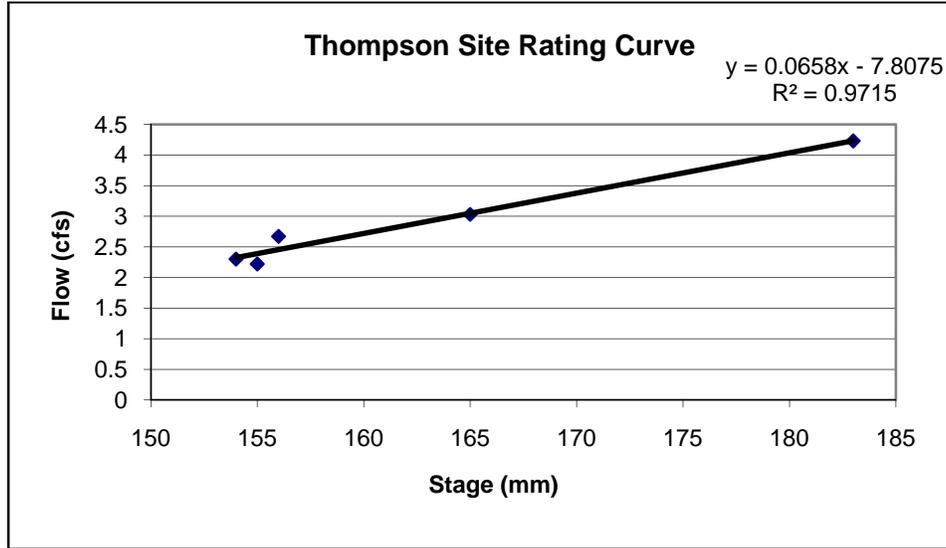


Figure 12. Rating curve for Thompson Creek.



Figure 13. Rating curve for Story Creek.

APPENDIX B

ALL DATA COLLECTED

Table 11. Thompson Site Raw Data

Site	Animal	Sample ID	Date	Flow $\text{ft}^3 \text{ s}^{-1}$	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC $\text{mg l}^{-1}$	TKN $\text{mg l}^{-1}$	TP $\text{mg l}^{-1}$	NO <sub>3</sub> $\text{mg l}^{-1}$	PO <sub>4</sub> $\text{mg l}^{-1}$
T1	A	3_7_T1_1	3/7/2007	-	2	2	1	2	115	-	-	1.30	2.00
T7	A	3_7_T7_1	3/7/2007	-	3	1	6	3	72	-	-	1.40	1.70
T1	A	4_6_T1_1	4/6/2007	2.67	1	0	0	0	24	-	-	3.90	0.07
T2	A	4_6_T2_1	4/6/2007	2.67	0	0	0	0	11	-	-	3.60	0.05
T3	A	4_6_T3_1	4/6/2007	2.67	0	1	0	0	2	-	-	3.60	0.06
T4	A	4_6_T4_1	4/6/2007	2.67	0	0	0	0	16	-	-	3.40	0.06
T5	A	4_6_T5_1	4/6/2007	2.67	0	0	0	0	14	-	-	3.40	0.05
T6	A	4_6_T6_1	4/6/2007	2.67	2	0	0	1	17	-	-	3.50	0.06
T7	A	4_6_T7_1	4/6/2007	2.67	2	1	1	1	20	-	-	3.50	0.07
T4	A	4_6_T4_2	4/6/2007	2.67	2	2	0	1	8	-	-	3.40	0.05
T5	P	4_6_T5_2	4/6/2007	2.67	6	57	110	58	73	-	-	3.40	0.07
T1	A	4_9_T1_1	4/9/2007	2.49*	21	31	27	26	32	-	-	2.90	0.03
T2	A	4_9_T2_1	4/9/2007	2.49*	12	11	16	13	37	-	-	2.80	0.03
T3	A	4_9_T3_1	4/9/2007	2.49*	13	11	21	15	24	-	-	2.80	0.04
T4	A	4_9_T4_1	4/9/2007	2.49*	11	16	16	14	25	-	-	2.80	0.04
T5	A	4_9_T5_1	4/9/2007	2.49*	11	6	16	11	23	-	-	2.80	0.04
T6	A	4_9_T6_1	4/9/2007	2.49*	14	11	21	15	11	-	-	2.80	0.04
T7	A	4_9_T7_1	4/9/2007	2.49*	70	101	49	73	18	-	-	2.80	0.04
T2	A	4_13_T2_1	4/13/2007	2.30	0	0	0	0	9	0.6	0.04	2.20	0.06
T3	P	4_13_T3_1	4/13/2007	2.30	0	0	0	0	4	0.0	0.04	2.10	0.03
T4	A	4_13_T4_1	4/13/2007	2.30	0	0	0	0	8	0.0	0.05	2.80	0.03
T5	P	4_13_T5_1	4/13/2007	2.30	0	43	1	15	57	0.8	0.12	2.80	0.03
T2	A	4_13_T2_2	4/13/2007	2.30	0	0	0	0	15	-	-	-	-
T3	P	4_13_T3_2	4/13/2007	2.30	0	0	0	0	14	-	-	-	-
T4	A	4_13_T4_2	4/13/2007	2.30	0	0	1	0	5	-	-	-	-
T5	P	4_13_T5_2	4/13/2007	2.30	5	25	102	44	36	-	-	-	-
T2	A	4_16_T2_1	4/16/2007	2.25*	0	0	0	0	29	0.6	0.06	1.90	0.00
T3	P	4_16_T3_1	4/16/2007	2.25*	1	0	0	0	22	0.6	0.05	1.80	0.02
T4	A	4_16_T4_1	4/16/2007	2.25*	1	0	3	1	26	0.5	0.05	1.90	0.00
T5	P	4_16_T5_1	4/16/2007	2.25*	107	121	197	142	110	1.5	0.22	1.90	0.08

