THESIS

IMPACT OF CATTLE GRAZING ON THE SURFACE WATER QUALITY OF A COLORADO FRONT RANGE STREAM

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY STEVEN R. JOHNSON ENTITLED IMPACT OF CATTLE GRAZING ON THE SURFACE WATER QUALITY OF A COLORADO FRONT RANGE STREAM BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

IMPACT OF CATTLE GRAZING ON THE SURFACE WATER QUALITY OF A COLORADO FRONT RANGE STREAM

The purpose of this study was to quantify the impact and evaluate the local and immediate downstream pollution potential of range cattle grazing with free stream access. Emphasis was placed on suspended solids, ammonia-nitrogen, nitrate-nitrogen, orthophosphate, fecal coliform and fecal streptococci concentrations.

Samples were collected at four sites along a 2.6 km section of Trout Creek, the only perennial stream within the Manitou Experimental Forest. The study was broken down into eight periods covering the two year period 1977-1978; two included 150 cows in the lower pasture, two involved grazing by 40 cows in an adjacent pasture while four periods involved no grazing in either pasture.

The findings of this study indicate that only fecal coliform and fecal streptococci concentrations reflected a cattle grazing impact. Ammonia-nitrogen and nitrate-nitrogen concentrations suggest a grazing impact while orthophosphate concentrations appeared to be independent of cattle grazing. During most of the study the suspended solids analyses were confounded by an area of breached beaver dams. Cattle location and defecation trends help to explain the low

concentrations of the parameters involved. In many instances the contribution by grazing cattle was minor in comparison to background concentrations measured at upstream sites.

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INTRODUCTION

Written accounts of interactions between humans and grazing animals in Colorado date back to 1820 in the Journal of the S. H. Long Expedition (Thwaites, 1905). While camped on a tributary of the South Platte River just south of the modern location of Colorado Springs, Colorado, the party observed heavy rain falling on Pikes Peak, some 32 kilometers to the northwest. Within six to eight hours, the stream had risen almost two meters and its surface was covered with bison dung. The expedition cook chose this time to fill his cooking kettle. To quote the Long Expedition Recorder: "The flavor of the cow-yard was found so prevalent, and the meat so filled with sand, that very little could be eaten."

Today, this area is part of the rapidly developing Colorado Front Range and interactions between grazing animals (mainly cattle) and other water users are still occurring. Over 2.5 million people live in this Front Range with recreation, hydroelectric power production, grazing, and domestic needs all demanding a share of the limited water resource. Current estimates predict a Front Range population of 2.7 million by 1980, an increase of over one million in only ten years, with even greater water demands (Bingham, 1967).

This rapid and continuing development along the Front Range has complicated the management of all natural resources, especially that of maintaining and improving the quality of the limited water resource. The physical development and growing recreational demands, coupled with the inherently erosive lands, low annual rainfall (380-500 mm) and streamflow (less than 75 mm), has created a need for broad based management guidelines for the entire region (Gary, 1975). Both potential and actual problems from this rapid growth/limited water interaction arise from the fact that the same water resource is utilized by many interests before it reaches its urban destination. Often times, the water resource is used by recreationists, irrigators and livestock interests within a 6 to 8 km stream reach.

Due to its proximity to the rapidly growing urban centers, its aesthetic appeal and its capacity to produce forage, the Front Range pine zone has been the area most affected by these interactions. The perennial streams and flood plains of this zone serve host to a wide variety of recreational activities in addition to serving as the prime watering areas for the cattle grazing industry. This concurrent usage of the water resource by recreationists and cattle, as well as the fact that this same water is to be used for domestic needs downstream, brings up some interesting questions. When cows are located in or near these surface water sources, is there a possibility of a physical, chemical or biological degradation of the quality of that water which might seriously affect its other uses? Can cattle cause soil surface impacts which will result in significant increases in erosion and sedimentation? Can the body wastes from grazing cattle cause eutrophication of lakes and reservoirs? Can cattle grazing transmit pathogenic diseases to both local and downstream human users?

Most studies of cattle impacts on water quality have dealt with feedlot runoff. Only a few studies have examined the effect of rangeland grazing on surface water quality (Johnson, et al., 1978; Buckhouse and Gifford, 1976; Darling, 1973; Campbell and Webber, 1970; Kunkle and Meiman, 1967; Morrison and Fair, 1966). Conclusive results with respect to cattle grazing effects on interactive water use are few, particularly in streams dependent on snowmelt runoff such as these of the Colorado Front Range.

The overall objective of this study was to quantify the impact of cattle grazing on a perennial, low flow stream in the Colorado Front Range. Specifically the study sought to determine the local and immediate downstream pollution potential of cattle grazing on a 2.6 km reach of Trout Creek through analysis of selected physical, chemical and biological parameters.

PAST WORK

Domestic cattle and sheep graze, at one time or another, on about one-half of the 110.5 million hectares of public rangeland in the 11 western states. Furthermore, grazing is permitted on one-fourth of the total public land area that has been withdrawn for recreation (Public Land Law Review Commission, 1970). The grazing of livestock may present an adverse impact on the other uses of the water found on these lands. Leopold (1975) states: "Fish and wildlife habitat in western rangeland is undergoing steady, chronic deterioration under existing patterns of multiple use. Livestock grazing in particular may be having cumulative ecological ill effects on productivity of both lands and water."

As noted by Miner and Willrich in 1970, little interest had been shown by water pollution control agencies concerning the pollutional effects of cattle grazing on range or pastures. These agencies assumed that manure distribution patterns, soil adsorption of liquids and vegetative cover usage of the added nutrients would interact to minimize any potential water quality effects. Supposedly, high intensity rainfalls in excess of soil infiltration rates would provide sufficient dilution water to minimize the concentrations of the potential pollutants in the runoff.

Based on these assumptions, most of the concern for livestock effects on water quality focused on feedlot and agricultural (manured) land runoff problems (Darling, 1973). Few, if any, studies sought to examine cattle grazing impacts on wildlands until the later 1960's and early 1970's. At this time, researchers and several government agencies began to examine the situation in terms of the effect on recreational and domestic water uses. Cities were growing and the people demanded pure water for both water-based recreation and domestic uses. At the same time, economics and the concept of multiple use management of public lands was drawing more and more grazing interests into the same areas. Thus, it was inevitable that interactions among these factions would occur.

This literature review will examine the effects of cattle grazing on water quality in small mountain streams. In addition to the water quality impact, mechanisms and processes involved in water pollution by cattle are also examined. Specific emphasis is placed on erosion and livestock wastes and the resultant impact on stream sediment, nutrient and bacteriological concentrations.

Cattle can dramatically affect land surfaces by removing vegetative cover as well as compacting the soil surface. The exposed and damaged soil surface is then more susceptible to raindrop splash while compaction reduces infiltration and increases overland flow.

The capacity of grazing animals to remove vegetation is well documented. Range cattle may consume over nine kilograms of forage material per day depending on the animal's physical condition, the climate and feed palatability (Stoddart and Smith, 1955). Today, most federal agencies concerned with land management feel that grazing management plans allowing for 30 percent or less cover removal will not seriously affect erosion rates unless other factors interfere (U.S. Environmental Protection Agency, 1978).

During their foraging activities, cattle hooves affect several important soil characteristics, mainly through surface compaction, and these effects have been found in both grasslands and forests (Johnston, 1962; Stoeckeler, 1959). Linnartz and others (1966) found that cattle grazing affected several important soil properties on a forested Louisiana watershed; bulk density increased while porosity, infiltration and percolation all decreased. Aldefer and Robinson (1947) reported that increased runoff from grazed pastures was due to a lack of soil cover together with high bulk density and low values for capillarity and porosity. These cover and soil effects of grazing cattle act collectively to increase the erosion hazard of the soil surface. This increased overland flow and the subsequent erosion can affect water quality due to greater dissolved and suspended sediment and nutrient and pathogenic organism loading and transport (U.S. Environmental Protection Agency, 1978).

Sediment has been called the greatest single pollutant in natural waters (Holt, et al., 1970). Several published studies have examined the grazing-sediment yield relationship (Craddock and Pearse, 1938; Aldefer and Robinson, 1947; Johnson and Moldenhauer, 1970). One study of particular interest was made at Badger Wash Basin in Southwestern Colorado (Lusby, 1970). Runoff and sediment yields were considerably less from ungrazed watersheds than from grazed watersheds on Mancos shale derived soils even though vegetation had not changed appreciably between the paired watersheds over the five year period. The differences were caused by the increased soil compaction resulting from the grazing animals as compared to compaction by raindrops only on the ungrazed watershed.

Of increasing importance today is the effect that grazing animals have on stream channels and the adjacent riparian vegetation zone (Behnke, 1978; Meehan and Platts, 1978; Berry, 1978). Although it only accounts for about one percent of the total rangeland acreage (Berry, 1978), the riparian zone contains the richest concentration of animal life and provides the most heavily utilized recreation areas (Behnke, 1978). Livestock naturally tend to congregate in and around stream bottoms due to the high palatability and moisture content of streamside vegetation as well as the close proximity to water (Ames, 1977). For these reasons, the zone has been considered a "sacrifice area" by range managers (Behnke, 1978).

Berry (1978) summarized the results of several investigations (all unpublished or in-press) which demonstrated a link between bank stability and overgrazing of the riparian zone. The effects of this reduction in riparian vegetation and bank stability are reduced cover for fish, increased water temperatures and increased silt in the stream. Another obvious effect would be mass wasting following bank failure, further increasing the eroded material delivered to the stream channel.

The consequences of cattle activities within a stream channel include disturbed bottom substrates, increases in both nutrient and bacterial levels, and possible turbidity problems with fish growth and behavior (Berry, 1978).

In summary and as illustrated in Figure 1, the primary effects of grazing on both riparian and upland vegetation may have secondary effects on the underlying soil and on stream banks. Reduced riparian vegetation may lead to less stable banks, increased stream temperatures and reduced cover for riparian zone wildlife. Soil exposure and compaction promotes erosion which may result in increased sedimentation of a stream. Once in the aquatic environment, sediment can reduce suitable substrates for invertebrate fish food organisms as well as bury organisms and larvae residing in the intragravellar zone (Berry, 1978).

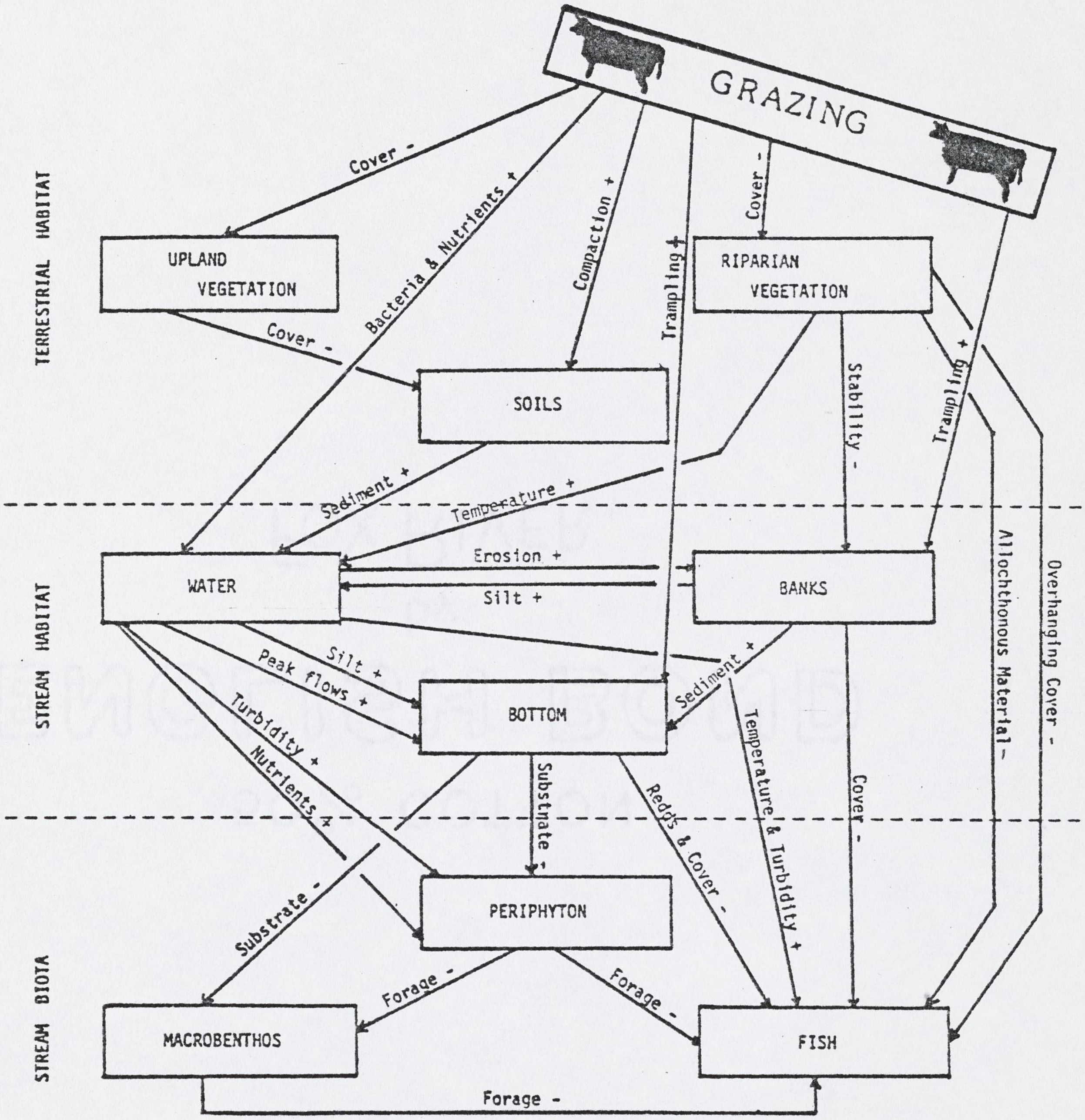


Figure 1. Flow chart diagram of major effects of grazing on both land and stream features and the resulting effects of changes in these features on the stream biota. A plus (+) sign indicates a net increase in effect and a minus (-) sign a net decrease (after Berry, 1978).

The major water pollutants derived from animal wastes are oxygen demanding organic materials, plant nutrients and infectious organisms (Miner and Willrich, 1970). Organic matter from livestock waste serves as substrate (food source) for aqueous bacteria when it enters a stream. The bacteria oxidize the organic matter to obtain energy for growth, development and reproduction. This process is referred to as Biochemical Oxygen Demand (BOD) and is commonly defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions (Sawyer and McCarty, 1967). The important point to note here is that this process exerts a demand on the stream's oxygen supply. When the rate of oxygen depletion exceeds the stream's reaeration rate, serious problems may result. Fish mortality or, if conditions persist, a shift toward an anaerobic stream condition may occur. Applying this terminology to grazing research, the carbonaceous BOD of a 454 kg beef cow has been estimated at 0.45 kg per day (Miner and Willrich, 1970).

The oxygen demand of ammonia, another product of cattle waste, has also been found to be significant. Ammonia-nitrogen concentrations in feedlot runoff have been found to range from 1 to 139 mg/ℓ (Miner and Willrich, 1970). To oxidize these concentrations of NH_3 to nitrate (NO_3) would require from 4.6 mg/ℓ to 638 mg/ℓ of oxygen.

Research to date does not suggest any BOD or ammonia problems with range cattle grazing, even though direct deposition of an ammonia rich manure represents a potential eutrophication problem. Rapid reaeration of stream water and ammonia breakdown are apparently eliminating the problem before it impacts water users.

The nutrients of concern in most water quality studies are nitrogen and phosphorous compounds since they are the principal agents of eutrophication in lakes and impoundments (Armstrong and Rohlick, 1970). Miner and Willrich (1970) reported that a 454 kg beef cow would excrete 0.136 kg of nitrogen and 0.045 kg of phosphorus per day, per 4.54 kg of solid excrement. Loehr (1977) discussed the chemical breakdown of wastes from cattle and also computed average losses of nitrogen and phosphorous. He reported an average value of 6.35 kg of nitrogen and 1.8 kg of phosphorous per 0.91 metric tons of manure (including urine), with a range of 17 to 35 kg of waste material per cow per day. Omernik (1977) reported annual losses per cow at 57 kg total nitrogen and 17 kg total phosphorous. The variance in these and other reported results are probably due to differences in feeds, climate and condition of the cattle.

Nitrogen in manure, including urine, is primarily in the organic and ammoniacal form (Loehr, 1977). Ammonia and other reduced forms are oxidized by nitrifying bacteria to nitrates in both water and in soils (Goldberg, 1970). The nitrate (NO_3^-) ion is both water soluble and readily adsorbed by plants, important factors for its role as an agent of eutrophication (Oglesby, 1971).

Phosphorous forms in manure are primarily organic with some orthophosphate. Both the organic and orthophosphate forms are sparingly soluble and tend to be strongly adsorbed by soil particles, reaching water supplies only from soil and organic particle movement (Oglesby, 1971; McCalla, 1970). The small fraction of this phosphate that is then made available to the aquatic community becomes the primary cause of eutrophication in natural waters (Oglesby, 1971).

While the preceding section demonstrates that substantial amounts of both nitrogen and phosphorous compounds are present in cattle wastes and in usable forms, results from wildland water quality examinations have not indicated any measurable impacts. Darling (1973), in studying grazing on small Utah streams, reported that cattle and sheep grazing impacts on chemical water quality were not detectable. He measured nitrate concentrations of 0.05 to 1.8 mg/ℓ and total phosphate concentrations of 0.05 to 0.85 mg/ℓ. He concluded that neither nitrates nor total phosphates changed with watershed activity (grazed or ungrazed) and blamed analytical techniques for much of his experimental variation. In a Canadian study of low density rangeland grazing, Campbell and Webber (1970) reported runoff concentrations of 0.65 kg NO_3-N and 0.76 kg total phosphorous per hectare per year.

Milne (1976), in studying the water quality effects of livestock on a winter range, reported three year mean concentrations at five sites for nitrate-nitrogen to be between 0.003 and 0.20 mg/ℓ, orthophosphate between 0.009 and 0.026 mg/ℓ and ammonia-nitrogen between 0.000 and 0.027 mg/ℓ. These measurements were taken with specific ion probes. Milne reported that his nitrate findings were probably below the threshold level of the probe. He discontinued most chemical analyses after the second year, concluding that little if any change could be detected. Berry (1978) felt that only those wastes deposited in or very near the channel would impact a stream and thus be measurable, and the research to date bear this out. Most investigators choose to leave chemical nutrient data out of their publications, possibly due to either the low values (often at or near analytically detectable limits) or the extreme variability and non-significance of the data.

Many studies from livestock feedlots and intensive agricultural areas have shown that cattle wastes contain pathogens and that these organisms can be transmitted to man via water (Diesch, 1970). Although waterborne diseases are relatively rare in the U.S.A., increasing emphasis on water based recreation creates new opportunities for this mode of infection (Miner and Willrich, 1970). Among the potential waterborne diseases transmissable from cattle are anthrax, brucelosis, coccidosis, mastitis, New Castle disease, ornithosis, gastroenteritis, leptospirosis and salmonellosis (Diesch, 1970).

Leptospirosis and Salmonella are the most widespread of these. Approximately 1,000 cases of Leptospirosis have been reported in the United States since 1941 (Diesch, 1970). Diesch summarized an outbreak of Leptospirosis among several young people on the Cedar River in Iowa. The disease was traced to their swimming below a point where infected cattle had access to the river. Diesch and McCulloch (1966) investigated an area in Iowa that had witnessed several Leptospirosis outbreaks. They traced the disease back to cattle contamination and concluded that continued use of the water source for cattle watering and recreation or drinking would probably lead to further outbreaks of the disease.