Table 11. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
T1	A	4_16_T1_2	4/16/2007	2.25*	0	0	0	0	42	0.8	0.06	1.80	0.02
T2	A	4_16_T2_2	4/16/2007	2.25*	1	0	2	1	24	0.7	0.05	1.60	0.03
T3	A	4_16_T3_2	4/16/2007	2.25*	0	0	0	0	27	0.6	0.05	1.60	0.03
T4	A	4_16_T4_2	4/16/2007	2.25*	0	1	1	1	18	0.5	0.05	1.50	0.03
T5	A	4_16_T5_2	4/16/2007	2.25*	28	11	1	13	38	0.6	0.05	1.40	0.04
T6	A	4_16_T6_2	4/16/2007	2.25*	14	2	11	9	32	0.5	0.05	1.40	0.03
T7	A	4_16_T7_2	4/16/2007	2.25*	21	28	25	25	31	0.6	0.05	1.50	0.04
T2	A	4_25_T2_1	4/25/2007	2.40*	0	0	1	0	9	-	-	-	-
T3	P	4_25_T3_1	4/25/2007	2.40*	0	0	5	2	7	-	-	-	-
T4	A	4_25_T4_1	4/25/2007	2.40*	0	1	1	1	1	-	-	-	-
T5	P	4_25_T5_1	4/25/2007	2.40*	1090	107	-	599	60	-	-	-	-
T2	A	4_29_T2_1	4/29/2007	2.22	1	0	0	0	14	-	-	-	-
T3	A	4_29_T3_1	4/29/2007	2.22	0	0	7	2	10	-	-	-	-
T4	A	4_29_T4_1	4/29/2007	2.22	0	3	0	1	10	-	-	-	-
T5	A	4_29_T5_1	4/29/2007	2.22	4	0	3	2	19	-	-	-	-
T2	A	4_29_T2_2	4/29/2007	2.22	0	1	2	1	18	-	-	-	-
T3	P	4_29_T3_2	4/29/2007	2.22	0	9	165	58	23	-	-	-	-
T4	A	4_29_T4_2	4/29/2007	2.22	0	1	2	1	11	-	-	-	-
T5	P	4_29_T5_2	4/29/2007	2.22	21	48	84	51	19	-	-	-	-
T7	A	4_29_T7_1	4/29/2007	2.22	5	4	-	5	-	-	-	-	-
T2	A	5_2_T2_1	5/2/2007	2.39*	2	0	1	1	8	0.0	0.05	1.30	0.01
T3	P	5_2_T3_1	5/2/2007	2.39*	0	1	2	1	-	-	-	-	-
T4	A	5_2_T4_1	5/2/2007	2.39*	0	1	2	1	5	0.0	0.05	1.60	0.00
T5	P	5_2_T5_1	5/2/2007	2.39*	1097	920	875	964	51	1.0	0.16	1.60	0.75
T1	A	5_2_T1_2	5/2/2007	2.39*	1	1	0	1	5	0.0	0.05	1.70	0.00
T2	A	5_2_T2_2	5/2/2007	2.39*	0	0	0	0	10	0.0	0.05	1.50	0.10
T3	A	5_2_T3_2	5/2/2007	2.39*	0	0	1	0	2	0.0	0.05	1.50	0.12
T4	A	5_2_T4_2	5/2/2007	2.39*	3	4	2	3	8	0.0	0.05	1.50	0.00
T5	A	5_2_T5_2	5/2/2007	2.39*	9	65	59	44	8	0.0	0.04	2.30	0.15
T7	A	5_2_T7_2	5/2/2007	2.39*	3	10	12	8	15	0.0	0.05	1.50	0.02
T2	A	5_2_T2_3	5/2/2007	2.39*	2	0	1	1	8	0.0	0.05	1.30	0.01
T3	P	5_2_T3_3	5/2/2007	2.39*	1	0	0	0	5	0.0	0.05	1.20	0.00

Table 11. Continued

Site	Animal	Sample ID	Date	Flow $\text{ft}^3 \text{ s}^{-1}$	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC $\text{mg l}^{-1}$	TKN $\text{mg l}^{-1}$	TP $\text{mg l}^{-1}$	NO <sub>3</sub> $\text{mg l}^{-1}$	PO <sub>4</sub> $\text{mg l}^{-1}$
T1	A	5_8_T1_1	5/8/2007	2.44*	0	1	1	1	10	-	-	-	-
T2	A	5_8_T2_1	5/8/2007	2.44*	0	0	1	0	11	-	-	-	-
T3	A	5_8_T3_1	5/8/2007	2.44*	1	2	0	1	12	-	-	-	-
T4	A	5_8_T4_1	5/8/2007	2.44*	1	0	0	0	22	-	-	-	-
T5	P	5_8_T5_1	5/8/2007	2.44*	62	88	9	53	29	-	-	-	-
T2	A	5_8_T2_2	5/8/2007	2.44*	0	0	0	0	14	-	-	-	-
T3	P	5_8_T3_2	5/8/2007	2.44*	0	0	2	1	8	-	-	-	-
T4	A	5_8_T4_2	5/8/2007	2.44*	0	1	0	0	13	0.6	0.05	1.90	0.02
T5	A	5_8_T5_2	5/8/2007	2.44*	8	8	1	6	12	0.0	0.04	1.90	0.01
T5	P	5_8_T5_3	5/8/2007	2.44*	36	15	40	30	31	1.0	0.16	1.80	0.09
T1	A	5_20_T1_1	5/20/2007	3.03	9	8	8	8	47	0.5	0.05	3.10	0.02
T2	A	5_20_T2_1	5/20/2007	3.03	5	7	10	7	24	0.6	0.06	3.00	0.02
T3	A	5_20_T3_1	5/20/2007	3.03	19	15	18	17	28	0.8	0.08	3.00	0.00
T4	A	5_20_T4_1	5/20/2007	3.03	9	14	8	10	22	0.6	0.06	3.60	0.14
T5	A	5_20_T5_1	5/20/2007	3.03	22	20	12	18	29	0.5	0.05	3.30	0.13
T2	A	5_20_T2_2	5/20/2007	3.03	8	3	8	6	29	0.5	0.07	2.70	0.02
T3	P	5_20_T3_2	5/20/2007	3.03	7	3	0	3	34	0.5	0.06	2.70	0.01
T4	A	5_20_T4_2	5/20/2007	3.03	10	8	5	8	20	0.6	0.04	2.90	0.02
T5	P	5_20_T5_2	5/20/2007	3.03	17	103	10	43	33	0.6	0.06	2.90	0.03
T5	P	5_20_T5_3	5/20/2007	3.03	10	59	38	36	50	6.1	0.17	3.90	0.10
T1	A	5_30_T1_1	5/30/2007	4.23	1	2	1	1	35	-	-	-	-
T2	A	5_30_T2_1	5/30/2007	4.23	4	5	7	5	49	-	-	-	-
T3	A	5_30_T3_1	5/30/2007	4.23	4	5	0	3	39	-	-	-	-
T4	A	5_30_T4_1	5/30/2007	4.23	5	0	3	3	30	-	-	-	-
T5	A	5_30_T5_1	5/30/2007	4.23	22	4	2	9	33	-	-	-	-
T2	A	5_30_T2_2	5/30/2007	4.23	0	0	0	0	26	-	-	-	-
T3	P	5_30_T3_2	5/30/2007	4.23	1	1	0	1	27	-	-	-	-
T4	A	5_30_T4_2	5/30/2007	4.23	0	0	1	0	27	-	-	-	-
T5	P	5_30_T5_2	5/30/2007	4.23	9	1	1	4	32	-	-	-	-

Table 11. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
P/A													
T1	A	6_16_T1_1	6/16/2007	5.19*	31	27	35	31	12	0.0	0.05	3.29	0.00
T2	A	6_16_T2_1	6/16/2007	5.19*	34	39	33	35	47	0.0	0.08	3.11	0.00
T3	A	6_16_T3_1	6/16/2007	5.19*	48	31	34	38	24	0.0	0.07	2.98	0.00
T4	A	6_16_T4_1	6/16/2007	5.19*	39	31	26	32	37	0.0	0.07	3.08	0.00
T5	A	6_16_T5_1	6/16/2007	5.19*	70	41	32	48	50	0.0	0.09	2.98	0.00
T2	A	6_16_T2_2	6/16/2007	5.19*	11	9	8	9	10	0.0	0.04	2.80	0.00
T3	P	6_16_T3_2	6/16/2007	5.19*	4	9	10	8	9	0.0	0.05	2.83	0.00
T4	A	6_16_T4_2	6/16/2007	5.19*	13	6	8	9	11	0.0	0.05	2.87	0.00
T5	P	6_16_T5_2	6/16/2007	5.19*	46	116	29	64	58	0.7	0.10	2.94	0.00
T5	P	6_16_T5_3	6/16/2007	5.19*	26	111	32	56	32	0.8	0.12	2.97	0.06
T1	A	6_18_T1_1	6/18/2007	5.40*	23	28	23	25	4	-	-	-	-
T2	A	6_18_T2_1	6/18/2007	5.40*	15	19	21	18	16	-	-	-	-
T3	A	6_18_T3_1	6/18/2007	5.40*	8	16	14	13	29	-	-	-	-
T4	A	6_18_T4_1	6/18/2007	5.40*	4	19	13	12	15	-	-	-	-
T5	A	6_18_T5_1	6/18/2007	5.40*	22	18	16	19	20	-	-	-	-
T2	A	6_18_T2_2	6/18/2007	5.40*	24	16	22	21	12	-	-	-	-
T3	P	6_18_T3_2	6/18/2007	5.40*	10	6	15	10	11	-	-	-	-
T4	A	6_18_T4_2	6/18/2007	5.40*	3	6	3	4	16	-	-	-	-
T5	P	6_18_T5_2	6/18/2007	5.40*	6	5	3	5	14	-	-	-	-