Salmonella, however, is the major zoonotic disease (transmitted between vertebrates and man) in the United States with 20,000 reported cases per year but estimates of one to two million actual cases. More than 1,300 serotypes of Salmonella have been identified with most being spread in the feces of infected animals (Diesch, 1970).

Agricultural animals, cows in particular, are frequent sources of Salmonella (Geldreich, et al., 1968). At the present time, Salmonella is one of the few pathogens which may be isolated from water by the means of a routine test with any degree of reliability (Millipore

Corporation, 1973; Geldreich, 1970; Gallagher and Spino, 1968). For this reason, it is the most often studied pathogenic organism in water pollution research. However, because most pathogenic organisms are usually present in natural waters in such extremely low densities (Diesch, 1970), the presence or absence of the coliform bacterial group is considered an indication of possible contamination by warm blooded animals and thus the possible presence of pathogenic organisms (Gallagher and Spino, 1968; Millipore Corporation, 1973).

As defined by Standard Methods (A.P.H.A., 1975), "the coliform group includes all the aerobic and facultative anaerobic gram-negative, non-spore-forming rod shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C." Coliforms are always present in the intestinal tract of humans and other warm blooded animals (Geldreich, 1967). As a group, coliforms are considered harmless but their presence in a water sample indicates the possible presence of waterborne pathogenic organisms (Millipore Corporation, 1973).

Further study of the coliform group revealed that a sub-group, fecal coliform, was a better indicator of warm blooded fecal pollution. Unlike many species of the coliform group, the fecal coliform is present only in the gut and feces of warm blooded animals (Geldreich, 1967 and 1970). The fecal coliform group has proved to be an excellent tool in water quality investigations, both domestic and wildland

(Geldreich, 1967; Kunkle and Meiman, 1967; Walter and Bottman, 1967; Johnson, et al., 1978).

Stream studies examining a relationship between fecal coliforms and pathogenic organisms, most notably Salmonella, have yielded varying results. Gallagher and Spino (1968), in summarizing their own and the work of several others, concluded that little apparent correlation could be made between concentrations of total or fecal coliforms and the probable isolation of Salmonellae. Van Donsel and Geldreich (1971) suggested that a concentration of 200 fecal coliforms/100 ml of water might represent a significant limiting relationship between indicator and Salmonella. They investigated mud samples from several stream and lake bottoms and recovered Salmonella in 19 percent of the samples when the fecal coliform count was 1 to 200 counts/100 ml, 50 percent when counts were 201-2,000 and 80 percent when counts were over 2,000. Smith and Twedt (1971) supported this relationship with their research. Geldreich (1970) also agreed but felt that a fecal coliform count of 2,000 colonies per 100 ml should result in a near 100 percent correlation with Salmonella.

The use of a second bacterial indicator group, fecal streptococcus, is increasing in stream pollution research (Geldreich and Kenner, 1969). Fecal Streptococci, as defined by Standard Methods (A.P.H.A., 1975), include the intestinal streptococci from all warm blooded animal fecal wastes. These gram-positive cocci occur in chains of two or more organisms and are capable of growth in Brain Heart Infusion broth either at 45^{o} and $10^{o}C$ (the enterococcus species) or at $45^{o}C$ only (*Streptococcus bovis* and *S. equinus*).

Generally, the occurrence of fecal streptococci in water indicates fecal pollution while its absence suggests little or no warm blooded animal contamination. More importantly, the presence of fecal streptococcus strongly suggests *recent* fecal pollution because these organisms generally do not multiply in water (Geldreich, 1970; Geldreich and Kenner, 1969).

Although the fecal coliform test will not distinguish between the contribution of human and non-human warm blooded animal wastes, such a separation may be established through density relationships of fecal coliform (FC) to fecal streptococci (FS) from the same sample (Geldreich, 1970). In human fecal material and in domestic wastes, fecal coliform densities exceed those of fecal streptococci by a ratio of 4 to 1. Bacterial densities of effluents related to livestock and poultry have a fecal coliform to fecal streptococci ratio generally less than 0.7 (Millipore Corporation, 1973). Table 1 illustrates these ratios for several farm and domestic animals.

For example, Geldreich (1966) reported daily per capita production by cows of 5.4×10^{9} FC and 31.0×10^{9} FS. This would yield a FC/FS ratio of 0.17. Improved recovery of two members of the fecal streptococci group, *Streptococcus bovis* and *S. equinus*, species

Table 1. Bacterial densities and fecal streptococcus distributions in warm-blooded animal feces (after Geldreich and Kenner, 1969).

Fecal Source	No. of Samples	Densities/G*		Ratio FC/FS	Total Strains Exam.	Occurrence (%)			
		Fecal Coliforms	Fecal Streptococci			Enterococci	S. bovis S. equinus	Atypical S. faecalis	S. faecalis liquifaciens
Human	43	13,000,000	3,000,000	4.4	1,067	73.8	None	None	26.2
Animal Pets									
Cat	19	7,900,000	27,000,000	0.3	268	89.9	1.5	2.2	6.3
Dog	24	23,000,000	980,000,000	0.02	585	44.1	32.0	14.4	9.6
Rodents	24	160,000	4,600,000	0.04	539	47.3	17.1	0.4	35.3
Livestock									
Cow	11	230,000	1,300,000	0.2	438	29.7	66.2	None	4.1
Pig	11	3,300,000	84,000,000	0.04	296	78.7	18.9	None	2.4
Sheep	10	16,000,000	38,000,000	0.4	321	38.9	42.1	None	19.0
Poultry									
Duck	8	33,000,000	54,000,000	0.6	328	51.2	48.8	None	None
Chicken	10	1,300,000	3,400,000	0.4	275	77.1	1.1	None	21.8
Turkey	10	290,000	2,800,000	0.1	317	76.7	1.6	None	21.8

*Median values.

which predominate in cattle feces, led to this ratio (Geldreich and Kenner, 1969). This FC/FS ratio, with certain restrictions such as pH range and time between deposition and collection can now be used to identify probable sources of fecal pollution in stream studies (Geldreich, 1967).

These bacterial indicators have become the most often used means of evaluating water pollution, particularly in wildland water quality studies examining grazing impacts. During a 12 day spring grazing period by 150 cows, Johnson and others (1978) reported average fecal coliform concentrations of 20 colonies per 100 ml in the control pasture and 105 in the grazed pasture. Mean fecal streptococci counts were 73 in the control pasture and 176 in the grazed pasture. Morrison and Fair (1966), Kunkle and Meiman (1967, 1968) and Milne (1976) all reported increased bacterial counts at sites below grazing cattle.

Johnson reported that both fecal coliform and fecal streptococci bacterial counts were highest in a grazed pasture bottom but quickly dropped to ungrazed levels when the cattle were removed. Similar results were reported by Coltharp and Darling (1973) and by Milne (1976). Darling (1973) reported fecal streptococci counts of 1,000 colonies/100 ml decreasing to less than 30 colonies/100 ml following the removal of cattle from a boggy area. While not as dramatic, fecal coliform counts dropped in a similar manner at most of his sites.

Working with streams in both Colorado and Vermont, Kunkle (1970) reported microbial densities in streams are not as dependent on the amount or type of land use activities per se on a watershed as on the location of the pollutants with reference to the stream channel. He found that when cattle were located away from streams, the fecal coliform counts were only slightly higher than in an ungrazed area. Kunkle concluded that the upland contributions of bacteria to streams were small compared to contributions from land surfaces near channels, the channel itself or direct inputs. Petersen and Boring (1960) found that cattle activities within the channel itself were most important in causing bacterial counts to increase. Geldreich and Kenner (1969) felt that the low levels of fecal contamination on the western prairie generally reflected the non-centralized grazing patterns of cattle, sheep and the indigenous wildlife populations.

In studying a snowmelt river in the Colorado Rockies, Morrison and Fair (1966) found that cattle grazing adjacent to a stream caused increase in both total and fecal coliform counts. They also found that surface runoff from summer rainstorms was the most important single factor in explaining variations in both chemical and bacterial parameters.

The survival rates of both indicator and pathogenic organisms are important considerations in evaluating the pollution potential from cattle wastes. Several studies have been made using both direct fecal deposits and bacterial seed populations.

Using a liquid bacterial seed added to soil plots, Van Donsel and others (1967) reported that times required for a 90 percent reduction in fecal coliforms ranged from a low of 3.3 days in summer to 13.4 days in autumn. For fecal streptocci, 90 percent reduction times ranged from 2.7 days in summer to a high of 20.1 days in winter. Ninety-five percent confidence intervals place these counts as accurate to about ± 1 day. To summarize, fecal coliforms survived slightly longer than fecal streptococci in summer but fecal streptococci survived much longer in spring and winter.

In working with fecal deposits placed directly on the soil surface, Buckhouse and Gifford (1976) reported that fecal coliform densities remained greater than 110,000 colonies/100 ml for over seven weeks. They surmised that the bacterial life span could be as long as several seasons since the bacteria are rather well protected within the surface desicated deposit. Van Donsel, et al. (1967) also indicated that a large proportion of the fecal coliform and fecal streptococci organisms remain localized at their deposition point and die within several weeks. In studying the soil surrounding one of their fecal deposits following artificial rain, Buckhouse and Gifford (1976) found that only the feces themselves and an area within about a one meter radius were subjected to any degree of fecal bacterial contamination. Geldreich (1967), in a summary paper on fecal coliform bacteria, reported that these organisms are able to survive from two to eight weeks in soils, governed by temperature, soil moisture, pH and antagonistic organisms. He also noted that bacteria deposited on soil via feces are immobilized and subject to the ecology of a specific site.

An important point to be drawn from these studies of indicator bacterial survival in or on soil is that Salmonella, brucella abortus and several other pathogens associated with cows are also able to survive under the same conditions (Van Donsel, et al., 1967). Thus, a fecal coliform contaminated soil means a distinct possibility of pathogens as well.

In studying the persistence of selected bacteria in stormwaters at varying temperatures, Geldreich and Kenner (1969) reported that at 10°C, 21 percent of the fecal coliforms, 80 percent of two of the three fecal streptococci species and 12 percent of the one Salmonella species involved survived after seven days. One important finding from the standpoint of cattle grazing/water quality research was made; Streptoccus bovis, one of the two prevalent streptococcus species in cattle feces, was reduced to less than 0.1 percent survival within one day. At 20°C and seven days time, only one percent of the fecal coliform, 10 to 28 percent of two fecal streptococci species and less than two percent of the Salmonella species had survived. For S. bovis, the third fecal streptococci species studied, only 0.2 percent survived through seven days. Mack (1974) as well as Hendricks and Morrison (1967) have demonstrated that coliform bacteria can persist and even multiply in natural waters, even cold mountain streams.

Research has indicated that bottom sediments and channel deposits might be reservoirs for large quantities of bacteria (Kunkle, 1970; Kunkle and Meiman, 1967; Geldreich, 1970). Kunkle (1970) reported that downstream fecal coliform counts rose an order of magnitude just by wading and stirring up water above a sampling point. Concentrations were halved after about 20 minutes of wading. Geldreich (1970) concluded that sedimentation entraps a large portion of a bacterial population, places these organisms in a more protective environment for extended survival and slows their movement downstream. The release of these organisms is possible following discharge increases or physical stimulation of the channel bottom (Kunkle, 1970).

Evaluating the bacterial transport mechanisms is another important point to consider in studying the pollution potential of cattle wastes. The potential paths that bacteria might take in reaching a stream include surface transport during storms (both sediment-attached and free flowing), during infiltration and percolation of soil water, or direct deposition within a channel. Stormflow and direct deposition are considered the most prominent paths of bacterial contamination (Geldreich, et al., 1968; Kittrell and Furfari, 1963; Kunkle and Meiman, 1967). Conclusions pertaining to the contributions from these two sources are difficult to draw due to the fact that coliform bacteria are capable of aftergrowth (Mack, 1974; Hendricks and Morrison, 1967). Sometimes this aftergrowth is on the order of 100 to 1,000 times the original population (Geldreich, 1967) but usually occurs within ten to 15 hours in natural streams (Kittrell and Furfari, 1963). Based on this fact, some bacterial increases attributed to surface runoff might be attributed to aftergrowth of bacteria already within the stream.

Morrison and Fair (1966), however, suggested that coliform bacteria were reaching a stream through groundwater without any surface runoff. Since the grazed meadow in the study sloped away from the stream, they felt the bacteria were apparently reaching the groundwater by infiltration of surface water without bacterial filtration by the alluvial granitic soil. Voelker, et al. (1960) also expressed a suspicion that bacteria are capable of permeating both sand and other soil materials to reach groundwater.

While these researchers suggest that the soil is acting as an incomplete filter of coliform bacteria, research since 1938 has indicated that soils are indeed excellent bacterial filters (Caldwell, 1938). Butler, et al. (1954) reported that tremendous numbers of bacteria are filtered in the first foot (0.3 m) of soil and that the number of coliform organisms penetrating one foot or more is independent of the intensity of pollution in the added wastewater. They concluded that the removal of bacteria from liquid percolating through a given depth of soil is inversely proportional to the particle size of the soil. They also included data indicating that bacteria are capable of horizontally traveling great distances (tens of meters) once they reach groundwater. Baars (1957) stated that bacteria cannot penetrate very far into sandy soils unless accompanied by a large quantity of water. If the groundwater table is high, however, bacteria which once reached the groundwater may stay there practically unchanged for a long time.

Romero (1970) wrote a paper summarizing the research on the movement of bacteria through porous media. He concluded that the bacterial filtering process involves both mechanical and biological straining (a result of soil clogging) and/or death induced by environmental changes. Soil defense mechanisms such as oxygenation, nitrification, and the inability of the new bacteria to adjust to the temperature, pH and pre-existing soil bacteria are also involved. Results summarized in his paper indicate that a large percentage (90 to 100 percent) of the coliform bacteria were separated within three to 12 feet (0.9 to 3.6 m) of penetration, with four to seven feet (1.22 to 2.13 m) being common. The soil types involved in these studies ranged from sandy loams to very coarse materials. Horizontal flow of pollutants has been found to be in the direction of groundwater flow (Romero, 1970; Butler, et al., 1954).

METHODS AND PROCEDURES

Study Area

The general area selected for this study was the Manitou Experimental Forest. Established in 1936 to study land use problems in the ponderosa pine zone, it is located about 48 km northwest of Colorado Springs, Colorado and has an area of nearly 6,500 ha (Love, 1958) (Figure 2).

The climate of the Experimental Forest is sub-humid with wide diurnal and annual temperature ranges and great variation in the occurrence and distribution of precipitation. Mean annual temperature is 4.8^{o}C with occasional 32^{o}C summer readings and extended winter periods of below -18^{o}C (Berndt, 1960). Average annual precipitation is 404 mm/yr with about two-thirds of this amount occurring from April to August. Most precipitation is received in late spring and summer and results from convective storms. The snow season extends from late September until May but snows commonly melt from southern exposures and valleys within a few days of occurrence (Gary, 1975). Streams originating in this area are usually intermittent, flowing only in late fall, winter and spring (Gary, 1975). Perennial streams will reach their minimum levels in late summer and early fall, sporadically interrupted by storm flows.

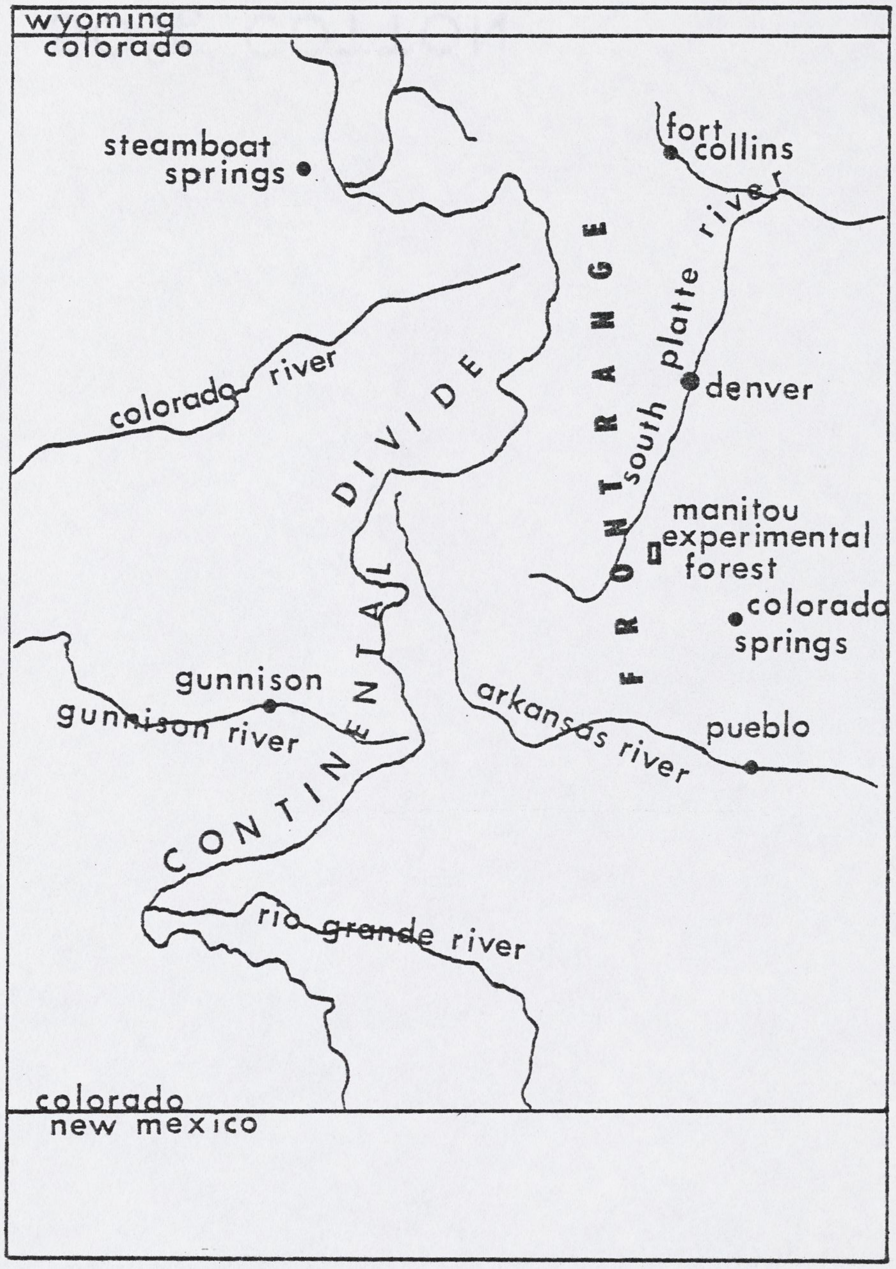


Figure 2. Map illustrating location of the Manitou Experimental Forest and the Colorado Front Range.

Geologically, most of the Experimental Forest is underlain by the Fountain Formation consisting of arkosic sandstones and conglomerates sparsely interbedded with thin shales (Marcus, 1973). Overlying the Fountain Formation is an accumulation of coarse, angular material which has washed down from the weathering of granitic outcrops on the neighboring peaks. Spring runoff and heavy rains have deposited this material in three separate layers (ages of deposition) of alluvium. These fan-shaped alluvial deposits vary from 3 to 7.5 m in depth beneath the Experimental Forest (Sweet, 1952).