\* = Flows estimated from rating curve

SSC = Suspended Sediment Concentration

TKN = Total Kjeldahl Nitrogen

TP = Total Phosphorus

Table 12. Story Site Raw Data

Site	Animal	Sample ID	Date	Flow $\text{ft}^3 \text{ s}^{-1}$	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	3_07_S1_1	3/7/2007	-	0	2	-	1	17	-	-	5.00	0.10
S2	A	3_07_S2_1	3/7/2007	-	2	5	-	4	17	-	-	5.10	0.10
S3	A	3_07_S3_1	3/7/2007	-	5	3	-	4	9	-	-	5.10	0.10
S4	A	3_07_S4_1	3/7/2007	-	3	4	-	4	16	-	-	5.10	0.10
S5	A	3_07_S5_1	3/7/2007	-	0	0	-	0	19	-	-	5.10	0.10
S6	A	3_07_S6_1	3/7/2007	-	0	0	-	0	12	-	-	5.14***	0.07
S1	A	3_16_S1_1	3/16/2007	3.44	1	0	0	0	24	-	-	6.00	0.10
S2	A	3_16_S2_1	3/16/2007	3.44	0	0	0	0	15	-	-	5.90	0.10
S3	A	3_16_S3_1	3/16/2007	3.44	0	0	1	0	9	-	-	5.80	0.10
S4	A	3_16_S4_1	3/16/2007	3.44	1	1	0	1	14	-	-	5.90	0.10
S5	A	3_16_S5_1	3/16/2007	3.44	0	0	0	0	11	-	-	5.80	0.00
S6	A	3_16_S6_1	3/16/2007	3.44	0	0	1	0	7	-	-	4.60	0.00
S1	A	3_16_S1_2	3/16/2007	3.44	0	0	0	0	4	-	-	1.90	0.00
S2	A	3_16_S2_2	3/16/2007	3.44	0	0	0	0	4	-	-	1.90	0.00
S3	A	3_16_S3_2	3/16/2007	3.44	0	0	0	0	13	-	-	1.80	0.00
S4	A	3_16_S4_2	3/16/2007	3.44	0	0	0	0	17	-	-	1.50	0.00
S5	A	3_16_S5_2	3/16/2007	3.44	0	0	0	0	5	-	-	1.30	0.00
S6	P	3_16_S6_2	3/16/2007	3.44	2	0	1	1	27	-	-	5.50***	0.00
S1	A	3_21_S1_1	3/21/2007	3.00*	0	0	0	0	16	0.0	0.04	1.30	0.00
S2	A	3_21_S2_1	3/21/2007	3.00*	0	0	0	0	14	0.0	0.04	5.90	0.10
S3	A	3_21_S3_1	3/21/2007	3.00*	0	0	0	0	18	0.0	0.04	5.90	0.10
S4	P	3_21_S4_1	3/21/2007	3.00*	0	0	1	0	12	0.0	0.04	5.90	0.10
S5	A	3_21_S5_1	3/21/2007	3.00*	0	0	0	0	19	0.0	0.04	5.90	0.10
S6	A	3_21_S6_1	3/21/2007	3.00*	0	0	0	0	26	0.0	0.05	5.80	0.10
S1	A	3_21_S1_2	3/21/2007	3.00*	0	0	0	0	13	0.0	0.04	5.80	0.00
S2	A	3_21_S2_2	3/21/2007	3.00*	0	0	0	0	16	0.6	0.04	5.80	0.10
S3	A	3_21_S3_2	3/21/2007	3.00*	0	0	0	0	14	0.7	0.04	5.80	0.10
S4	A	3_21_S4_2	3/21/2007	3.00*	0	0	0	0	21	0.0	0.04	5.80	0.10
S5	A	3_21_S5_2	3/21/2007	3.00*	0	0	0	0	7	0.0	0.04	5.80	0.10
S6	A	3_21_S6_2	3/21/2007	3.00*	0	0	0	0	10	0.6	0.03	5.70	0.10

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	3_30_S1_1	3/30/2007	3.13	5	7	7	6	18	-	-	7.20	0.02
S2	A	3_30_S2_1	3/30/2007	3.13	9	3	7	6	12	-	-	7.10	0.02
S3	A	3_30_S3_1	3/30/2007	3.13	4	7	5	5	12	-	-	7.20	0.03
S4	A	3_30_S4_1	3/30/2007	3.13	5	4	4	4	10	-	-	7.10	0.02
S5	A	3_30_S5_1	3/30/2007	3.13	8	3	5	5	8	-	-	7.10	0.02
S6	A	3_30_S6_1	3/30/2007	3.13	3	0	0	1	12	-	-	7.20	0.02
S3	A	3_30_S3_2	3/30/2007	3.13	8	4	2	5	13	0.0	0.04	7.20	0.02
S4	P	3_30_S4_2	3/30/2007	3.13	3	9	6	6	9	0.0	0.04	7.20	0.02
S5	A	3_30_S5_2	3/30/2007	3.13	2	3	4	3	9	0.0	0.04	7.10	0.05
S6	P	3_30_S6_2	3/30/2007	3.13	1	4	1	2	15	0.0	0.04	7.00	0.02
S1	A	4_09_S1_1	4/9/2007	3.36*	3	2	2	2	4	-	-	6.70	0.01
S2	A	4_09_S2_1	4/9/2007	3.36*	3	3	3	3	7	-	-	6.70	0.01
S3	A	4_09_S3_1	4/9/2007	3.36*	2	2	2	2	2	-	-	6.60	0.01
S4	A	4_09_S4_1	4/9/2007	3.36*	2	2	4	3	6	-	-	6.60	0.00
S5	A	4_09_S5_1	4/9/2007	3.36*	6	3	1	3	4	-	-	6.70	0.03
S6	A	4_09_S6_1	4/9/2007	3.36*	6	3	3	4	11	-	-	6.50	0.01
S2	A	4_14_S2_1	4/14/2007	2.96*	0	0	0	0	18	0.0	0.03	5.82***	0.00
S3	P	4_14_S3_1	4/14/2007	2.96*	0	0	0	0	11	0.0	0.03	7.10	0.00
S3	A	4_14_S3_2	4/14/2007	2.96*	0	3	0	1	11	0.6	0.03	6.80	0.00
S4	P	4_14_S4_2	4/14/2007	2.96*	3	0	0	1	9	0.6	0.03	6.80	0.00
S5	A	4_14_S5_1	4/14/2007	2.96*	0	1	1	1	7	0.5	0.03	6.70	0.00
S6	P	4_14_S6_1	4/14/2007	2.96*	0	1	2	1	12	0.0	0.03	6.60	0.00
S1	A	4_20_S1_1	4/20/2007	3.22*	0	0	0	0	14	-	-	-	-
S2	A	4_20_S2_1	4/20/2007	3.22*	0	0	1	0	15	-	-	-	-
S3	A	4_20_S3_1	4/20/2007	3.22*	1	0	0	0	10	-	-	-	-
S4	A	4_20_S4_1	4/20/2007	3.22*	0	0	0	0	14	-	-	-	-
S5	A	4_20_S5_1	4/20/2007	3.22*	0	1	1	1	10	-	-	-	-
S6	A	4_20_S6_1	4/20/2007	3.22*	0	1	0	0	8	-	-	-	-

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S2	A	4_25_S2_1	4/25/2007	2.84*	0	0	0	0	19	0.0	0.03	4.66	0.00
S3	P	4_25_S3_1	4/25/2007	2.84*	0	0	0	0	16	0.0	0.03	4.62	0.00
S5	A	4_25_S5_1	4/25/2007	2.84*	0	0	0	0	18	0.5	0.03	4.55	0.00
S6	P	4_25_S6_1	4/25/2007	2.84*	0	0	0	0	22	1.4	0.03	4.48	0.00
S2	A	4_25_S2_2	4/25/2007	2.84*	0	0	0	0	18	-	-	-	-
S3	P	4_25_S3_2	4/25/2007	2.84*	0	0	0	0	12	-	-	-	-
S5	A	4_25_S5_2	4/25/2007	2.84*	1	0	0	0	12	-	-	-	-
S6	P	4_25_S6_2	4/25/2007	2.84*	1	1	0	1	27	-	-	-	-
S3	A	4_25_S3_3	4/25/2007	2.84*	0	1	1	1	19	0.0	0.03	4.54	0.00
S4	P	4_25_S4_3	4/25/2007	2.84*	0	1	0	0	11	0.0	0.03	4.53	0.00
S5	A	4_25_S5_3	4/25/2007	2.84*	1	0	0	0	12	-	-	-	-
S6	P	4_25_S6_3	4/25/2007	2.84*	0	0	0	0	27	-	-	-	-
S2	A	5_8_S2_2	5/8/2007	2.37*	4	5	4	4	17	-	-	-	-
S3	P	5_8_S3_2	5/8/2007	2.37*	0	2	1	1	22	-	-	-	-
S3	A	5_8_S3_1	5/8/2007	2.37*	5	0	0	2	18	-	-	-	-
S4	P	5_8_S4_1	5/8/2007	2.37*	1	1	1	1	16	-	-	-	-
S5	A	5_8_S5_1	5/8/2007	2.37*	2	0	2	1	2	-	-	-	-
S6	P	5_8_S6_1	5/8/2007	2.37*	6	7	3	5	48	-	-	-	-
S1	A	5_17_S1_1	5/17/2007	1.77	9	12	7	9	0	0.5	0.03	6.00	0.00
S2	A	5_17_S2_1	5/17/2007	1.77	12	18	8	13	0	0.5	0.04	5.20	0.00
S3	A	5_17_S3_1	5/17/2007	1.77	12	5	7	8	11	0.6	0.09	5.80	0.00
S4	A	5_17_S4_1	5/17/2007	1.77	1	8	9	6	5	0.0	0.03	6.10	0.04
S5	A	5_17_S5_1	5/17/2007	1.77	9	7	11	9	2	1.2	0.04	6.40	0.16
S6	A	5_17_S6_1	5/17/2007	1.77	24	8	4	12	7	0.0	0.03	5.40	0.02
S2	A	5_17_S2_2	5/17/2007	1.77	1	2	2	2	5	0.6	0.04	5.30	0.00
S3	P	5_17_S3_2	5/17/2007	1.77	3	1	2	2	11	0.5	0.04	5.70	0.00
S5	A	5_17_S5_2	5/17/2007	1.77	2	2	1	2	0	0.5	0.04	5.70	0.00
S6	P	5_17_S6_2	5/17/2007	1.77	125	57	101	94	95	3.4	0.22	6.00	0.08

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	6_8_S1_1	6/8/2007	6.39*	18	13	14	15	10	0.0	0.03	2.99	0.00
S2	A	6_8_S2_1	6/8/2007	6.39*	9	7	11	9	13	0.0	0.03	3.04	0.00
S3	A	6_8_S3_1	6/8/2007	6.39*	17	17	14	16	-3	0.0	0.07	3.11	0.00
S5	A	6_8_S5_1	6/8/2007	6.39*	9	18	14	14	5	0.0	0.04	3.05	0.00
S6	A	6_8_S6_1	6/8/2007	6.39*	20	14	12	15	16	0.0	0.04	3.00	0.00
S2	A	6_8_S2_2	6/8/2007	6.39*	2	1	0	1	8	0.0	0.03	3.05	0.00
S3	P	6_8_S3_2	6/8/2007	6.39*	1	1	7	3	5	0.0	0.04	2.99	0.00
S5	A	6_8_S5_2	6/8/2007	6.39*	5	6	2	4	12	0.0	0.04	3.12	0.00
S6	P	6_8_S6_2	6/8/2007	6.39*	3	2	5	3	28	0.0	0.08	3.40	0.00
S1	A	6_11_S1_1	6/11/2007	7.68	5	9	6	7	18	-	-	-	-
S2	A	6_11_S2_1	6/11/2007	7.68	4	4	8	5	18	-	-	-	-
S3	A	6_11_S3_1	6/11/2007	7.68	6	10	8	8	21	-	-	-	-
S5	A	6_11_S5_1	6/11/2007	7.68	8	12	12	11	17	-	-	-	-
S6	A	6_11_S6_1	6/11/2007	7.68	10	14	8	11	29	-	-	-	-
S2	A	6_11_S2_2	6/11/2007	7.68	11	13	7	10	22	-	-	-	-
S3	P	6_11_S3_2	6/11/2007	7.68	14	11	9	11	30	-	-	-	-
S5	A	6_11_S5_2	6/11/2007	7.68	9	11	10	10	23	-	-	-	-
S6	P	6_11_S6_2	6/11/2007	7.68	16	15	10	14	35	-	-	-	-
S1	A	6_15_S1_1	6/15/2007	5.20*	8	6	8	7	-2	0.0	0.03	2.49	0.00
S2	A	6_15_S2_1	6/15/2007	5.20*	8	11	16	12	-2	0.0	0.03	2.54	0.00
S3	A	6_15_S3_1	6/15/2007	5.20*	14	10	10	11	-4	0.0	0.03	2.49	0.00
S5	A	6_15_S5_1	6/15/2007	5.20*	15	12	9	12	3	0.0	0.03	2.52	0.00
S6	A	6_15_S6_1	6/15/2007	5.20*	31	24	30	28	5	0.0	0.06	2.48	0.00
S2	A	6_15_S2_2	6/15/2007	5.20*	8	11	3	7	8	0.0	0.02	2.47	0.00
S3	P	6_15_S3_2	6/15/2007	5.20*	3	8	10	7	3	0.0	0.04	2.51	0.00
S5	A	6_15_S5_2	6/15/2007	5.20*	16	17	4	12	7	0.0	0.03	2.46	0.00
S6	P	6_15_S6_2	6/15/2007	5.20*	17	26	11	18	13	0.0	0.04	2.44	0.00
S6	P	6_15_S6_3	6/15/2007	5.20*	25	13	20	19	55	0.6	0.07	2.44	0.00