This study was conducted on a section of Trout Creek, the only perennial stream within the Experimental Forest. Trout Creek is a tributary of the South Fork of the South Platte River, a major water source for the City of Denver to the north. The specific study area was a 2.6 km section of Trout Creek flowing through two adjacent fenced pastures just north of the Experimental Forest Headquarters (Figure 3). Each pasture had about an equal length of stream and similar amounts of suitable grazing forage. Figures 4 and 5 illustrate the upper and lower pastures, respectively. The upper pasture contained an area of 74 ha while the lower pasture had about 85 ha. Mean elevation of the study pastures was about 2,357 m.

Upland portions of the Trout Creek floodplain have soils consisting of coarse textured alluvium while lower areas tend to be more finely textured. These alluvial deposits are derived from the disintegration of Pikes Peak Granite, an even grained to porphyritic pink

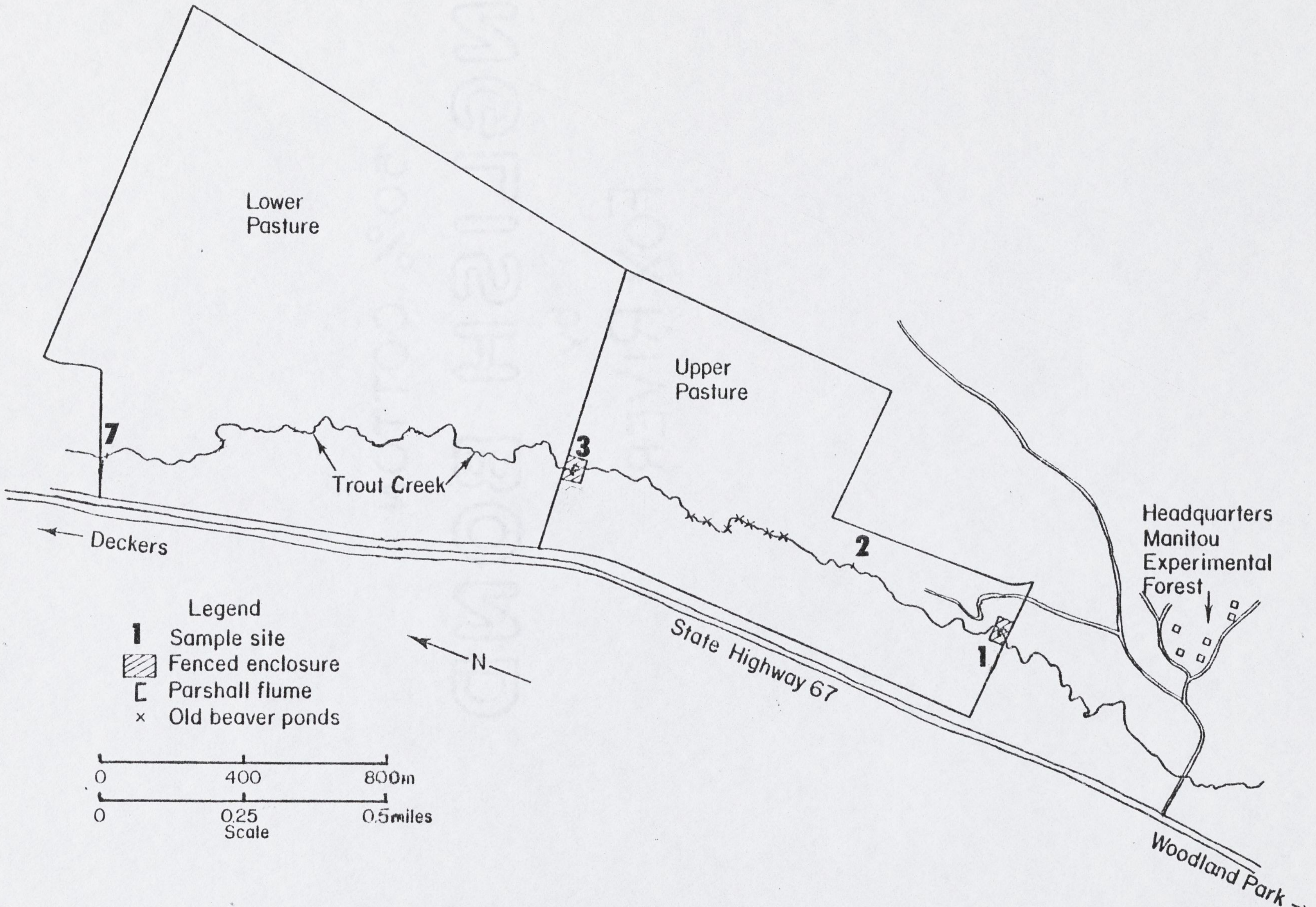


Figure 3. Map of Trout Creek grazing study area (Johnson, et al., 1978).

Figure 4. Upper study pasture including part of fenced enclosure around site 1.

Figure 5. Lower study pasture with Pikes Peak in background

rock consisting mostly of microcline and quartz (Marcus, 1973). This soil type has a high erosion potential, particularly if the plant cover is either removed or damaged. Figures 6 and 7 illustrate unstable soil and bank areas in both pastures. In addition, the soils have a high infiltration rate which precludes most overland flow (Dortignac and Love, 1961).

Upland vegetation in the study area was mainly bunchgrass such as Arizona fescue, mountain muhly or open ponderosa pine stands. The vegetation in the Lower floodplain included willows, sedges, rushes, buttercups, Kentucky bluegrass, common dandelion and various stages of weed succession (Figure 8). Approximately ten percent of the study area was contained within the moist floodplain, the remainder being in the drier and less productive slopes above (Johnson, et al., 1978).

The Trout Creek hydrograph is typified by a spring snowmelt peak followed by a recession limb sporadically interrupted by summer storm runoff. Following high intensity thunderstorms, these secondary peaks are occasionally greater than the snowmelt peak. Average non-flood stream flow varies from less than seven liters per second (ℓps) to over 550 ℓps (U.S.F.S., unpublished data). The stream course, during the past 35 years, has meandered over most of its 150 m wide floodplain in response to both floods and beaver activity (Gary, 1975). During this migration, the stream has deeply

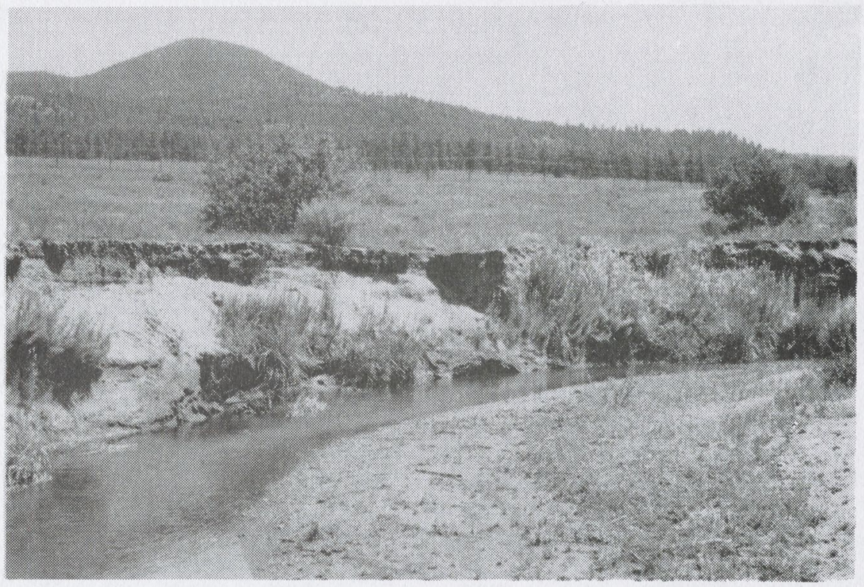


Figure 6. Unstable soil and bank area below site 1 in the upper pasture.

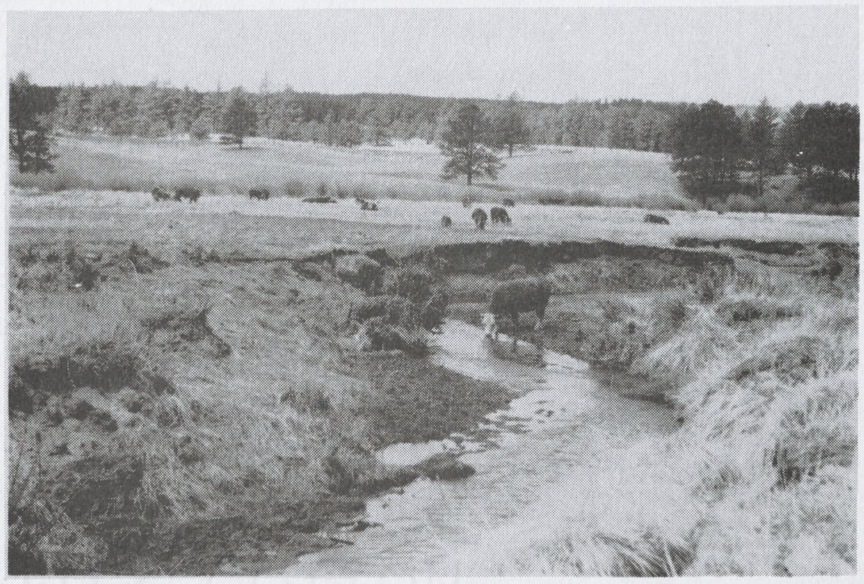


Figure 7. Unstable and trampled banks about midway between sites 3 and 7 in the lower pasture.

Figure 8. Upper pasture view illustrating the typical vegetative pattern found in the study area.

cut its alluvial base, leaving unstable and easily erodable banks of one to three meters high (Figures 6 and 7).

For the past several years, both study pastures have been used as spring holding areas for cattle and have been heavily stocked from mid-April until early June. The cattle are then removed and placed in other study areas, leaving these pastures ungrazed until the following spring. Overgrazing by this large number of cattle is insignificant due to the length of the holding period.

Study Sites

Initially four sampling sites were selected, three in the upper pasture and one in the lower pasture (Figure 3). Criteria used in site selection included location of flumes, pasture boundaries and areas of past beaver activity.

Site 1 was located just above a flume within a fenced enclosure at the upper pasture boundary. Site 2 was positioned about midway between the upper pasture boundaries but still above an area of breached beaver dams. Figure 9 illustrates one of the breached beaver dams and the accumulated silt and sediment behind the dam. These dams were destroyed and the beaver population removed during the winter prior to the first sampling season. Any additional beaver that attempted to build dams during the study period were live-trapped and their dams destroyed. Site 3 was placed within a fenced enclosure

Figure 9. View illustrating accumulated silt and sediment behind one of the breached beaver dams in the upper pasture.

just above a flume at the upper/lower pasture boundary. Site 7 was located just above the boundary fence in the lower pasture.

Sampling

The study was divided into eight time periods as shown in Table 2: two periods represent grazing by 150 cows in the lower pasture only; two periods represent grazing by 40 cows in the upper pasture only; and four periods represent non-grazing of either pasture. One-half of these numerical amounts were calves in both cases. As illustrated in Table 2, the number of sample collection events varied from twice in Period 7 to 11 times in Period 3. Sampling frequency varied from every other day in Period 1 to monthly in Period 4. Samples were drawn at least weekly during all grazing periods. No samples were drawn during the winter between Periods 4 and 5. Infrequent storm samples were also collected during both grazing seasons.

Sampling was done at the same approximate time each day (7:00 - 8:30 AM) when grab samples were collected in sterilized polyethylene bottles. The order of sample collection was site 7 through site 1, working upstream. Samples were iced from time of collection until analysis at the Experimental Forest laboratory, usually within 1.5 hours of the site 7 collection.

Table 2. Listing of treatment periods, with inclusive dates, numbers and locations of grazing cattle by period, and number of sampling events in each period.

PERIOD	DATE	PASTURES UPPER	PASTURES LOWER	STOCKING INTENSITY	SAMPLING EVENTS
1	15 April - 14 June 1977 (sampling began on 2 June)	un-grazed	grazed	150	6
2	15 June - 24 June 1977	un-grazed	un-grazed		5
3	25 June - 14 Oct 1977	grazed	un-grazed	40	11
4	15 Oct - 12 Nov 1977	un-grazed	un-grazed		3
5	4 Mar - 20 April 1978	un-grazed	un-grazed		4
6	21 Apr - 14 June 1978	un-grazed	grazed	150	7
7	15 June - 25 June 1978	un-grazed	un-grazed		2
8	26 June - 16 August 1978	grazed	un-grazed	40	8

Parameters Sampled and Methods of Determination

Field Measurements

Discharge (Q) was measured at sites 1 and 3 using the depth-discharge relationship in the Parshall Flumes. These flumes were equipped with FW-1 Stream Height Recorders, providing a continuous record of discharge for most of the study period.

Water temperature was obtained from the thermister on a dissolved oxygen probe and recorded to the nearest 0.5°C. The temperature was frequently checked with a laboratory-grade mercury thermometer.

Laboratory Measurements

Hydrogen ion activity (pH), suspended and total dissolved solids, nitrate-nitrogen, ammonia-nitrogen, orthophosphates and bacterial densities were analyzed in the Experimental Forest laboratory. All analyses except final weighing and bacterial counts were accomplished the same day as collection.

Hydrogen ion activity was measured with a Hach Specific Ion Meter, routinely within two hours of collection and recorded to the nearest 0.1 pH unit. The meter was equipped with a temperature compensation dial readable to 1°C. Sample temperatures were maintained at or below their collection temperatures prior to pH determination.

Suspended solids (SS) and total dissolved solids (TDS) concentrations were determined using the gravimetric filtration technique as described in Standard Methods (A.P.H.A., 1975). Two hundred to 400 ml sample volumes were filtered while 100 ml of the filtrate was used in the TDS analysis. GF/C filters and porcelain crucibles were used and all weighing was done on a Mettler-H Balance. Suspended solids and total dissolved solids results were recorded as mg/ℓ.

Nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N) and orthophosphate (PO_4) concentrations were made colorimetrically on filtered samples following procedures outlined in the Hach Procedures Manual (Hach Chemical Company, 1975). Premeasured reagent powder pillows and reagent solutions were obtained from the Hach Company. A Bausch and Lomb Spec 70 Spectrometer was used in these determinations.

A filtered sample was used to remove any turbidity effects which might have interfered with the reagent-induced color. Thus, results were recorded as mg/ℓ NH_3-N, NO_3-N and PO_4 following filtration. The standard curves used in this procedure were prepared for each reagent batch and checked occasionally using standard solutions.

Fecal coliform and fecal streptococci bacterial densities were determined using the membrane filtration technique with two dilutions per sample to assure a countable range (Millipore Corporation, 1973).

Total elapsed time from sample collection at site 7 until incubation of the last dish was routinely two hours. Results were recorded as colonies/100 mℓ of sample.

Cattle Observations

In addition to water quality analyses and in an attempt to correlate water quality with cattle usage, observations of cattle numbers and activities were made during both grazing seasons. The first season's data consisted of numbers and locations of cows at one to three hour intervals. The second season data consisted primarily of observations collected by following one cow for 12 hour periods and noting its location and both physical and physiological activity every five minutes. Notation was made at the end of each hour as to location of most of the cattle herd.

Fecal Deposit Collection

In May 1977, an attempt was made to estimate the potential cattle waste contribution within three meters either side of the stream channel. Fifteen days after all fecal deposits within the three meter strip on either side of the channel had been painted orange, all new deposits were counted, collected and weighed. This weight was then used with other available information such as average fecal deposition per cow per day to calculate an estimate of the available pollution potential within a nine meter band (three meters either side of the channel which averaged about three meters in width). This calculation assumed that a calf would deposit only three-quarters of the amount of fecal material of an adult.

Statistical Analyses

A two-way Analysis of Variance was used to examine differences between the three main sites. Site and Time were the two main factors while the 90 percent level of confidence was used in this comparison.

Additional comparisons of site means for each period were then made to identify homogeneous and heterogeneous groupings. That is, sites which had means significantly different from the other two means at the 95 percent confidence limit ($\alpha = 0.05$) were identified. The specific name for this test is Tukey's H.S.D. Test or simply a Multiple Comparison Procedure.

RESULTS AND DISCUSSION

The amounts of raw data and statistical analyses collected and generated during this study were too voluminous to be included in this paper. However, data and statistical comparisons are provided in a tabular, summarized form in this section. The raw data and statistical information is on file at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

The results of this study will be discussed in ten sections. The first nine correspond to the various grazing/non-grazing periods illustrated in Table 2. For convenience of comparison, the figures and tables included in this section were prepared for each year, 1977 and 1978, with four periods included on each. Section ten will discuss the cow observation and fecal deposit data.

The figures in this chapter include individual site measurements for each of the three sites for periods 1 through 4 and 5 through 8. Tables provided are divided into sections labeled "Mean and Standard Deviation" and "Statistical Significance", comparing both sites and periods. The section labeled "Statistical Significance" refers to the two-way Analysis of Variance comparing the three sites. Within the "Mean and Standard Deviation" section of the table, an asterisk (*) denotes a statistical difference between this mean and the others at the five percent level ($\alpha = 0.05$).

Occasional reference is made in this section to both discharge and precipitation data. Discharge for site 1 is included in Appendices A and B while precipitation data collected at the Experimental Forest Headquarters is summarized in Appendix G.

The results of the eight grazing/non-grazing periods are summarized in Tables 3 through 12. In general, only the fecal coliform and fecal streptococci densities consistently demonstrated a cattle grazing impact. The two nitrogen species occasionally suggested a grazing contribution while the suspended solids analysis was confounded by contributions from the breached beaver dam area. Orthophosphate concentrations were highly variable both between and among sites and appear to be independent of cattle grazing. As a result, the orthophosphate data will not be included in the various period discussions but are included in Appendices C-F.

During several of these periods, moderate to high concentrations of several parameters were measured at site 1. Wildlife centered in and around the active beaver dams just above site 1 are assumed to be responsible. The metabolic wastes of these animals would be readily available for stream transport and subsequent measurement at site 1. Besides beaver, muskrat and numerous other small mammals were often seen in this area.

Period 1

The 150 cows had been present in the lower pasture (between sites 3 and 7) for over 45 days prior to collection of the first water sample. A total of six samples were collected during the period. Significant differences were found in suspended solids, fecal coliform and fecal streptococci concentrations.

The results of the suspended solids analyses are illustrated in Figure 10 and summarized in Table 3. Figure 10 illustrates the contribution of the breached beaver dam area in that site 3 is high or highest on all sampling days. Analysis of site 2 data confirmed the source area. Table 3 presents several important points: 1) a significant difference was found between sites ($\alpha = .011$); 2) the site 1 mean was significantly different from the means at sites 3 and 7; and 3) the mean suspended solids concentration increased dramatically between sites 1 and 3 while decreasing only slightly at site 7.

Clearly, silt and sediment which had accumulated behind the beaver dams prior to breaching was now being transported to the downstream sites, only part of which settled out before site 7. Visual comparison of the suspended solids filters, particularly the darker colors on site 3 filters, suggested a much higher proportion of fine silt and sand at sites below these dams. The instability of this area is reflected in the fact that even small (less than 14 ℓps) increases

Figure 10. Suspended Solids Concentrations at Sites 1, 3 and 7 for Periods 1 through 4, 1977.