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	6_18_S1_1	6/18/2007	7.49*	7	5	7	6	4	-	-	-	-
S2	A	6_18_S2_1	6/18/2007	7.49*	4	6	8	6	13	-	-	-	-
S3	A	6_18_S3_1	6/18/2007	7.49*	7	4	8	6	7	-	-	-	-
S5	A	6_18_S5_1	6/18/2007	7.49*	7	7	5	6	9	-	-	-	-
S6	A	6_18_S6_1	6/18/2007	7.49*	5	8	14	9	15	-	-	-	-
S2	A	6_18_S2_2	6/18/2007	7.49*	6	11	12	10	10	-	-	-	-
S3	P	6_18_S3_2	6/18/2007	7.49*	9	10	8	9	12	-	-	-	-
S5**	A	6_18_S5_2	6/18/2007	7.49*	26	25	29	27	44	-	-	-	-
S6**	A	6_18_S6_2	6/18/2007	7.49*	20	23	22	22	57	-	-	-	-
S2**	A	6_18_S2_3	6/18/2007	7.49*	11	14	15	13	23	-	-	-	-
S3**	A	6_18_S3_3	6/18/2007	7.49*	28	42	44	38	19	-	-	-	-
S5**	A	6_18_S5_3	6/18/2007	7.49*	4	10	3	6	13	-	-	-	-
S6**	A	6_18_S6_3	6/18/2007	7.49*	16	13	13	14	40	-	-	-	-
S1	A	7_1_S1_1	7/1/2007	6.21*	10	17	9	12	9	0.0	0.03	2.48	0.00
S2	A	7_1_S2_1	7/1/2007	6.21*	9	11	11	10	21	0.0	0.04	2.45	0.00
S3	A	7_1_S3_1	7/1/2007	6.21*	16	7	17	13	12	0.0	0.03	2.48	0.00
S5	A	7_1_S5_1	7/1/2007	6.21*	6	19	18	14	14	0.0	0.03	2.48	0.00
S6	A	7_1_S6_1	7/1/2007	6.21*	24	14	24	21	15	0.0	0.03	2.46	0.00
S2	A	7_1_S2_2	7/1/2007	6.21*	8	9	11	9	10	0.0	0.03	1.94	0.00
S3	P	7_1_S3_2	7/1/2007	6.21*	14	14	16	15	12	0.0	0.03	1.95	0.00
S5	A	7_1_S5_2	7/1/2007	6.21*	13	16	11	13	5	0.7	0.04	1.98	0.00
S6	P	7_1_S6_2	7/1/2007	6.21*	21	18	23	21	21	0.5	0.07	1.95	0.07
S6	P	7_1_S6_3	7/1/2007	6.21*	28	26	19	24	25	0.9	0.05	2.05	0.00
S1	A	7_2_S1_1	7/2/2007	6.19*	17	11	17	15	1	-	-	-	-
S2	A	7_2_S2_1	7/2/2007	6.19*	21	38	18	26	6	-	-	-	-
S3	A	7_2_S3_1	7/2/2007	6.19*	28	34	35	32	10	-	-	-	-
S5	A	7_2_S5_1	7/2/2007	6.19*	21	19	22	21	17	-	-	-	-
S6	A	7_2_S6_1	7/2/2007	6.19*	20	22	21	21	4	-	-	-	-
S2	A	7_2_S2_2	7/2/2007	6.19*	11	20	14	15	6	-	-	-	-
S3	P	7_2_S3_2	7/2/2007	6.19*	15	21	17	18	12	-	-	-	-
S5	A	7_2_S5_2	7/2/2007	6.19*	17	16	19	17	6	-	-	-	-
S6	P	7_2_S6_2	7/2/2007	6.19*	22	26	18	22	24	-	-	-	-
S3	P	7_2_S3_3	7/2/2007	6.19*	28	34	14	25	11	-	-	-	-

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	7_4_S1_1	7/4/2007	5.81*	5	13	7	8	-2	0.0	0.03	1.96	0.00
S2	A	7_4_S2_1	7/4/2007	5.81*	10	12	15	12	2	0.0	0.03	1.95	0.00
S3	A	7_4_S3_1	7/4/2007	5.81*	19	17	15	17	-11	0.0	0.03	1.96	0.00
S5	A	7_4_S5_1	7/4/2007	5.81*	11	11	12	11	7	0.0	0.03	1.09	0.00
S6	A	7_4_S6_1	7/4/2007	5.81*	15	10	7	11	9	0.0	0.03	0.82	0.00
S2	A	7_4_S2_2	7/4/2007	5.81*	13	9	10	11	-14	0.0	0.03	1.97	0.00
S3	P	7_4_S3_2	7/4/2007	5.81*	22	21	13	19	0	0.6	0.03	1.95	0.00
S5	A	7_4_S5_2	7/4/2007	5.81*	8	12	12	11	7	0.0	0.03	1.05	0.00
S6	P	7_4_S6_2	7/4/2007	5.81*	17	7	14	13	4	0.5	0.05	0.98	0.00
S1	A	7_6_S1_1	7/6/2007	5.97	11	8	14	11	7	-	-	-	-
S2	A	7_6_S2_1	7/6/2007	5.97	10	11	7	9	1	-	-	-	-
S3	A	7_6_S3_1	7/6/2007	5.97	12	12	14	13	8	-	-	-	-
S5	A	7_6_S5_1	7/6/2007	5.97	13	21	11	15	11	-	-	-	-
S6	A	7_6_S6_1	7/6/2007	5.97	19	7	21	16	5	-	-	-	-
S2	A	7_6_S2_2	7/6/2007	5.97	18	11	15	15	9	-	-	-	-
S3	P	7_6_S3_2	7/6/2007	5.97	12	14	23	16	7	-	-	-	-
S5	A	7_6_S5_2	7/6/2007	5.97	7	7	12	9	3	-	-	-	-
S6	P	7_6_S6_2	7/6/2007	5.97	10	15	11	12	22	-	-	-	-
S1	A	7_13_S1_1	7/13/2007	4.25*	6	3	12	7	10	0.6	0.03	1.33	0.00
S2	A	7_13_S2_1	7/13/2007	4.25*	13	7	5	8	5	0.0	0.03	1.29	0.00
S3	A	7_13_S3_1	7/13/2007	4.25*	7	8	9	8	2	0.0	0.03	1.20	0.00
S5	A	7_13_S5_1	7/13/2007	4.25*	11	9	8	9	-3	0.5	0.02	1.05	0.00
S6	A	7_13_S6_1	7/13/2007	4.25*	6	5	3	5	5	0.6	0.02	1.10	0.00
S2	A	7_13_S2_2	7/13/2007	4.25*	5	9	3	6	-2	0.7	0.02	1.19	0.00
S3	P	7_13_S3_2	7/13/2007	4.25*	9	10	10	10	-2	0.0	0.03	0.87	0.00
S5	A	7_13_S5_2	7/13/2007	4.25*	14	6	11	10	2	0.0	0.03	1.14	0.00
S6	P	7_13_S6_2	7/13/2007	4.25*	7	8	4	6	0	0.8	0.03	2.51	0.00

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	7_16_S1_1	7/16/2007	3.79*	5	9	11	8	-2	-	-	-	-
S2	A	7_16_S2_1	7/16/2007	3.79*	8	2	8	6	0	-	-	-	-
S3	A	7_16_S3_1	7/16/2007	3.79*	21	63	12	32	9	-	-	-	-
S5	A	7_16_S5_1	7/16/2007	3.79*	14	6	17	12	6	-	-	-	-
S6	A	7_16_S6_1	7/16/2007	3.79*	13	14	26	18	-1	-	-	-	-
S2	A	7_16_S2_2	7/16/2007	3.79*	13	7	6	9	3	-	-	-	-
S3	P	7_16_S3_2	7/16/2007	3.79*	14	13	48	25	6	-	-	-	-
S5	A	7_16_S5_2	7/16/2007	3.79*	18	10	16	15	-1	-	-	-	-
S6	P	7_16_S6_2	7/16/2007	3.79*	6	10	11	9	1	-	-	-	-
S2	A	7_16_S2_3	7/16/2007	3.79*	6	7	10	8	0	-	-	-	-
S3	P	7_16_S3_3	7/16/2007	3.79*	11	57	14	27	6	-	-	-	-
S5	A	7_16_S5_3	7/16/2007	3.79*	3	4	7	5	4	-	-	-	-
S6	P	7_16_S6_3	7/16/2007	3.79*	4	7	3	5	4	-	-	-	-
S1	A	8_7_S1_1	8/7/2007	5.42*	105	64	82	84	5	-	-	-	-
S2	A	8_7_S2_1	8/7/2007	5.42*	54	61	68	61	-4	-	-	-	-
S3	A	8_7_S3_1	8/7/2007	5.42*	72	72	67	70	0	-	-	-	-
S5	A	8_7_S5_1	8/7/2007	5.42*	68	63	63	65	2	-	-	-	-
S6	A	8_7_S6_1	8/7/2007	5.42*	82	64	71	72	7	-	-	-	-
S2	A	8_7_S2_2	8/7/2007	5.42*	39	44	46	43	4	-	-	-	-
S3	A	8_7_S3_2	8/7/2007	5.42*	39	39	36	38	7	-	-	-	-
S5	A	8_7_S5_2	8/7/2007	5.42*	37	39	48	41	-3	-	-	-	-
S6	P	8_7_S6_2	8/7/2007	5.42*	63	43	59	55	-3	-	-	-	-
S5	A	8_7_S5_3	8/7/2007	5.42*	32	49	45	42	4	-	-	-	-
S6	P	8_7_S6_3	8/7/2007	5.42*	57	45	64	55	4	-	-	-	-
S6	P	8_7_S6_4	8/7/2007	5.42*	61	62	52	58	2	-	-	-	-