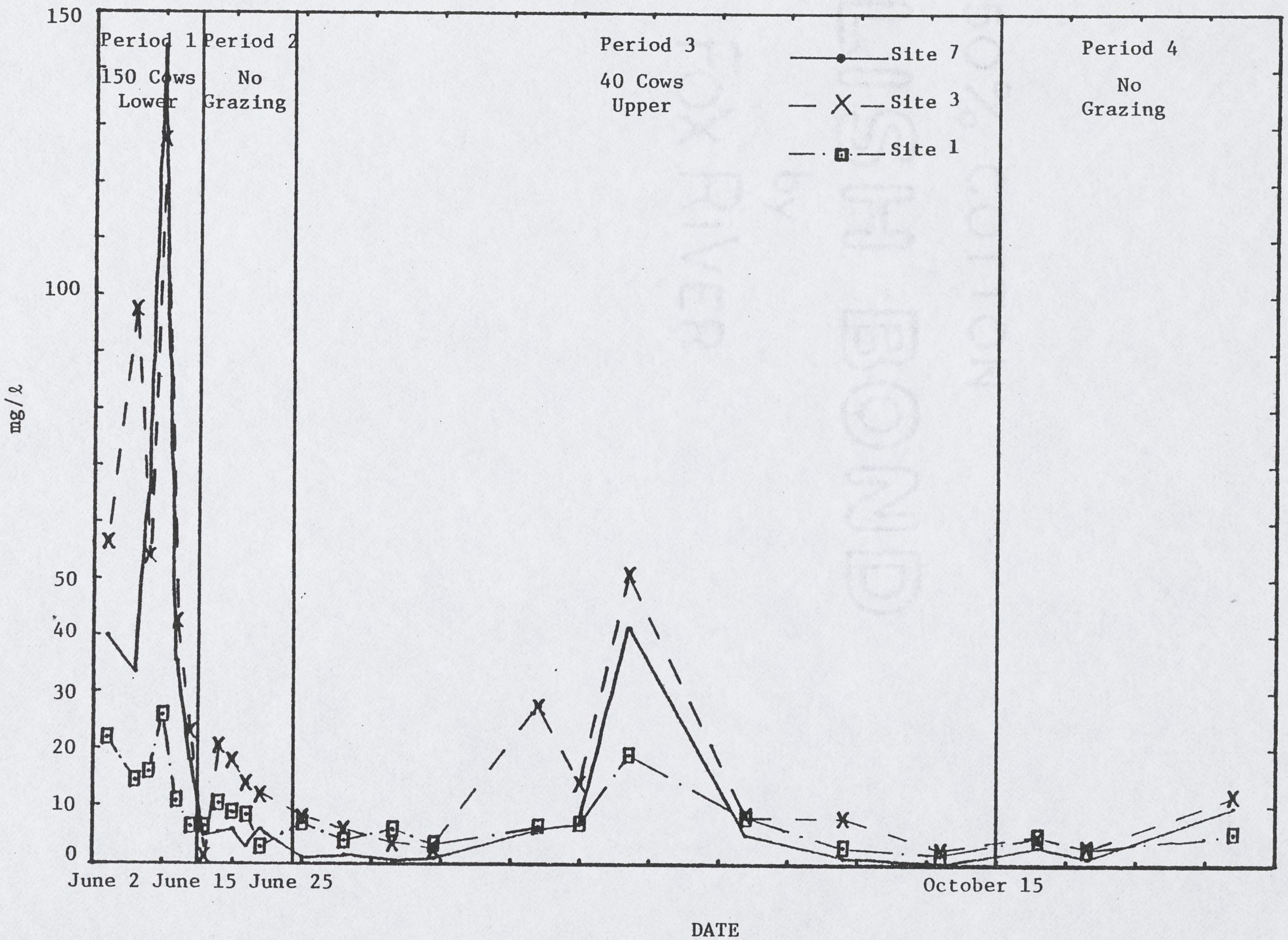


Table 3. 1977 Suspended Solids Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 1 through 4.

	PERIODS							
SITE	1 150 Cows Lower Pasture		2 No Grazing		3 40 Cows Upper Pasture		4 No Grazing	
	MEAN AND STANDARD DEVIATION (mg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	16*	7	7.5	2.9	6.6	4.9	4.3	1.6
3	67	38	13.2	7.4	13.2	15.2	6.5	4.8
7	56	46	5.1	1.2	6.5	12.6	4.7	4.7
	STATISTICAL SIGNIFICANCE							
	.011		.01		.038		N.S.	

*Significant Difference in this mean at .05 level.

N.S. - Non-significant at .10 level.

in discharge resulted in increased suspended solids concentrations at downstream sites.

Figure 11 illustrates the ammonia-nitrogen concentrations for 1977. Examination of Period 1 data suggests a similar decreasing trend among all three sites, but no trend between sites is apparent. The overall trend illustrated among these sites appears to be a mirror image of the discharge pattern (Appendix A), suggesting a discharge dilution effect. Table 4 illustrates both the uniformity and increasing downstream trend for the three site means. The site 1 mean of 273 $\mu g/\ell$ reveals the moderate background concentration of ammonia-nitrogen present in the stream even before it reaches the grazed area.

Analysis of nitrate-nitrogen concentrations for this period suggests a cattle impact partially masked by measurement variability and upstream or groundwater contributions. Figure 12 illustrates the variability both between and among sites, revealing no visible trend in measured concentrations.

Examination of the standard deviations about the means in Table 5 statistically illustrates this variability. Also shown is a trend toward a downstream increase in mean concentrations. Thus, any suggestion of a grazing impact based on the increase in mean concentrations between sites 3 and 7 is weakened. The mean increase of only 73 $\mu g/\ell$ between sites 3 and 7, particularly when compared to the mean background concentration of 354 $\mu g/\ell$ measured at site 3,

Figure 11. Ammonia-Nitrogen Concentrations at Sites 1, 3 and 7 for Periods 1 through 4, 1977.

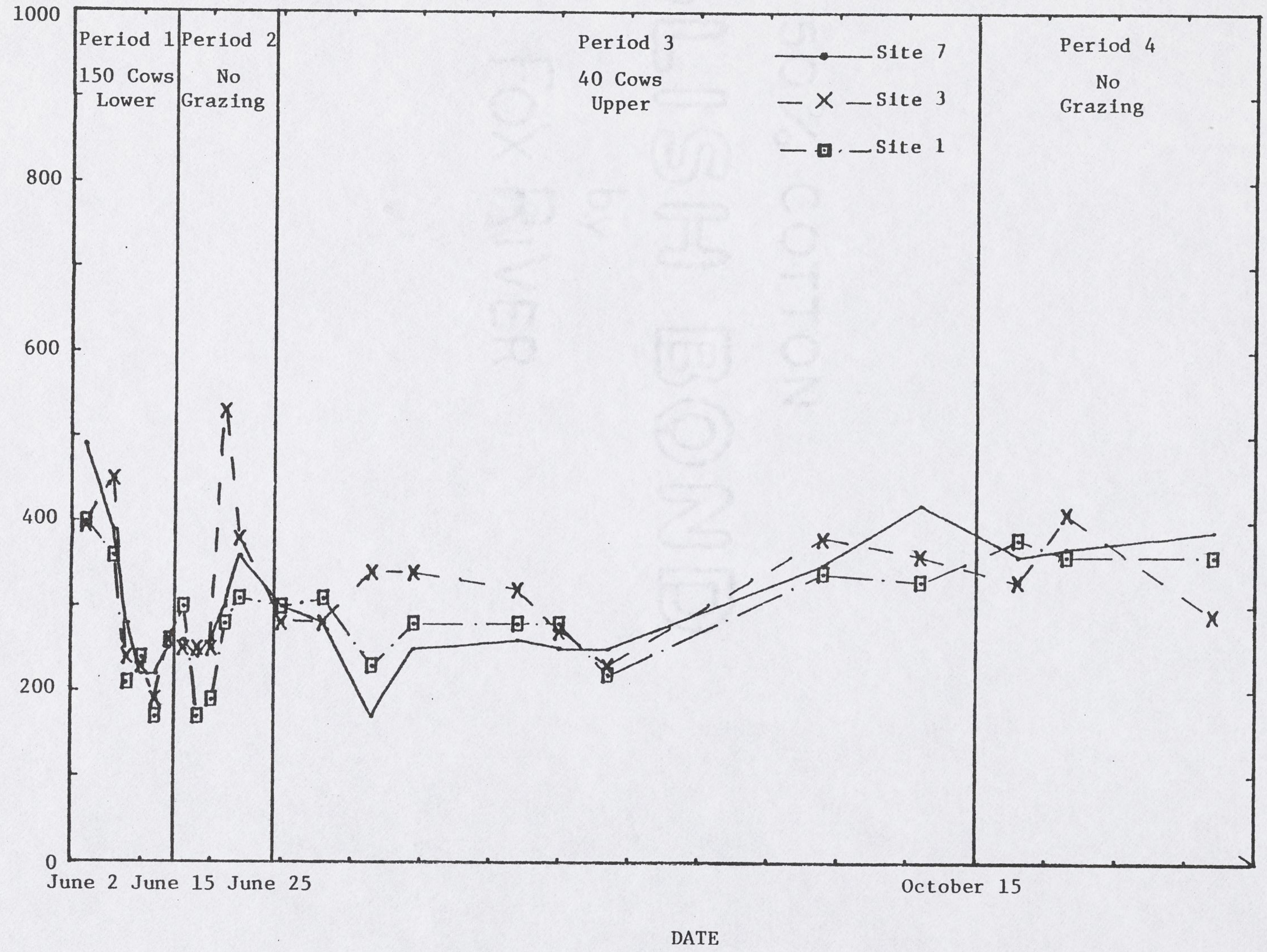


Table 4. 1977 Ammonia-Nitrogen Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 1 through 4.

	PERIODS							
SITE	1 150 Cows Lower Pasture		2 No Grazing		3 40 Cows Upper Pasture		4 No Grazing	
	MEAN AND STANDARD DEVIATION (μg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	273	89	250	65	286	41	367	12
3	294	103	332	124	311	49	343	61
7	308	109	284	48	281	71	373	15
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		N.S.		N.S.	

N.S. - Non-significant at .10 level.

Figure 12. Nitrate-Nitrogen Concentrations at Sites 1, 3 and 7 for Periods 1 through 4, 1977.

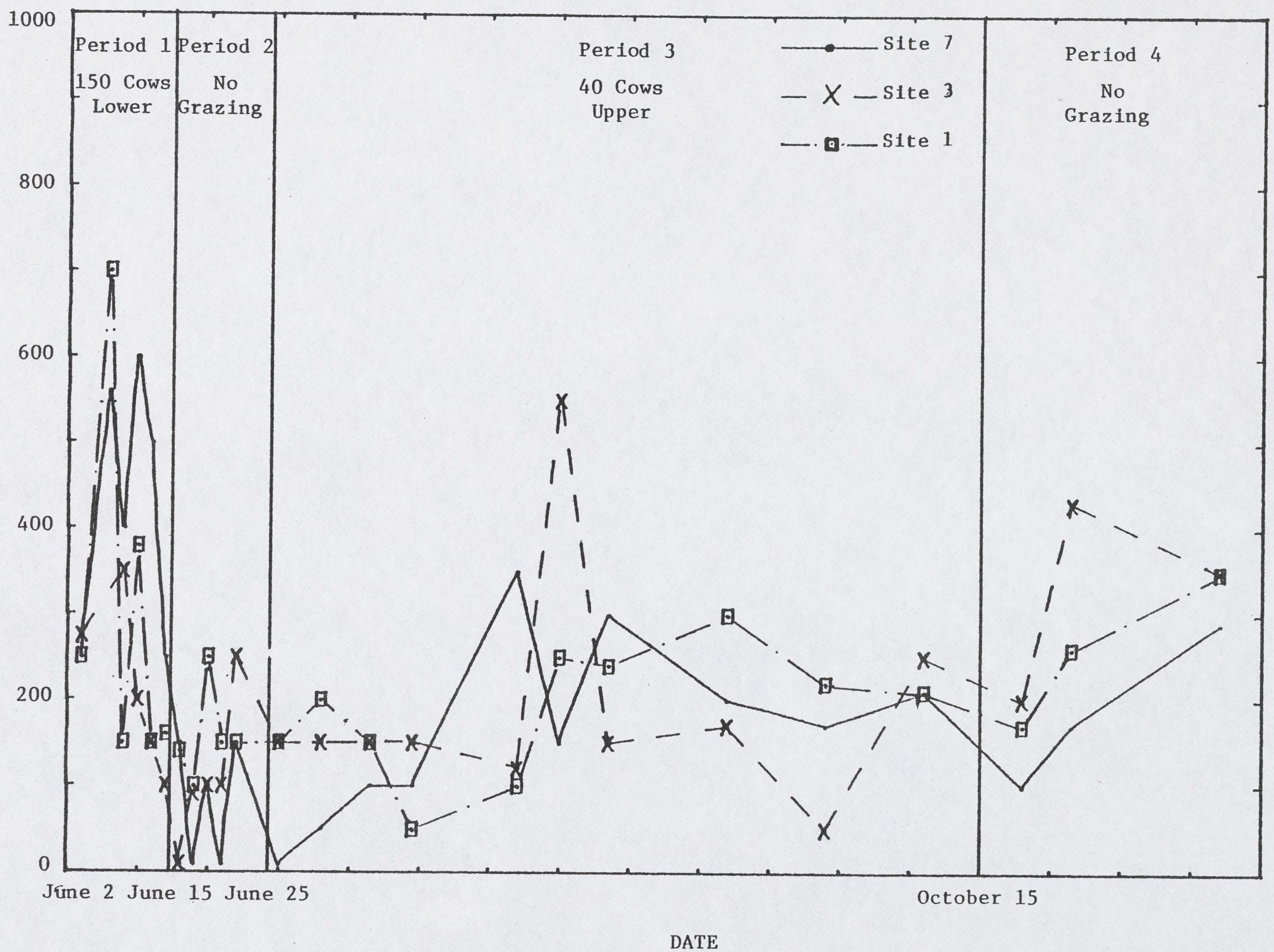


Table 5. 1977 Nitrate-Nitrogen Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 1 through 4.

	PERIODS							
	1 150 Cows Lower Pasture		2 No Grazing		3 40 Cows Upper Pasture		4 No Grazing	
SITE	MEAN AND STANDARD DEVIATION ($\mu g/\ell$)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	298	216	158	55	187	75	260	90
3	354	352	110	87	189	136	327	117
7	427	152	84	71	164	106	187	96
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		N.S.		.095	

N.S. - Non-significant at .10 level.

implies that any grazing contributions were minor. The mean increase of 73 represents less than 21 percent of the site 7 mean.

Fecal coliform densities for this period clearly indicate the contributions of cattle in the lower pasture. As illustrated in Figure 13, site 7 was highest on all six sampling days while sites 1 and 3 were both similar but much lower. Table 6 reveals: 1) the substantial increase in the mean concentration between sites 3 and 7; 2) a highly significant difference between sites ($\alpha = .001$); and 3) the site 7 mean was significantly different from the means at sites 1 and 3. While comparison of the means at sites 1 and 3 demonstrate an increasing amount of background fecal coliform contamination, cattle were clearly contributing additional fecal coliform organisms between sites 3 and 7. The site 7 mean was over seven times the site 3 mean and 13 times the site 1 mean.

Table 6 also lists median concentrations in a format similar to the means. Calculation of a median is often valuable in removing the effects of extreme values, a common problem in indicator bacteria research. In this case, however, the median results are much the same as the comparisons of the means, suggesting a significant grazing contribution between sites 3 and 7.

Fecal streptococci concentrations for this period also suggest a grazing cattle contribution. Figure 14 illustrates both the variability and magnitude of the site 7 concentrations, the latter implying

Figure 13. Fecal Coliform Concentrations at Sites 1, 3 and 7 for Periods 1 through 4, 1977.

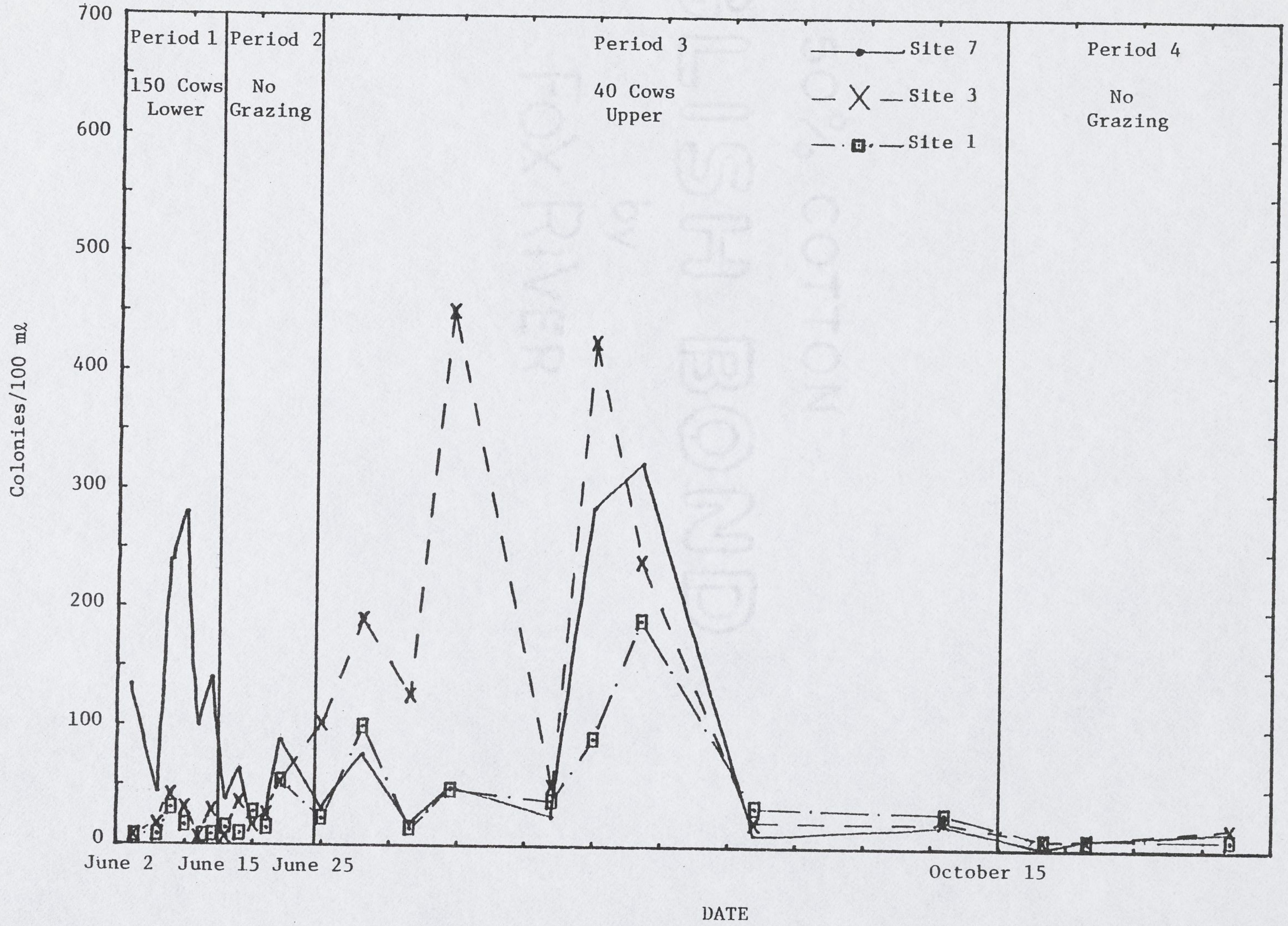


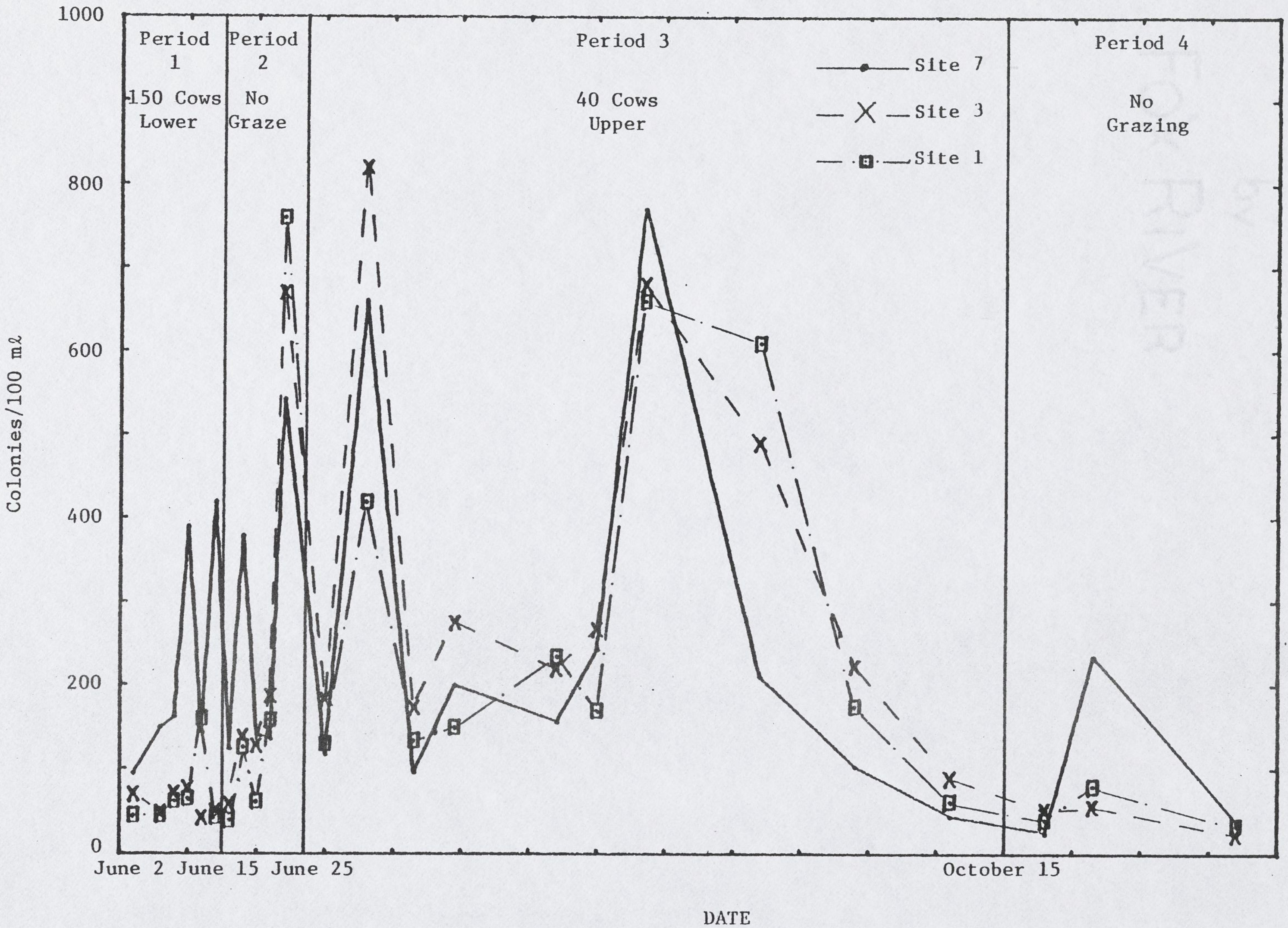
Table 6. 1977 Fecal Coliform Mean ($\bar{x}$), Standard Deviation (s), Statistical Significance and Median Concentration for Sites 1, 3 and 7 for Periods 1 through 4.

SITE	1 150 Cows Lower Pasture		2 No Grazing		3 40 Cows Upper Pasture		4 No Grazing	
	MEAN AND STANDARD DEVIATION (colonies/100 mℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	12	11	24	18	63	56	6	4
3	21	15	28	18	180	163	9	8
7	156*	88	47	29	93	122	9	8
	STATISTICAL SIGNIFICANCE							
	.001		.06		.032		N.S.	
	MEDIAN CONCENTRATION (colonies/100 mℓ)							
1	9		15		38		7	
3	23		26		126		8	
7	137		38		31		9	

*Significant Difference in this mean at .05 level.

N.S. - Non-significant at .10 level.

Figure 14. Fecal Streptococci Concentrations at Sites 1, 3 and 7 for Periods 1 through 4, 1977.



a grazing impact. Table 7 more clearly illustrates this conclusion. Important points to be drawn from this fecal streptococcus analysis include: 1) the highly significant difference between sites ($\alpha = 0.014$); 2) the substantial increase in mean concentration between sites 3 and 7 (from 60 to 227 colonies/100 $m\ell$); and 3) the site 7 mean was statistically different from the means at sites 1 and 3. Similar to the fecal coliform analysis, the grazing cattle were providing fecal streptococci bacteria by way of their feces which was reaching the stream and adding to the background concentration. Comparison of fecal streptococci median concentrations yields the same conclusions as those indicated by the means.

Variability in both indicator bacterial densities, and particularly in the fecal streptococci counts, appeared partially dependent upon precipitation events. These precipitation events were of such long duration and low intensity ($\leq$ five mm spread over several hours) that surface runoff from all but within-channel areas was negligible. Likewise, discharge increases were hardly detectable. Increased counts following such events are probably due to bacteria within the channel being flushed into the stream or perhaps the cloud cover has a significant effect upon the ultra-violet (UV) radiation-bacterial die-off relation. Kunkle and Meiman (1968) reported that exposure to sunlight had a significant influence on coliform bacteria die-off. They reported

Table 7. 1977 Fecal Streptococci Mean ($\bar{x}$), Standard Deviation (s), Statistical Significance and Median Concentration for Sites 1, 3 and 7 for Periods 1 through 4.

SITE	PERIODS 1 150 Cows Lower Pasture		2 No Grazing		3 40 Cows Upper Pasture		4 No Grazing	
	MEAN AND STANDARD DEVIATION (colonies/100 mℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	70	45	229	301	275	212	51	25
3	60	15	236	247	342	241	44	18
7	227*	140	265	189	260	249	99	118
	STATISTICAL SIGNIFICANCE							
	.014		N.S.		N.S.		N.S.	

*Significant Difference in this mean at .05 level.

N.S. - Non-significant at .10 level.

SITE	1	2	3	4
	MEDIAN CONCENTRATION (colonies/100 mℓ)			
1	54	126	173	40
3	60	138	245	52
7	156	141	178	38

extreme die-off in the unshaded bottle of a pair within only one to two hours of exposure.

Another important factor in this precipitation/increased count relation is the release of sediment-attached bacteria as these particles are picked up and transported. Kunkle (1970) reported that channel stimulation by wading resulted in bacterial counts increasing a full order of magnitude. A combination of the above explanations was probably responsible for the measured variability.

As indicated before, indigenous wildlife such as beaver, muskrat and other small mammals were probably responsible for the concentrations measured at site 1. They may also be responsible for some of the measured variation between sites in the study area. Mundt (1963) reported on the enterococci bacteria found in several wildlife species, particularly mammals and birds. He reported that the raccoon was found to have up to 37 million fecal streptococci colonies/gram of feces. Thus a single streamside defecation during a visit from a certain wildlife species represents a tremendous source of measurement variation.

Period 2

This period represented a ten day post-grazing interval intended to examine residual effects from grazing in the lower pasture. Five samples were collected and analyzed. Only the suspended solids and fecal coliform analyses displayed any significant differences.

As in Period 1, a significant difference between sites in the suspended solids analysis was due to the influence of the breached beaver dams on the site 3 measurement (Figure 10). As shown in Table 3, the significant difference between sites was sustained during this period although the level of significance was higher (less significant) and the individual site means were much lower, apparently in response to the reduced discharge. Site 7 had the lowest mean concentration for the period (5.1 mg/ℓ), indicating that a majority of the sediment concentration measured at site 3 (mean of 13.2 mg/ℓ) was redeposited in the stream before reaching site 7.

Ammonia-nitrogen concentrations were still somewhat variable, particularly with respect to site 3 (Figure 11). The means were less similar than during Period 1 (Table 4). Mean concentrations were only slightly different from the preceding grazed period, implying that ammonia-nitrogen concentrations were independent of grazing activity.

Nitrate-nitrogen concentrations during this period were substantially lower than Period 1 means, at least partially due to the reduction in the upstream contribution (Table 5). Directly opposite the Period 1 trend, mean concentrations now <u>decrease</u> in the downstream direction. This suggests a lack of residual grazing effects as well as an increase in plant usage in the lower pasture. Since the upper pasture supported a larger amount of streamside vegetation, the dense algal growth in the lower pasture stream reach may have been responsible for this increased plant usage. The reduced discharge and scarcity of rain may have removed the pathway that nitrate-nitrogen compounds were using to reach the lower sites, thus the lower measured concentrations.

As illustrated in Figure 13, the fecal coliform concentrations were more variable between sites during this period while site 7 was no longer consistently highest. Site 7 measurements were substantially higher than values at the other two sites until about midway in Period 2, however, suggesting a short-term residual effect. Concentrations at sites 1 and 3 were very similar to Period 1 measurements while site 7 concentrations were lower.

Table 6 more clearly defines the trends suggested in Figure 13. There was still a significant difference between the three sites ($\alpha = 0.06$) but the site 7 mean was no longer statistically different from the means at sites 1 and 3. The most important point shown in the table for this period was the residual effect at site 7, as mentioned in the figure analysis. Sites 1 and 3 registered increases in mean counts (to 12 and 7 colonies/100 mℓ, respectively) but were still less than the decreased mean at site 7 (47 colonies/100 mℓ, down from the Period 1 mean of 156). Median values were similar to those of the means.

As illustrated in Figure 14, the site 7 fecal streptococci concentration was highest until about midway in Period 2, as well as the most variable of the period. The high counts at all three sites on the 24th of June came on a morning following a precipitation event of 43 mm on the preceding afternoon and evening. The storm probably flushed fecal streptococci bacteria into the stream from the active beaver dam area, hence the higher count at site 1.

In general, fecal streptococci means for this period were much higher than those recorded in Period 1 but the smallest mean increase occurred at site 7 (Table 7). The overall increase was attributed to an increase in upstream contribution measured at site 1 (from 70 to 229 colonies/100 mℓ between the two periods). There was no longer a significant difference between the three sites, nor was the site 7 mean still statistically different from the other two means. The loss of a significant difference between sites and between means following removal of the cattle further suggested a grazing impact during Period 1. The increase in upstream fecal streptococci concentrations measured at site 1 confounds the analysis of residual effects.

Median concentrations were much lower but very similar in trend to mean concentrations. These median values were lower because the calculation removed most of the effect of the one high count at all three sites on June 24th.

Period 3

In this period, 40 cows were allowed to graze the upper pasture while the lower pasture remained ungrazed. Samples were collected on 11 occasions, revealing significant differences in both the suspended solids and fecal coliform concentrations. The most important comparisons will be made between sites 1 and 3, located above and below the grazed pasture.

Figure 10 illustrates the continuing tendency for site 3 to maintain the highest suspended solids concentrations, apparently a residual effect of the breached beaver dams. The high concentrations shown for all three sites on August 16th resulted from a precipitation event of ten mm on the preceding evening. Storm generated discharge peaked at about 114 ℓps (up from a pre-storm average of about 72 ℓps), providing the stream energy to both erode and transport channel material, particularly from the breached beaver dam area.

As shown in Table 3, the means for sites 1 and 7 were very similar but the site 3 mean was about double this figure. Clearly the breached beaver dam area was still providing a substantial amount of sediment to the stream, masking any impacts from the 40 cows. The significant difference between sites ($\alpha = .038$) was due to both this source area and the fact that most of the sediment settled out before site 7. During the second statistical comparison, substantial variance about the means prevented the site 3 mean from being significantly different from the means at sites 1 and 3.

Ammonia-nitrogen concentrations were somewhat less during this period as compared to the preceding period and, in general, a similar trend was evident among all three sites for the interval (Figure 11). Comparison of period means in Table 4 reveals a similarity between all three sites, particularly between sites 1 and 7. The mean increase in stream concentration between sites 1 and 3 of 25 $\mu g/\ell$ was attributed to a grazing contribution but this amount was minimal when compared to the measured background concentration of 286 $\mu g/\ell$.

Nitrate-nitrogen concentrations appeared to be independent of grazing influences, illustrating a high degree of variability both between and among sites and a lack of any definite trend in site 3 measurements (Figure 12). Table 5 indicates an increase in mean concentration at all three sites for this period but more importantly, reveals that sites 1 and 3 were almost identical while site 7 was slightly lower. Both the ammonia-nitrogen and nitrate-nitrogen concentrations continued to reflect a moderate amount of upstream contamination.

The fecal coliform analysis clearly suggests a cattle contribution in addition to background stream counts between sites 1 and 3. Figure 13 illustrates that site 3 recorded the highest counts for most of this period. Site measurements were highly variable until mid-period (early September) at which time all three sites began to exhibit similar, low counts on all sample days.

Table 6 more clearly suggests the grazing contribution. The mean at site 3 is substantially higher than the means at sites 1 and 7 and a statistically significant difference ($\alpha = 0.032$) was found between the three sites. Apparently the cattle contributed fecal coliform bacteria to the background stream concentration and only part of this total was removed before site 7.

Indigenous wildlife, still primarily based in and around the active beaver dams just above site 1 are probably responsible for at least part of the variability in the measured concentrations at all three sites. Activities of cattle within the channel such as direct fecal deposition, sediment disruption or tracking in of land deposited feces might also be responsible for much of the variation in downstream measurements.

Precipitation events (both less than 13 mm) appear to have influenced fecal coliform peaks on both July 6th and August 16th when moderate counts were recorded at all three sites. These small magnitude events apparently flushed bacteria into the stream from both above and within the study area because all sites demonstrated similar increases. Site 3 was highest on one occasion while site 7 was greatest on the other.

Fecal streptococci concentrations also suggest a grazing cattle contribution in addition to moderate background counts. Figure 14 illustrates the variability in measured concentrations at all three sites, as well as exposing a trend for site 3 to record higher counts. Both fecal streptococci peaks during this period occurred in samples which followed precipitation events on the preceding afternoon and evenings, the same events detailed in the fecal coliform analysis Channel flushing, sediment disturbance, rainfall simulation or UV radiation interception by cloud coverage might all have interacted to cause these higher counts.

Comparison of site means in Table 7 suggests a cattle contribution between sites 1 and 3 but there was no significant difference between sites during this period. Data variability, as reflected in the standard deviations about the means, most likely caused the lack of statistical significance. The mean at site 3 increased from Period 2 while the means at sites 1 and 7 remained very similar. The trend of these means suggest that cattle waste products were adding additional fecal streptococci bacteria to the stream between sites 1 and 3 and natural die-off apparently removed the addition before site 7. Wildlife are again the probable sources of the upstream background concentration while UV radiation and bacterial predators are probably responsible for the reduction in concentrations measured at site 7.

Period 4

This period was designed as a post-grazing analysis of residual grazing effects in the upper pasture. Three samples were collected during this one month interval. Only the nitrate-nitrogen concentration demonstrated a significant difference between sites.

Suspended solids concentrations during this period were similar among the three sites (Figure 10). Table 3 reflects the overall low concentration among sites but also reveals the decreasing impact of the breached beaver dams. Sites 1 and 7 recorded similar mean concentrations while site 3 was only slightly higher. The differences were not statistically significant. Aside from a decreasing influence from the breached beaver dams, these results possibly suggest that a part of the site 3 grazed interval (Period 3) mean was attributable to cattle impacts. Freezing soils and a lack of precipitation events probably resulted in these lower mean concentrations during Period 4.

Ammonia-nitrogen concentrations remained variable between sites but varied in about the same range, 300-400 $\mu g/\ell$ (Figure 11). All three sites ranged from highest to lowest on at least one of the sampling days. Mean concentrations among sites were similar and are presented in Table 4.

The means at all three sites increased over those of Period 3 and were the highest of the entire study. Discharge during Periods 3 and 4 were very similar, suggesting that a dilution effect is not responsible for these higher concentrations. The larger contributions above site 1 were apparently solely responsible for higher means in the study area.

The source of the ammonia-nitrogen increase may have been the beaver located just above the study area. These animals were very active in this pre-winter period, reflected in the fact that three invading beaver had to be live-trapped and removed from the study area. As beaver release their waste products directly into water, the high concentration of ammonia-nitrogen measured at site 1 may have been influenced by the metabolic wastes of beaver above this site.

Nitrate-nitrogen concentrations illustrated little variability between sites as well as a trend towards increasing levels at all three sites (Figure 12). As seen in Table 5, the site 3 mean was substantially larger than the other two means and appears to suggest a residual effect from the cattle grazing period (Period 3) in addition to the upstream contribution. The increase in mean concentrations at all sites for this period as compared to the preceding period was due either to the increased wildlife activity or possibly to increased groundwater additions to the stream.

Fecal coliform concentrations have followed the trend observed in mid to late Period 3 in that all three sites exhibited both low and similar counts on sampling days (Figure 13). Apparently the bacteria were responding to climatic effects which were masking any residual effects from the grazing period.

Table 6 also demonstrates this point by revealing only a slight increase (3 colonies/100 mℓ) in the mean concentrations between sites 1 and 3. Lower stream and air temperatures as well as a scarcity of precipitation events apparently negated the residual effects which were found in the earlier grazed-postgrazed comparison (Periods 1-2). Comparisons of median values were also similar to the mean concentrations.

Fecal streptococci concentrations also reflected this climatic effect and decreased to the lowest overall levels of the season. Figure 14 illustrates the trend towards lower concentrations at all three sites as well as an increase at all three sites on October 22nd. These higher counts were apparently related to stream channel flushing from a small precipitation event (four mm) on the preceding day. Table 7 illustrates the similarity between means for sites 1 and 3 while the site 7 mean was about double this figure. The site 7 peak on October 22nd contributed substantially to this higher mean. The influence of this point was removed however, in the median calculation. Comparison of the medians in Table 7 illustrated a similarity among the three sites and implied little residual effect from the cattle above site 3.

Period 5

This was the first period of the 1978 study season and was designed to provide pre-grazing data for lower pasture comparisons in the period to follow. Four samples were collected at sites 1 and 3 while only three samples were taken at site 7 due to an iced-over condition during one sampling run. In addition, only one fecal coliform analysis was obtained due to a malfunction of the water bath incubator.

Both Figure 15 and Table 8 show that the breached beaver dams were continuing to influence downstream suspended solids concentrations. Discharge during this period averaged about 85-110 ℓps, providing the stream energy to transport accumulated sediment from the area. Visually, vegetation had begun to stabilize much of the higher channel areas but low lying areas continued to be highly susceptible to erosion. The site 3 mean of 12.3 mg/ℓ was over twice the size of the means at sites 1 and 7, which were similar at 6.1 and 5.3 mg/ℓ, respectively. The variability illustrated in Figure 15, possibly due to the small snowmelt period and ice conditions, resulted in these differences being non-significant. Standard deviations about the means listed in Table 8 also express this degree of variability and further explain the lack of significant difference.

Ammonia-nitrogen concentrations continued to be highly variable both between and among sites as illustrated in Figure 16 while Table 9

Figure 15. Suspended Solids Concentrations at Sites 1, 3 and 7 for Periods 5 through 8, 1978.