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	8_12_S1_1	8/12/2007	4.15*	12	10	12	11	7	-	-	-	-
S2	A	8_12_S2_1	8/12/2007	4.15*	9	15	9	11	5	-	-	-	-
S3	A	8_12_S3_1	8/12/2007	4.15*	11	11	7	10	16	-	-	-	-
S5	A	8_12_S5_1	8/12/2007	4.15*	8	12	39	20	7	-	-	-	-
S6	A	8_12_S6_1	8/12/2007	4.15*	11	21	24	19	20	-	-	-	-
S2	A	8_12_S2_2	8/12/2007	4.15*	6	4	10	7	25	-	-	-	-
S3	P	8_12_S3_2	8/12/2007	4.15*	5	7	13	8	10	-	-	-	-
S5	A	8_12_S5_2	8/12/2007	4.15*	16	11	7	11	13	-	-	-	-
S6	A	8_12_S6_2	8/12/2007	4.15*	32	14	11	19	-5	-	-	-	-
S2	A	8_12_S2_3	8/12/2007	4.15*	3	9	31	14	8	-	-	-	-
S3	P	8_12_S3_3	8/12/2007	4.15*	5	19	12	12	10	-	-	-	-
S1	A	8_15_S1_1	8/15/2007	4.34*	6	15	5	9	0	-	-	-	-
S2	A	8_15_S2_1	8/15/2007	4.34*	2	8	3	4	10	-	-	-	-
S3	A	8_15_S3_1	8/15/2007	4.34*	8	7	3	6	7	-	-	-	-
S5	A	8_15_S5_1	8/15/2007	4.34*	11	7	4	7	7	-	-	-	-
S6	A	8_15_S6_1	8/15/2007	4.34*	14	8	21	14	-7	-	-	-	-
S5	A	8_15_S5_2	8/15/2007	4.34*	4	8	4	5	-2	-	-	-	-
S6	P	8_15_S6_2	8/15/2007	4.34*	7	8	14	10	2	-	-	-	-
S6	P	8_15_S6_3	8/15/2007	4.34*	14	10	12	12	4	-	-	-	-
S6	P	8_15_S6_4	8/15/2007	4.34*	22	13	19	18	12	-	-	-	-
S1	A	8_21_S1_1	8/21/2007	2.86*	4	5	5	5	1	-	-	-	-
S2	A	8_21_S2_1	8/21/2007	2.86*	9	6	1	5	7	-	-	-	-
S3	A	8_21_S3_1	8/21/2007	2.86*	6	7	3	5	3	-	-	-	-
S5	A	8_21_S5_1	8/21/2007	2.86*	8	3	6	6	0	-	-	-	-
S6	A	8_21_S6_1	8/21/2007	2.86*	5	8	7	7	4	-	-	-	-
S2	A	8_21_S2_2	8/21/2007	2.86*	5	4	1	3	0	-	-	-	-
S3	P	8_21_S3_2	8/21/2007	2.86*	8	8	8	8	9	-	-	-	-
S3	P	8_21_S3_3	8/21/2007	2.86*	8	4	6	6	4	-	-	-	-

Table 12. Continued

Site	Animal	Sample ID	Date	Flow ft <sup>3</sup> s <sup>-1</sup>	Plate 1 CFU (3 ml) <sup>-1</sup>	Plate 2 CFU (3 ml) <sup>-1</sup>	Plate 3 CFU (3 ml) <sup>-1</sup>	E. coli Mean CFU (3 ml) <sup>-1</sup>	SSC mg l <sup>-1</sup>	TKN mg l <sup>-1</sup>	TP mg l <sup>-1</sup>	NO <sub>3</sub> mg l <sup>-1</sup>	PO <sub>4</sub> mg l <sup>-1</sup>
S1	A	8_24_S1_1	8/24/2007	4.30*	0	3	4	2	6	-	-	-	-
S2	A	8_24_S2_1	8/24/2007	4.30*	5	2	5	4	5	-	-	-	-
S3	A	8_24_S3_1	8/24/2007	4.30*	3	2	1	2	4	-	-	-	-
S5	A	8_24_S5_1	8/24/2007	4.30*	6	3	1	3	-1	-	-	-	-
S6	A	8_24_S6_1	8/24/2007	4.30*	25	22	11	19	0	-	-	-	-
S5	A	8_24_S5_2	8/24/2007	4.30*	4	2	2	3	4	-	-	-	-
S6	P	8_24_S6_2	8/24/2007	4.30*	7	10	12	10	0	-	-	-	-
S6	P	8_24_S6_3	8/24/2007	4.30*	14	18	10	14	6	-	-	-	-
S6	P	8_24_S6_4	8/24/2007	4.30*	7	7	14	9	5	-	-	-	-
S6	P	8_24_S6_5	8/24/2007	4.30*	3	10	8	7	31	-	-	-	-
S1	A	8_29_S1_1	8/29/2007	2.68	8	13	10	10	4	-	-	-	-
S2	A	8_29_S2_1	8/29/2007	2.68	12	7	6	8	5	-	-	-	-
S3	A	8_29_S3_1	8/29/2007	2.68	7	7	9	8	3	-	-	-	-
S5	A	8_29_S5_1	8/29/2007	2.68	8	8	9	8	8	-	-	-	-
S6	A	8_29_S6_1	8/29/2007	2.68	10	16	13	13	0	-	-	-	-
S2	A	8_29_S2_2	8/29/2007	2.68	6	10	9	8	2	-	-	-	-
S3	P	8_29_S3_2	8/29/2007	2.68	2	9	6	6	4	-	-	-	-

\* = Flows estimated from rating curve

\*\* = High flow moving over stanchion platform

SSC = Suspended Sediment Concentration

TKN = Total Kjeldahl Nitrogen

TP = Total Phosphorus