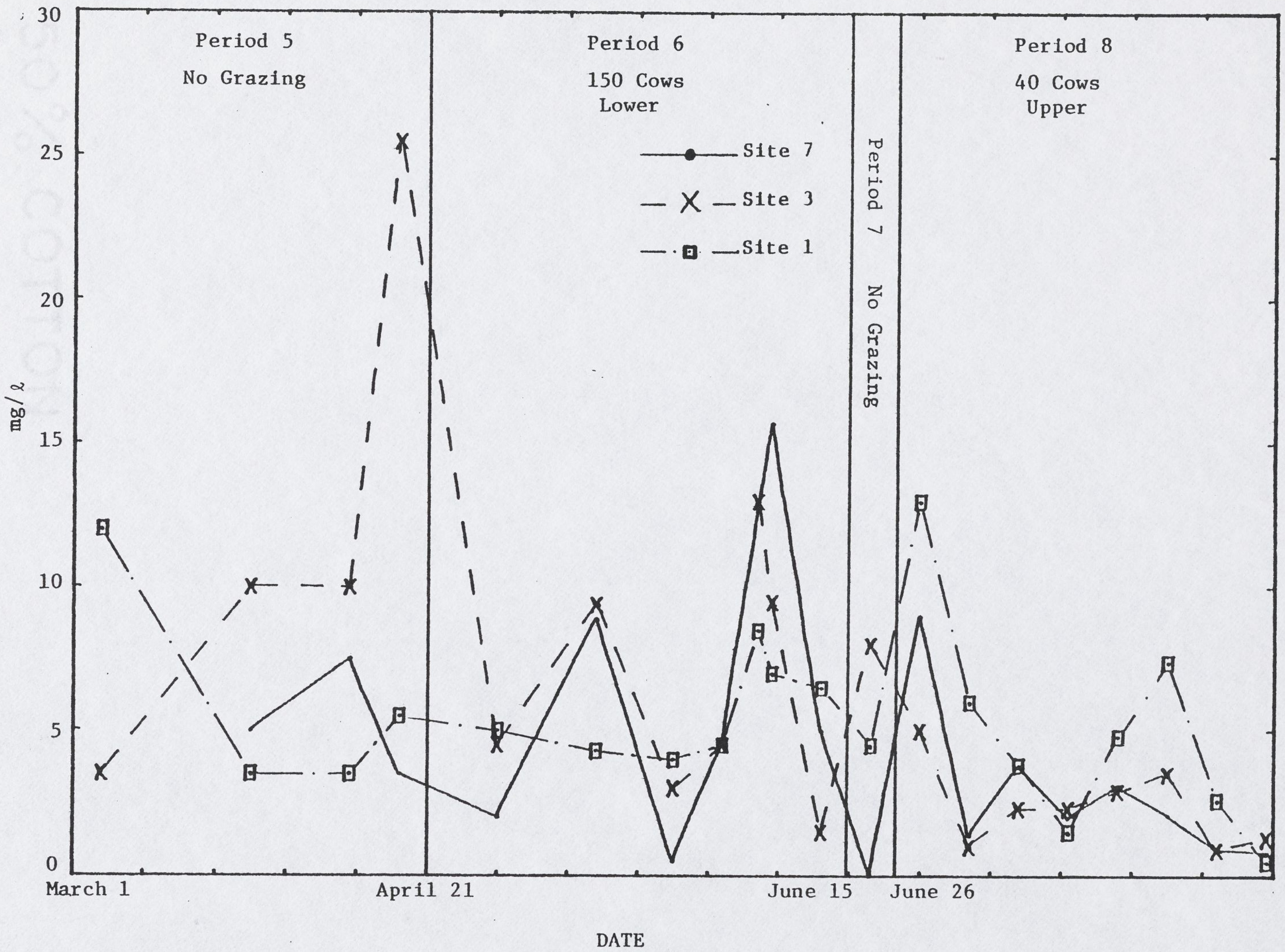


Table 8. 1978 Suspended Solids Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 5 through 8.

SITE	5 No Grazing		6 150 Cows Lower Pasture		7 No Grazing		8 40 Cows Upper Pasture	
	MEAN AND STANDARD DEVIATION (mg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	6.1	4.0	5.7	1.7	4.5	-	5.0	4.0
3	12.3	9.3	6.5	4.2	8.0	-	2.4	1.4
7	5.3	2.0	6.1	5.5	0.0	-	2.9	2.7
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		-		.02	

N.S. - Non-significant at .10 level.

Figure 16. Ammonia-Nitrogen Concentrations at Sites 1, 3 and 7 for Periods 5 through 8, 1978.

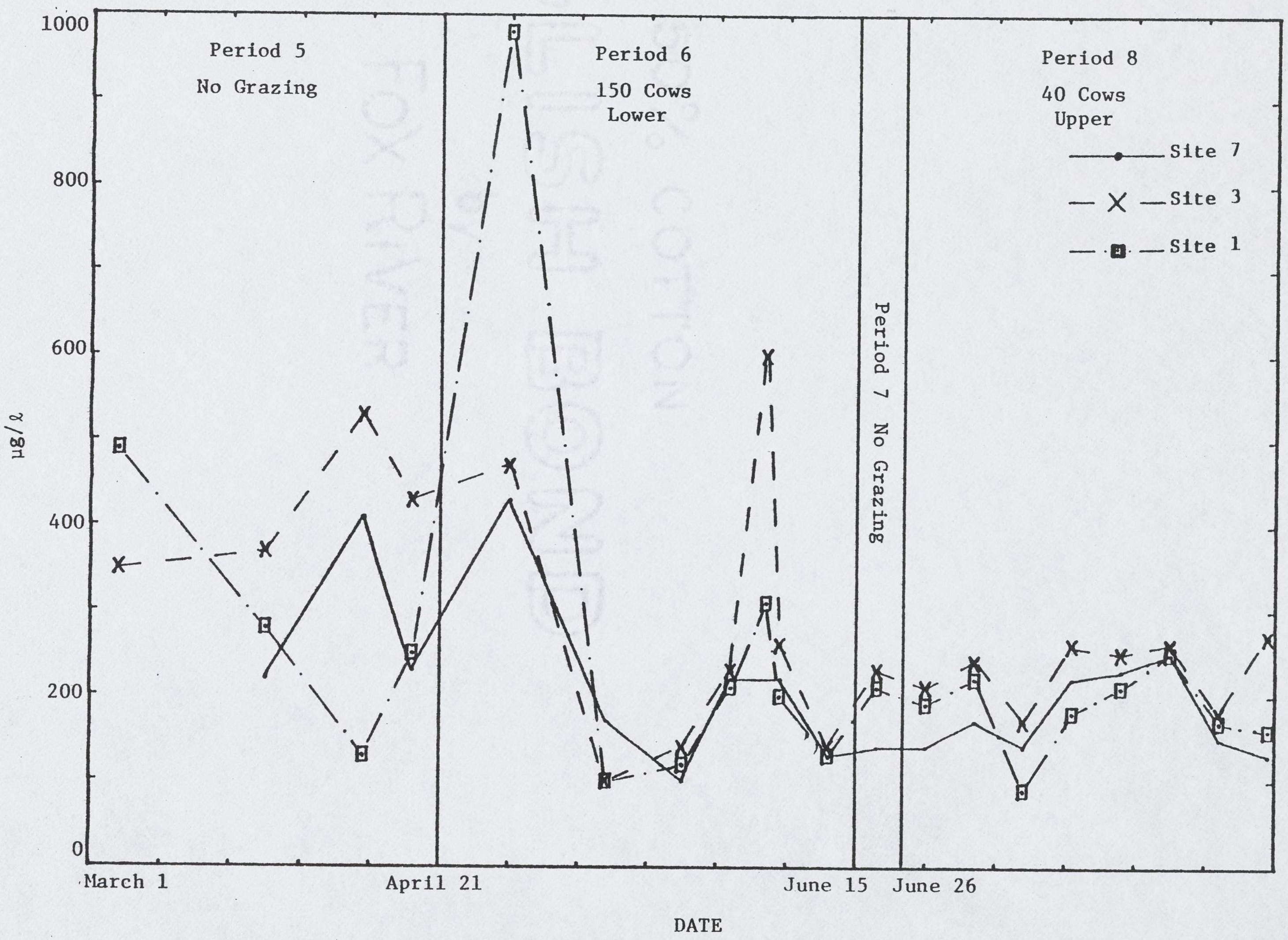


Table 9. 1978 Ammonia-Nitrogen Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 5 through 8.

SITE	PERIODS 5 No Grazing		6 150 Cows Lower Pasture		7 No Grazing		8 40 Cows Upper Pasture	
	MEAN AND STANDARD DEVIATION (μg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	288	150	293	311	210	-	184	48
3	420	81	277	188	230	-	230*	39
7	287	107	212	117	140	-	179	47
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		-		.005	

*Significant Difference in this mean at .05 level.

N.S. - Non-significant at .10 level.

revealed that the means for sites 1 and 7 were nearly equal (288-287 μg/ℓ). The magnitude of the mean at site 3 cannot be explained other than to imply a wildlife contribution between sites 1 and 3 which was removed before site 7.

Figure 17 indicates a general trend toward higher nitrate-nitrogen concentrations at all three sites. Table 10 indicates a similarity among mean nitrate-nitrogen for the three sites, as well as the moderate background concentration measured at site 1. Possibly a spring flush of winter accumulated organics along with increasing activities of wildlife was responsible for the magnitude of the measured concentrations.

As previously mentioned, a water-bath malfunction resulted in only one successful fecal coliform analysis during this period (Figure 18). The concentrations increased slightly in the downstream direction for this one sample (Table 11). Activities of wildlife both above and within the study area may have been responsible for the measured concentrations.

All three sites demonstrated similar low fecal streptococci counts during this period (Figure 19). As Table 12 illustrates, the three sites were within one colony of a 15 colonies/100 mℓ mean. This mean for the whole study area can probably be assumed to be the normal background contribution from wildlife throughout the area, at least during this period. Median concentrations were very similar to mean concentrations.

Figure 17. Nitrate-Nitrogen Concentrations at Sites 1, 3 and 7 for Periods 5 through 8, 1978.

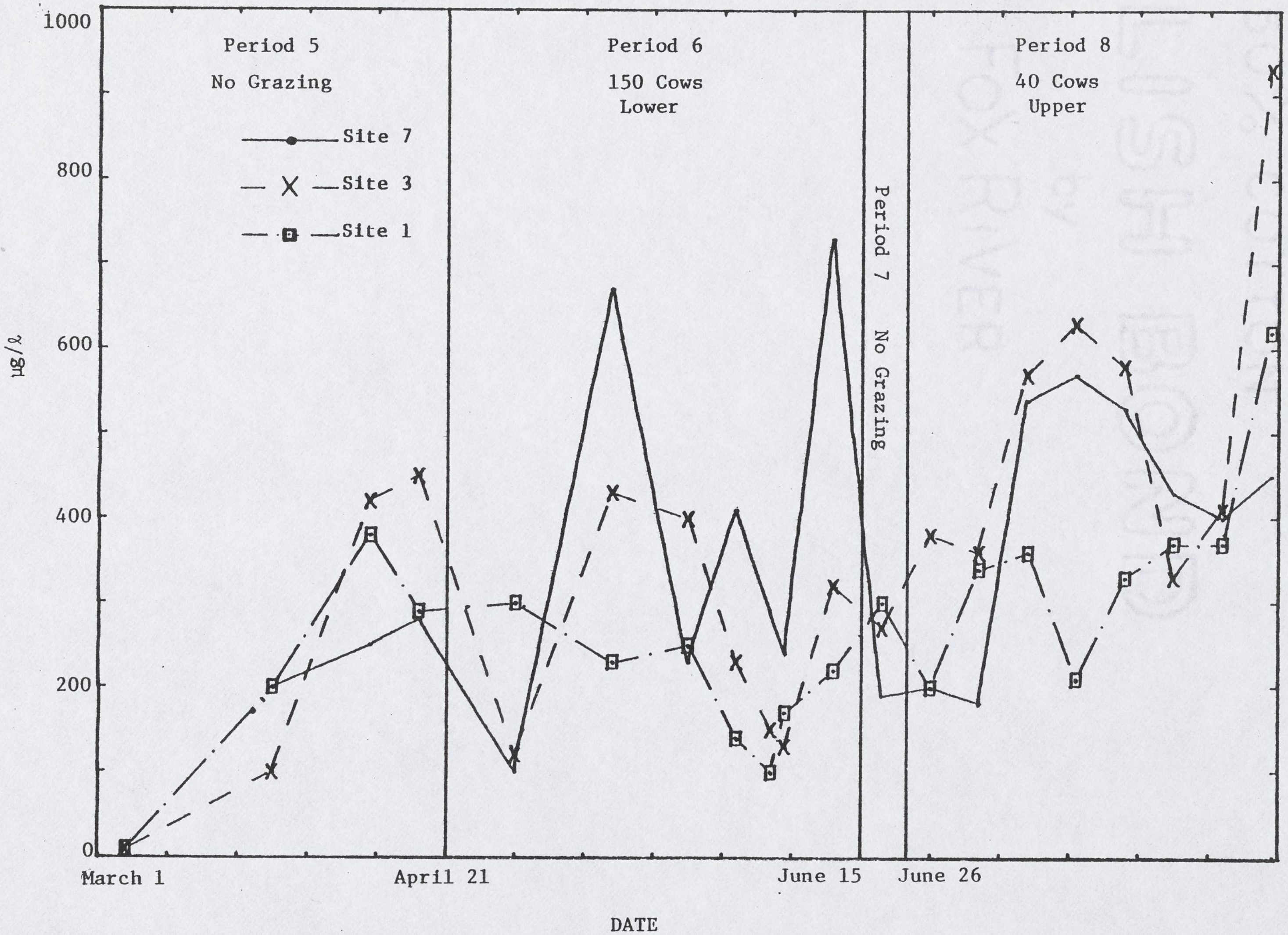


Table 10. 1978 Nitrate-Nitrogen Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 5 through 8.

SITE	PERIODS 5 No Grazing		6 150 Cows Lower Pasture		7 No Grazing		8 40 Cows Upper Pasture	
	MEAN AND STANDARD DEVIATION (μg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	220	158	201	69	300	-	350	129
3	245	223	254	130	270	-	524	200
7	243	40	397	255	190	-	413	149
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		-		.037	

N.S. - Non-significant at .10 level.

Figure 18. Fecal Coliform Concentrations at Sites 1, 3 and 7 for Periods 5 through 8, 1978.

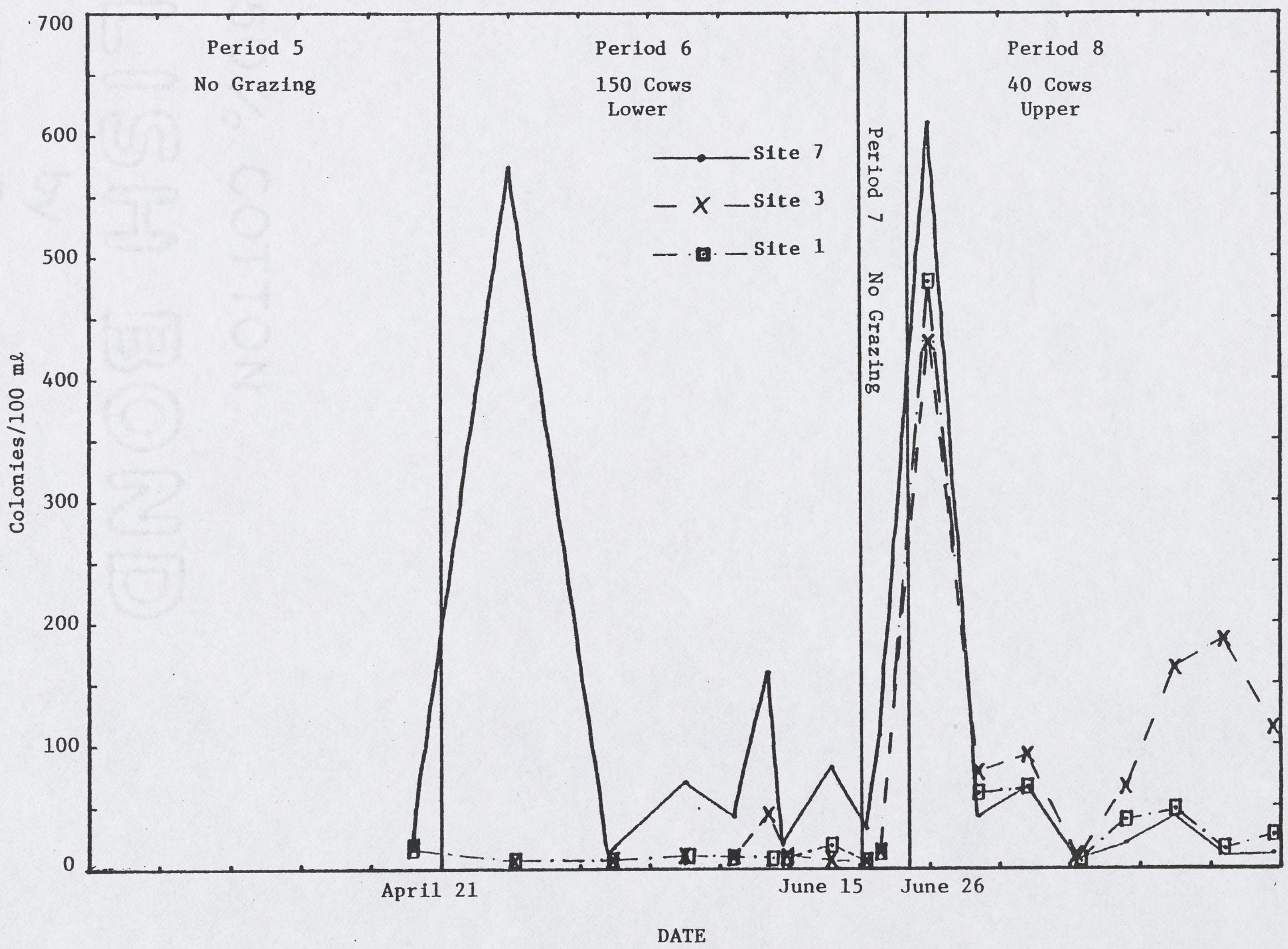


Table 11. 1978 Fecal Coliform Mean ($\bar{x}$), Standard Deviation (s), Statistical Significance and Median Concentration for Sites 1, 3 and 7 for Periods 5 through 8.

SITE	PERIODS 5 No Grazing		6 150 Cows Lower Pasture		7 No Grazing		8 40 Cows Upper Pasture	
	MEAN AND STANDARD DEVIATION (colonies/100 mℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	16	-	6	6	10	5	92	158
3	19	-	11	15	10	6	143	129
7	24	-	137*	199	70	54	101	207
	STATISTICAL SIGNIFICANCE							
	-		.096		N.S.		N.S.	

*Significant Difference in this mean at .05 level.
N.S. - Non-significant at .10 level.

SITE	5	6	7	8
	MEDIAN CONCENTRATION (colonies/100 mℓ)			
1	16	3	10	44
3	19	7	10	103
7	24	70*	70	31

Figure 19. Fecal Streptococci Concentrations at Sites 1, 3 and 7 for Periods 5 through 8, 1978.

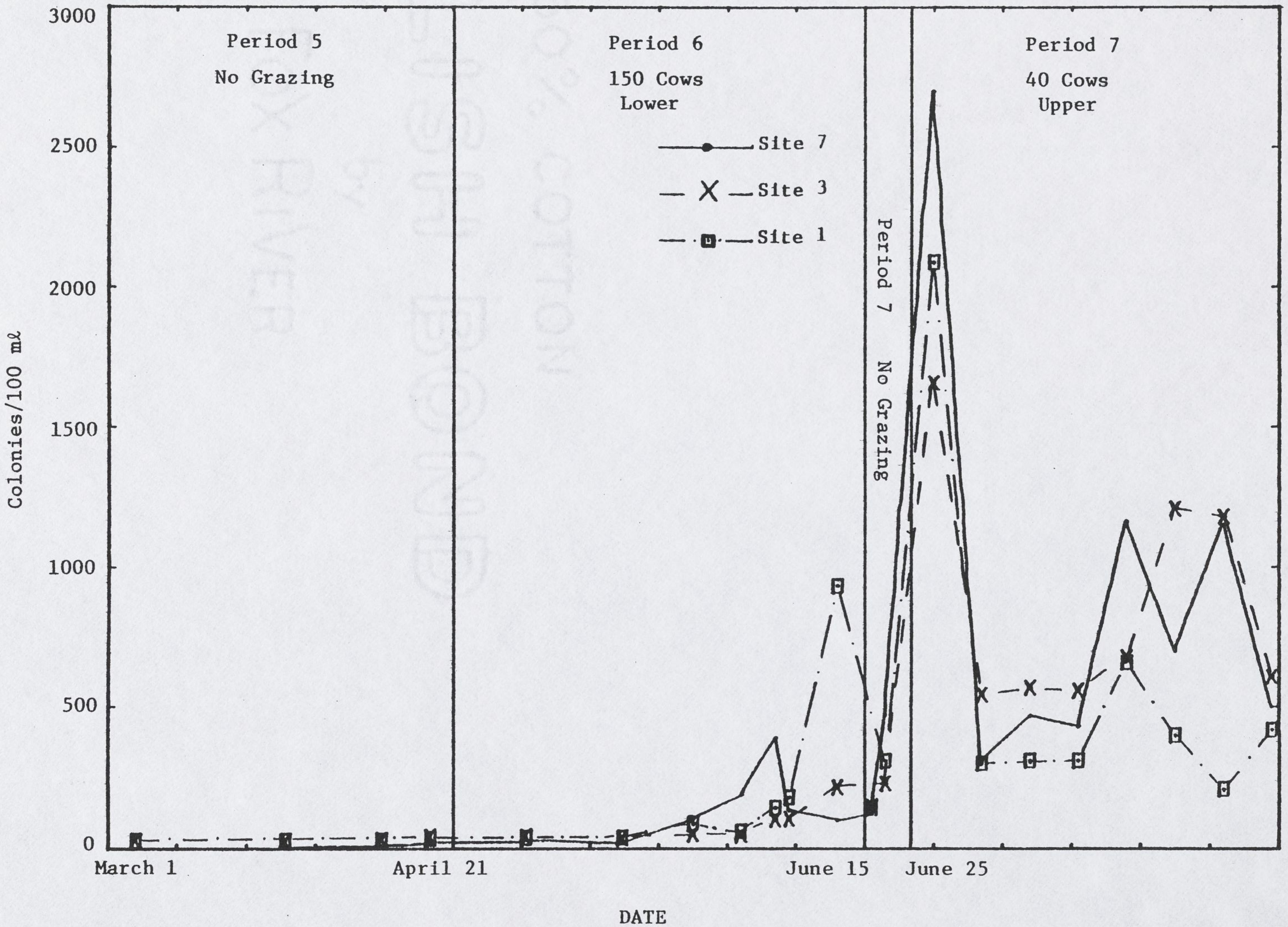


Table 12. 1978 Fecal Streptococci Mean ($\bar{x}$), Standard Deviation (s), Statistical Significance and Median Concentration for Sites 1, 3 and 7 for Periods 5 through 8.

SITE	PERIODS 5 No Grazing		6 150 Cows Lower Pasture		7 No Grazing		8 40 Cows Upper Pasture	
	MEAN AND STANDARD DEVIATION (colonies/100 mℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	14	10	206	327	225	120	588	622
3	16	12	80	70	189	58	877	420
7	15	10	138	126	297	245	929	786
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		N.S.		.079	
	MEDIAN CONCENTRATION (colonies/100 mℓ)							
1	10		90		225		355	
3	16		53		189		645	
7	15		107		297		600	

N.S. - Non-significant at .10 level.

Period 6

During Period 6, 150 cows were present in the lower pasture for seven weeks. Six water samples were collected during this interval. Significant differences were found only in the fecal coliform concentrations.

Earlier removal of the most transportable sediments, stabilization by vegetation and decreased streamflow reduced some of the effects of the breached beaver dams on the suspended solids yield. Results at sites 3 and 7 were still highly variable (Figure 15), with the higher concentrations corresponding readily to increases in discharge. For the first time in this study, the figure indicates that site 3 was not consistently supporting the greatest suspended solids load. It is evident from Table 8 that suspended solids concentrations are becoming more uniform between the three sites. The site 3 mean was still highest, however.

Ammonia-nitrogen concentrations were still highly variable, particularly at site 1 (Figure 16). The 980 $\mu g/\ell$ concentration measured at site 1 on April 29th probably resulted from an error in analysis since the nitrate-nitrogen concentration measured on this date did not respond in a similar fashion. Comparison of means for this period suggest that ammonia-nitrogen concentrations were independent of cattle grazing (Table 9). These means were either slightly higher or much lower than the means of the preceding period and further suggest a grazing/concentration independence.

Nitrate-nitrogen concentrations were also highly variable, particularly at site 7 (Figure 17). There was no significant difference between sites. A comparison of means, however, suggest a cattle contribution of nitrate-nitrogen to the stream in addition to the background level measured at site 1 (Table 10). The site 7 mean of almost 400 µg/ℓ as compared to a mean of just over 250 µg/ℓ at site 3 implies this grazing impact. Variability in these measured concentrations may be attributable to both wildlife and groundwater inputs.

A grazing impact was also clearly suggested by the fecal coliform results. As illustrated in Figure 18, site 7 recorded the highest concentrations on all sampling times during the period. Site 7 was much more variable than sites 1 or 3 during this period, yielding counts which varied from 13 to 574 colonies/100 mℓ.

Table 11 more clearly indicates this grazing contribution. Three important points can quickly be discerned from examination of this table: 1) there was a significant difference between sites ($\alpha = 0.096$) during this period; 2) the site 7 mean was significantly different from the means at sites 1 and 3; and 3) site 7 recorded a substantial increase in mean concentration following the addition of cows while the means at sites 1 and 3 decreased. Cattle were obviously conbributing significant quantites of fecal coliform bacteria to the stream between sites 3 and 7. This conclusion was also made during Period 1 when the 150 cows were last present in this lower pasture.

Comparison of medians also led to a grazing impact conclusion, even though median concentrations were about one-half of the mean concentrations. Calculation of median values removed the effect of the occasional high counts measured at all three sites.

Fecal streptococci densities remained relatively uniform and very low throughout the first part of this period (Figure 19). Concentrations then became highly variable, particularly with respect to site 1. Counts at this site varied from 16 to 935 colonies/100 mℓ during this period, generating a standard deviation of over 325 (Table 12).

Comparison of mean concentrations for this period in Table 12 precludes any conclusions as to grazing impacts. Two points within the table are obvious: 1) the mean concentration measured at site 1 was by far the highest, due in part to the June 14th sample; and 2) all three sites demonstrated dramatic increases over the pre-grazed means. Calculation of median concentrations removed much of the bias generated by the higher counts at all three sites. Once again, the magnitude of the cattle contribution was small in comparison to the background concentration measured at sites 1 or 3.

Period 7

This period represented the ten day post-grazing interval for the lower pasture and was designed to examine residual effects. Bacterial concentrations were sampled twice while all other parameters were sampled only once.

Suspended solids concentrations in the one sample varied from 0 mg/ℓ at site 7 to 8.0 mg/ℓ at site 3. Mean discharge during this period was less than 21 ℓps, providing a limited amount of stream energy to transport any sediment.

Ammonia-nitrogen concentrations decreased at all three sites from the means of the preceding period. The inflow concentration measured at site 1 was still much higher than that of site 7 (210 and 140 μg/ℓ, respectively, from Table 9), further suggesting an independence from grazing impacts mentioned in the Period 6 results.

Nitrate-nitrogen concentrations ranged from 300 μg/ℓ at site 1 to 190 μg/ℓ at site 7, decreasing in the downstream direction (Table 10). Sites 1 and 3 increased over their Period 6 means while site 7 decreased to less than half its Period 6 mean. This implied a lack of residual effect as well as strengthening the suggestion that the Period 6 means imply a grazing impact. In both this and the ammonia-nitrogen sample, the amount of upstream contribution was considerable when compared to measured concentrations in the study area.

In both fecal coliform samples analyzed during this period, site 7 had the highest count. The mean at site 7 was substantially larger than the means at sites 1 and 3 (Table 11) but was only about one-half the Period 6 value. This implied a residual effect from the preceding grazed period, an effect also noted during the Period 2 analysis. Conclusions in this case are tempered by the fact that the mean was generated from two samples collected only two days apart. The median values were the same as the means due to the two samples.

Fecal streptococci concentrations implied a residual contribution from the grazing cattle in addition to a significant amount of background concentration measured at sites 1 and 3. All three sites recorded increased mean counts during this period as compared to Period 6, particularly at sites 3 and 7 (Table 12), confounding the implication as to residual effects. This was also the case in Period 2, the other post-grazing analysis of the 150 cow grazing treatment.

Period 8

During this period, the last of the study, 40 cows were again allowed to graze the upper pasture. Eight samples were collected prior to the study termination on August 16th. Sampling was terminated on this date because the stream had become intermittent in its lower reaches. Discharge during the period varied from 7 to about 21 ℓps. Ammonia-nitrogen, nitrate-nitrogen, suspended solids and fecal streptococci all exhibited significant differences between sites.

The suspended solids concentrations were highly variable during the period but were less than 15 mg/ℓ on all occasions (Figure 15). Site 1 was highest on most sampling dates while site 3 was frequently lowest. This further suggests a stabilization of the breached beaver dam area.

Table 8 indicates a significant difference between the sites ($\alpha = 0.02$) while the site 1 mean was twice that of the lower site mean in the grazed pasture. This indicates that the suspended solids concentrations were independent of cattle grazing. Mean suspended solids concentration among the three sites was the lowest of the study. The reduced discharge recorded during this period probably influenced these lower mean concentrations.

Ammonia-nitrogen concentrations again suggest cattle contributions in addition to moderate background stream levels. As Figure 16 illustrates, a similar trend among sites existed while site 3 was highest on all sampling days. Table 9 indicates there was a significant difference ($\alpha = 0.005$) between sites and the site 3 mean of 230 μg/ℓ was significantly different from the other two very similar means. This implies that cattle were contributing ammonia-nitrogen to the stream between sites 1 and 3 and that this amount was either utilized, removed or transformed in the 1.3 km reach between sites 3 and 7.

The table also reveals that mean concentrations during this period were very similar to concentrations recorded in Period 7. The similarity between these two periods probably resulted from the uniformity in streamflow. This ammonia-nitrogen concentration dependence on discharge was also suggested in the Period 1 results.

The nitrate-nitrogen concentrations measured during this period also suggest an input by cattle because site 3 was highest on all but one sampling date (Figure 17). A large amount of variability was involved in the measurements at all sites, illustrated in the figure as well as the Standard Deviation column in Table 10. This table also shows the statistically significant difference ($\alpha = 0.037$) between sites while site 3 recorded the highest mean concentration. All three sites recorded substantial increases over their Period 7 means, producing the highest average concentration of the entire study. Sites 3 and 7 both doubled, suggesting the cattle were contributing nitrate-nitrogen to the background stream level, only part of which was removed by the time the water reached site 7. An increase in the groundwater contributions to the stream throughout the study area may have caused these higher mean concentrations.

The fecal coliform results imply a grazing impact but the magnitude of the upstream contribution suggests that this contribution was minimal. Figure 18 illustrates a similar trend among the sites for the period but the sites still display a degree of variability. The peak concentrations at all three sites on June 28th probably resulted from the precipitation event on the preceding afternoon and evening. The slight increase in discharge from this event (less than seven ℓps) probably flushed fecal coliform bacteria from channel areas and bottom sediments into the stream, both from within and above the study area.

Table 11 demonstrates that all three sites recorded higher mean concentrations during this period than those of the preceding period while site 3 increased the most and site 7 the least. The increase in mean concentration from site 1 to site 3 for this period (from 92 to 143 colonies/100 mℓ) suggests a grazing contribution. The magnitude of this contribution was minimal, however, when compared to the background concentration measured at site 1. Differences between the sites were non-significant owing to the degree of variability illustrated in Figure 12 and in the Standard Deviations included in Table 11. Comparison of median concentrations more strongly suggest the grazing contribution. The site 3 median value was substantially greater than the medians at sites 1 or 7.

The fecal streptococci results for this period illustrate a tremendous degree of variability, influenced by precipitation events and a lack-of-dilution due to the low discharge (Figure 19). Table 12 demonstrates three important points concerning the fecal streptococci results: 1) all three sites increased dramatically over Period 7 mean concentrations; 2) a significant difference ($\alpha = 0.079$) existed between the three sites; and 3) the largest increase in mean count occurred between sites 1 and 3 in the grazed pasture. These results suggest that the grazing cattle were contributing fecal streptococci bacteria between sites 1 and 3. Any suggestion as to a grazing contribution must be tempered by the point that the site 7 mean was higher than the site 3 mean.

The significance of the assumed cattle contribution was reduced in scope when compared to the mean concentration measured at site 1. Counts at this site ranged as high as 2090 colonies/100 mℓ (following a storm), suggesting that higher counts may be independent of cattle grazing. Comparison of median concentrations more clearly implied the grazing impact, mainly be reducing the site 7 value.

Summary of Periods 1-8

Orthophosphate concentrations appeared independent of cattle grazing throughout the study. The suspended solids analyses were confounded by the breached beaver dams during most of the study, masking any grazing effects.

In Period 1 (1977), the fecal coliform and fecal streptococci concentrations suggested a grazing contribution from the cows in the lower pasture. Both nitrogen species were highest in the grazed pasture bottom but the increase in concentration between sites was minimal. In Period 2, designed as a post-grazing comparison, only the fecal coliform analysis implied a residual grazing effect. Any residual effects suggested by the fecal streptococci concentrations were masked by dramatic increases in upstream counts. During Period 3, the fecal coliform and fecal streptococci concentrations clearly reflected the impact of the cows in the upper pasture. The ammonia-nitrogen analysis indicated a small contribution from the cattle but mean concentrations were similar to those recorded in Periods 1 and 2. The Period 4 nitrate-nitrogen mean and the fecal streptococci median concentrations implied a residual effect from grazing. Mean ammonia-nitrogen concentrations were the highest of the entire study but were similar among sites.

During Period 5, a 1978 pre-grazing examination, ammonia-nitrogen and nitrate-nitrogen concentrations were both moderately high while the fecal coliform and fecal streptococci concentrations were low. In Period 6, the fecal coliform and nitrate-nitrogen concentrations indicated contributions from the cattle in the lower pasture while the fecal streptococci analysis was confounded by high counts at the uppermost study site. Both the nitrate-nitrogen and ammonia-nitrogen analyses reflected moderate background concentrations, possibly confounding the latter. Period 7 fecal coliform and fecal streptococci concentrations suggested a residual grazing effect while the data compiled during the one nutrient analysis does not reflect this effect. In Period 8, ammonia-nitrogen, nitrate-nitrogen and both fecal coliform and fecal streptococci concentrations reflected the contributions of cattle in the upper pasture. Moderate background concentrations were recorded in all four of these parameters, particularly in the fecal streptococci analysis. The suspended solids analysis was no longer confounded by the breached beaver dams but appeared independent of grazing during this period.

Cattle Observation and Fecal Deposit Collection

Cattle Observations

Cattle observations for the two sampling seasons revealed the following pertinent information:

1) Between 7 AM and 7PM, when the most intensive observations were made, cows spent 21 percent of their time within an estimated 25 meters of the stream channel and only six percent of their time within the channel, usually just drinking.
2) Hourly herd location data suggested that the cows remained within the floodplain during the day but preferred the upland areas during the evening through early morning hours. Temperature and vegetative preferences were probably at least partially responsible for this behavior.

Fecal Deposit Collection

Following the 15 day test interval during Period 6 and subsequent air-drying for over 30 days, the weight of the collected specimens was 62.6 kg. Using Miner and Willrich's (1970) estimate of 4.54 kg of dry weight fecal material per cow, per day, and knowing that 150 cows (75 cows, 75 calves) were in the lower pasture for 15 days, a figure of 7,650 kg of dry weight fecal material was estimated to have been deposited. This calculation assumes that a calf produces only 3/4 of the amount of fecal material of an adult. Thus, 0.8 percent ((62.6 ks/7,650 kg) * 100) of these cows' potential total fecal deposits were within the three meter distance of the stream.

Assuming that cattle waste products beyond three meters of the channel would have little or no effect on stream concentrations, these results help to explain the apparent grazing independence and low concentrations of many of the measured parameters. Beyond this distance, natural die-off, mechanical soil filtering and natural soil defense mechanisms such as nitrification, pH, and pre-existing soil bacteria probably interacted to remove the indicator bacteria while plant utilization and microbial transformations altered the nitrogen nutrient concentrations. Several researchers (Kunkle and Meiman, 1967 and 1968; Darling, 1973) have concluded that cattle impacts are measurable and significant only when the cows are located in or very near a stream channel. The three meter distance used in this procedure was purely subjective but seemed appropriate from field examination.

One other point may be important in helping to explain the low levels of measurement. All water samples were collected between 7:00-8:30 AM when few, if any, cows were normally located within the floodplain or near the stream. Thus, it seems likely that these measured concentrations were sampling the impacts of cattle that had been located in the grazed areas at least 12 to 15 hours earlier.

SUMMARY AND CONCLUSIONS

This study, conducted along a small stream in the Colorado Front Range, was designed to quantify the impact of cattle grazing on surface water quality as well as evaluate the local and immediate downstream pollution potential of cattle grazing with free stream access. Measurement emphasis was placed on the concentrations of two nitrogen species and on two indicator bacteria densities. On the basis of the data collected during this study, the following conclusions were drawn:

1) Cattle grazing with free stream access caused significant increases in downstream fecal coliform and fecal streptococci concentrations.

2) Ammonia-nitrogen and nitrate-nitrogen concentrations suggest a cattle grazing contribution.

3) The breached beaver dam area in the upper pasture was responsible for significant differences in suspended solids concentrations and masked grazing impacts which may have occurred.

4) Ammonia-nitrogen, nitrate-nitrogen, orthophosphate, fecal coliform and fecal streptococci concentrations measured during this study indicate that only small fractions of the potential contributions from cattle wastes were reaching the

stream. These results may be explained, in part, by observed location and defecation trends of the grazing cattle.

5) Contributions from the cattle of nitrogen and indicator bacteria were usually small in comparison to the background concentrations measured at the upstream sites.

SUGGESTIONS FOR FURTHER STUDY

This study was designed to quantitatively determine the impact of cattle grazing on a short reach of Trout Creek. It was felt that measurements of suspended solids, ammonia-nitrogen, nitrate-nitrogen, orthophosphate, fecal coliform and fecal streptococci would best indicate grazing impacts. However, the suspended solids analysis was confounded by inputs from the breached beaver dam area while concentrations of the other parameters were at or very near the minimum detectability limits of the analysis procedures used. I felt that concentrations of these parameters in surface runoff from short duration-high intensity storms would be significant, but no such storms occurred that could be sampled during the study. With these problems and limitations in mind, the following suggestions for further research are made:

1) Conduct investigations which more closely monitor the impact of cattle grazing on suspended solids concentrations.
2) Design and conduct a study that would specifically concentrate on storm flows and storm-related surface runoff.
3) Conduct investigations to evaluate the bacterial filtering capacity of the alluvial soils found in the area.
4) Sample more extensively under two different stocking intensities, sampling more intensively during shorter time periods.

5) Evaluate channel and bottom sediments as source areas for both indicator and pathogenic bacteria.

6) Conduct a study to relate indicator bacteria densities to the presence of pathogenic organisms.

7) Perform a study similar to this one but concentrate sampling times to correspond to periods of maximum recreational use.

8) Possibly re-conduct this investigation but use procedures which measure nutrient concentrations more accurately.

9) Design and conduct a similar study but concentrate more strongly on the relationship between measured concentrations and cattle locations.

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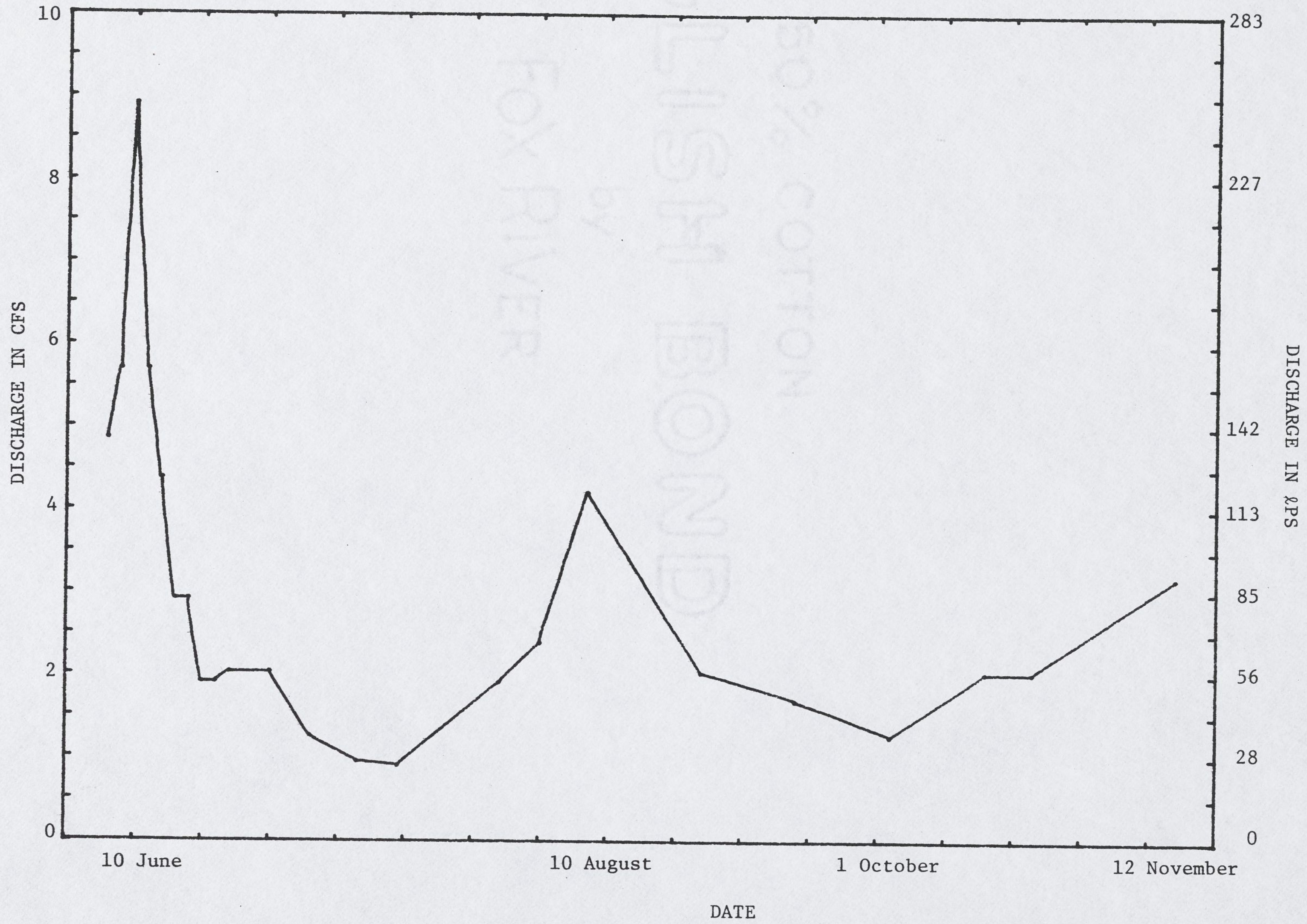
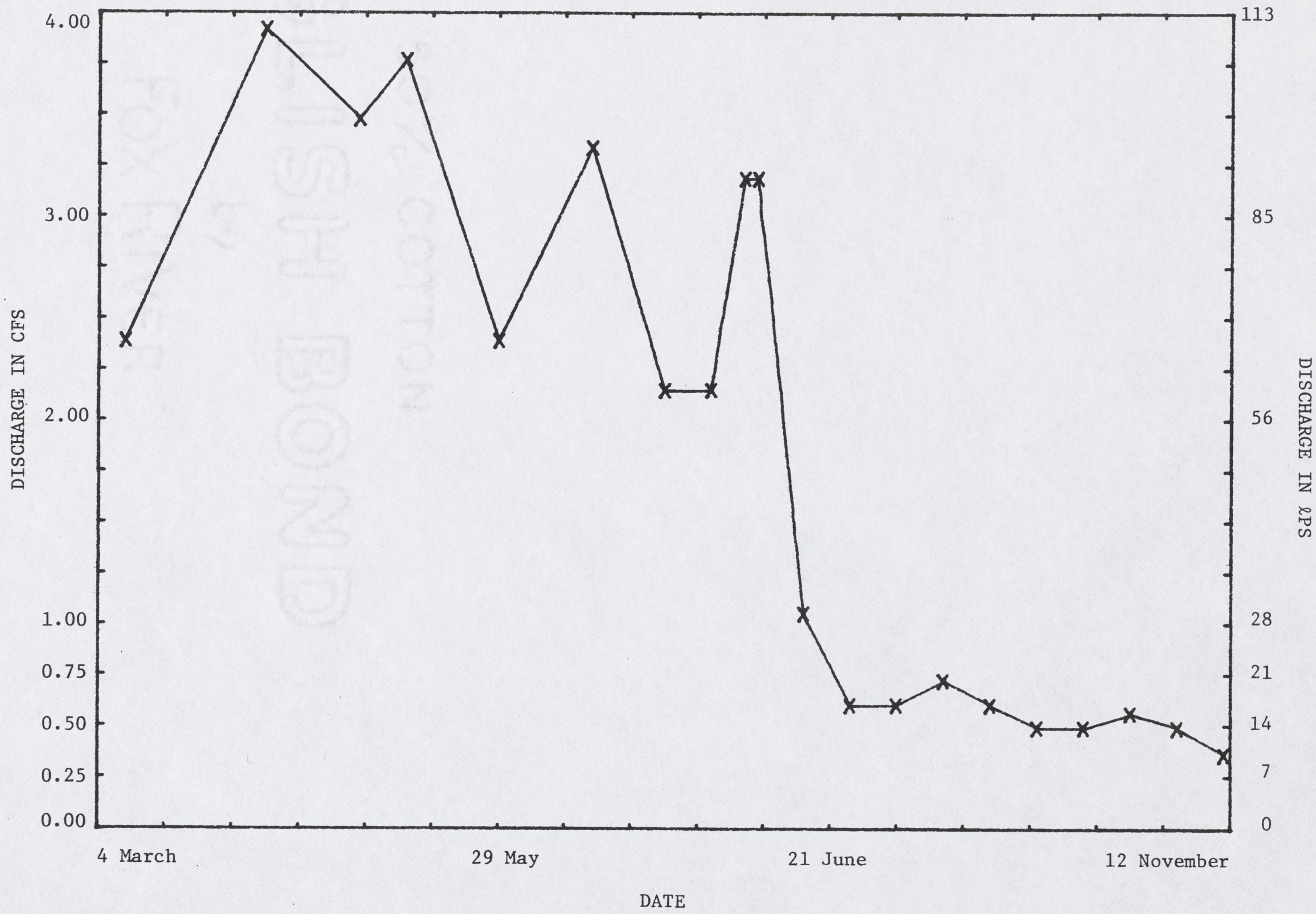
APPENDICES

APPENDIX A: 1977 Discharge at site 1 (flow recorded at sample)
6 June - 12 November.



APPENDIX B: 1978 Discharge at site 1 (flow recorded at sample)
8 March - 16 August.



APPENDIX C: 1977 Orthophosphate Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 1 through 4.

SITE	PERIODS 1 150 Cows Lower Pasture		2 No Grazing		3 40 Cows Upper Pasture		4 No Grazing	
	MEAN AND STANDARD DEVIATION (μg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	210	88	228	121	287	185	130	10
3	203	34	190	23	242	80	227	99
7	251	169	194	22	294	155	147	35
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		N.S.		N.S.	

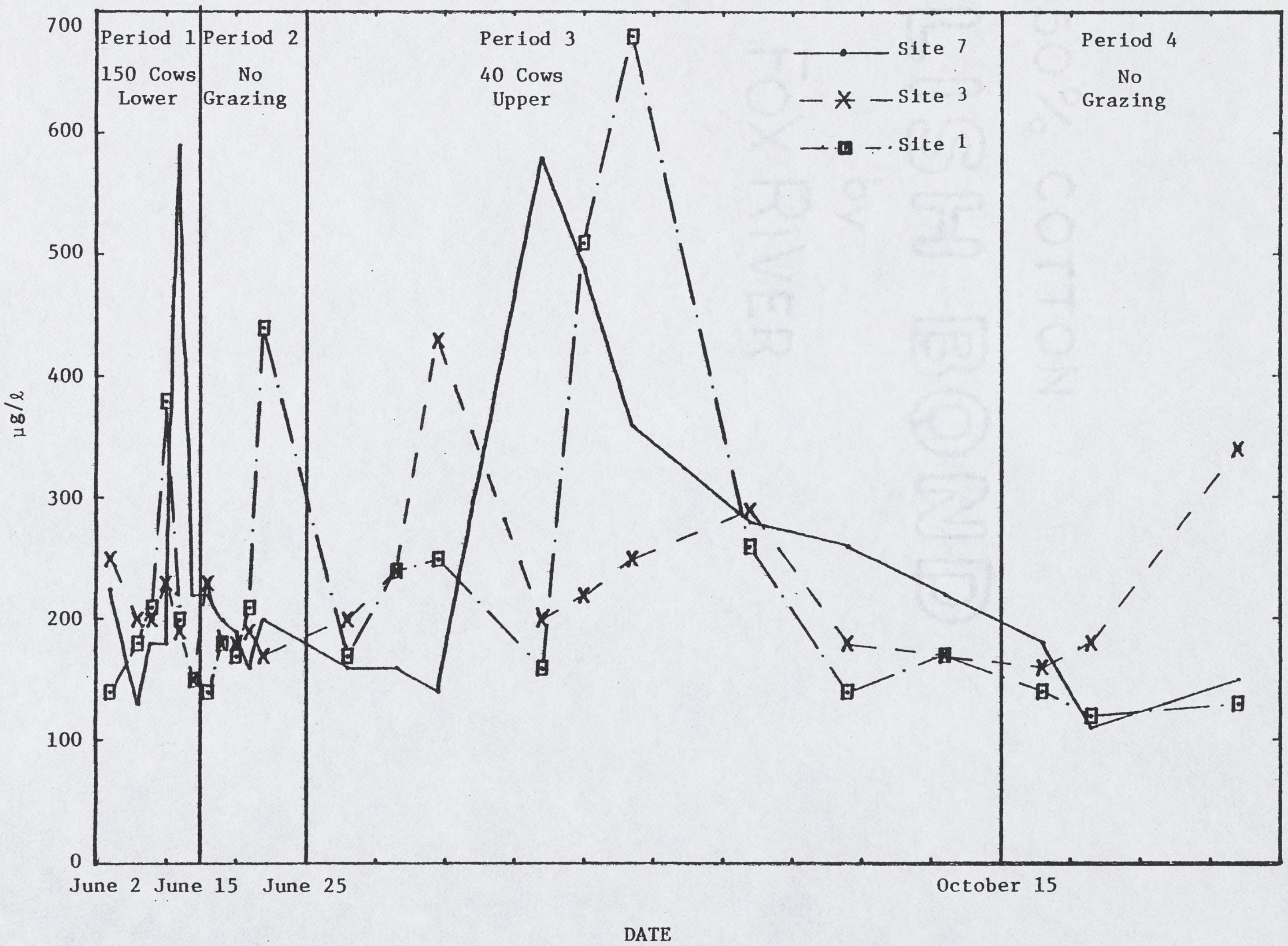
N.S. - Non-significant at .10 level.

APPENDIX D: 1978 Orthophosphate Mean ($\bar{x}$), Standard Deviation (s) and Statistical Significance for Sites 1, 3 and 7 for Periods 5 through 8.

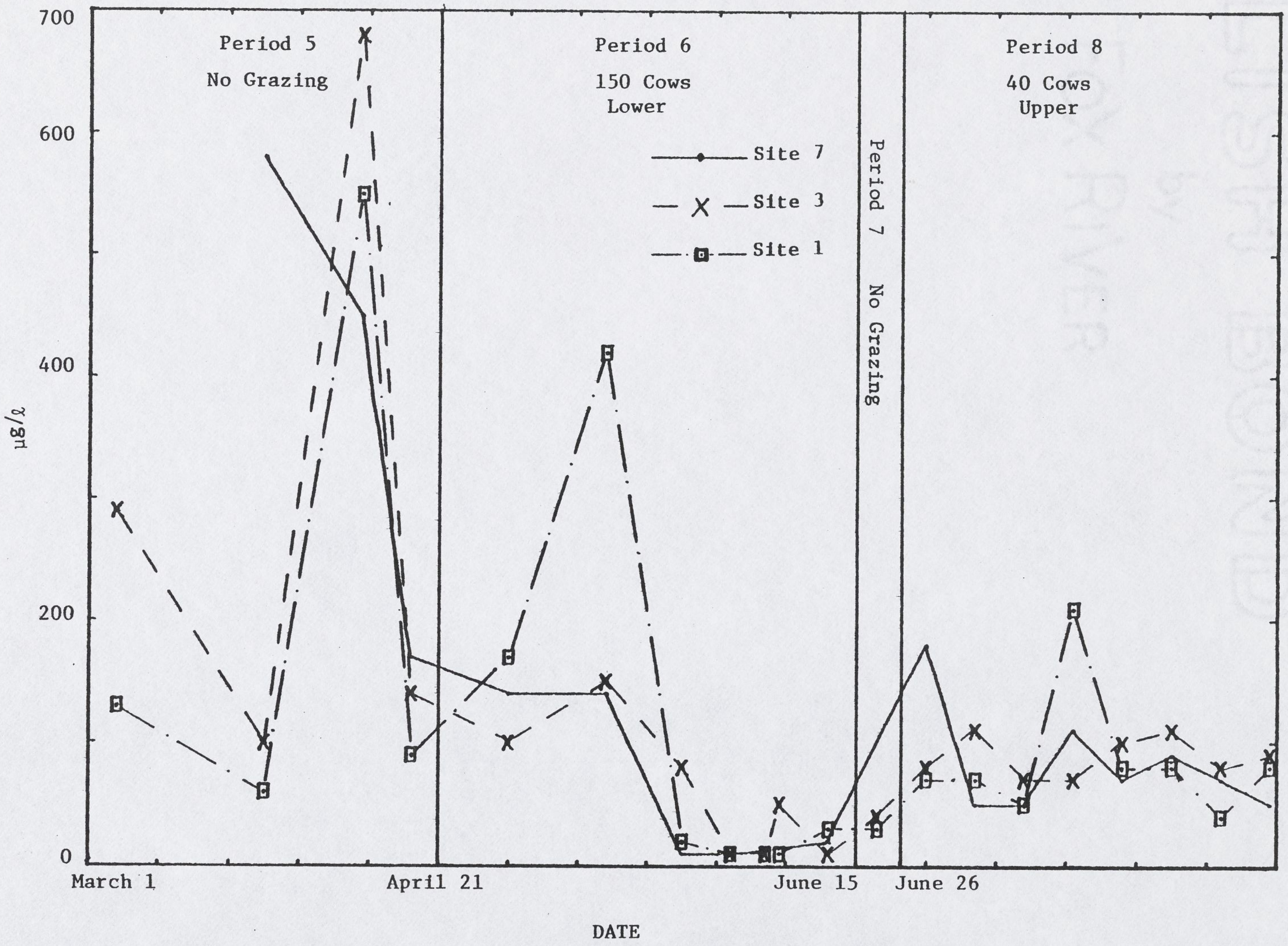
SITE	PERIODS: 5 No Grazing		6 150 Cows Lower Pasture		7 No Grazing		8 40 Cows Upper Pasture	
	MEAN AND STANDARD DEVIATION (μg/ℓ)							
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
1	208	230	96	154	30	-	85	53
3	303	265	59	54	40	-	89	16
7	400	210	53	67	0	-	84	44
	STATISTICAL SIGNIFICANCE							
	N.S.		N.S.		N.S.		N.S.	

N.S. - Non-significant at .10 level.

APPENDIX E: Orthophosphate Concentrations at Sites 1, 3 and 7 for Periods 1 through 4, 1977.



APPENDIX F: Orthophosphate Concentrations at Sites 1, 3 and 7 for Periods 5 through 8, 1978.



APPENDIX G

Precipitation Measured at Manitou Experimental Forest Headquarters During Study.
Date listed is 8 AM measurement date, unit is millimeters.

1977													
June	Amt	July	Amt	Aug	Amt	Sept	Amt	Oct	Amt	Nov	Amt	Dec	Amt
5	5.3	4	4.3	5	3.6	5	1.8	6	1.8	7	5.3	2	2.5
7	1.8	6	12.2	6	4.3	12	9.7	21	3.6	8	15.7	5	1.8
8	1.8	7	17.8	10	0.8	13	2.5	31	4.3	21	0.8		
19	3.6	8	1.8	11	3.6					24	2.5		
18	1.8	14	2.5	12	2.5								
24	4.3	15	1.8	14	0.8								
		20	7.9	15	4.3								
		21	16.5	16	10.4								
		22	6.1	17	3.6								
		23	2.5	18	1.8								
		24	26.2	14	1.8								
		25	8.6	21	9.7								
		26	5.3	24	5.3								
		28	2.5										

1978											
Mar	Amt	Apr	Amt	May	Amt	June	Amt	July	Amt	Aug	Amt
3	4.3	10	15.7	1	12.2	3	1.8	9	28.4	1	4.3
7	14.7	30	8.6	2	1.8	4	7.9	11	5.3	4	1.8
20	4.3			3	3.6	5	8.6	13	14.7	13	2.5
23	2.5			4	0.8	7	3.6	17	0.8	22	0.8
				8	3.6	8	5.3	20	2.5	26	1.8
				26	2.5	28	11.4	21	6.9	29	1.8
				27	3.6	30	17.5	23	1.8	30	3.6
				29	1.8	31	3.6	24	5.3		
								29	1.8		
								31	5.3		

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