STRATFORD AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT

AN INTENSIVE WATER QUALITY SURVEY OF STREAM CATTLE ACCESS SITES

Technical Report R-19

by: L. Demal

Rural Sub-Committee

SAREMP

PREFACE

This report is one of a series of technical reports resulting from work undertaken as part of the Stratford/Avon River Environmental Management Project (SAREMP).

This three-year project was initiated in April 1980, at the request of the City of Stratford. The SAREMP is funded entirely by the Ontario Ministry of the Environment. The purpose of the project is to provide a comprehensive water quality management strategy for the Avon River Basin. In order to accomplish this considerable investigation, monitoring and analysis has taken place. The outcome of these investigations and field demonstrations will be a documented strategy outlining the program and implementation mechanisms most effective in resolving the water quality problems now facing residents of the basin. The project is assessing urban, rural and in-stream management mechanisms for improving water quality.

This report results directly from the aforementioned investigations. It is meant to be technical in nature and not a statement of policy or program direction. Observations and conclusions are those of the authors and do not necessarily reflect the attitudes or philosophies of the agencies and individuals affiliated with the project. In certain cases the results presented are interim in nature and should not be taken as definitive until such time as additional support data is collected.

Reference to equipment, brand names or supplies in this publication is not to be interpreted as an endorsement of that particular product or supplier.

Enquiries with respect to this report should be directed to the authors or to:

Upper Thames River Conservation Authority
P. O. Box 6278, Station "D"
London, Ontario
N5W 5S1
(519) 451-2800

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ABSTRACT

As part of an investigation of the relative importance of rural diffuse pollution sources in the Avon River basin, the Stratford-Avon River Environmental Management Project (SAREMP) conducted a pilot study in 1982 of the impacts of livestock on water quality at cattle access sites. Five sites were chosen on the basis of the following criteria: intensity of in-stream livestock activity, variability in length and type of access, accessibility for field work, and good farmer cooperation. Water chemistry and bacterial inputs were studied during both dry and wet weather conditions, in conjunction with physical site characteristics and livestock activity in or near the stream channel.

During the summer grazing season livestock activities at or near the stream had a detrimental impact on the downstream water quality. Substantial increases in nutrient and bacterial loadings occurred as a direct result of in-stream cattle activity during the dry weather survey. Wet weather impacts observed in this study were limited to large increases in bacterial contamination at the cattle access site. Detection of *Pseudomonas aeruginosa* during the storm event indicated that direct human waste inputs may also be responsible for the elevated background levels of bacteria.

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1.0 INTRODUCTION

Routine water quality monitoring on the Avon River throughout 1980 and 1981 revealed that fecal coliform bacteria and total phosphorus frequently exceed the MOE guidelines during dry weather summer flows (Huber, 1982). Both urban point sources and rural diffuse sources are responsible for the elevated levels of these pollutants. For example, of the estimated summer phosphorus loads for the Avon River basin, 50% originate from urban sources, 44% from agricultural diffuse source runoff and 6% from background ground water supplies (Fortin and Demal, 1983).

As part of an investigation of the relative importance of rural diffuse pollution sources in the Avon River basin, the Stratford-Avon River Environmental Management Project (SAREMP) conducted a pilot study in 1982 of the impacts of livestock activity on water quality at cattle access sites.

It has been well recognized that pastured cattle have several impacts on stream water quality (Ryan, 1982; Doran, Schepers and Swanson, 1981; Shelton and Lessman, 1978, Semple, 1970). A summary of these has been outlined in Figure 1. Although there is much information describing water quality of pasture runoff, there is little available information quantifying livestock behaviour and the water quality impacts at stream access sites. This study is concerned with estimating in-stream loads of sediment, nutrients and bacteria caused by livestock activity at cattle access sites in the Avon River basin.

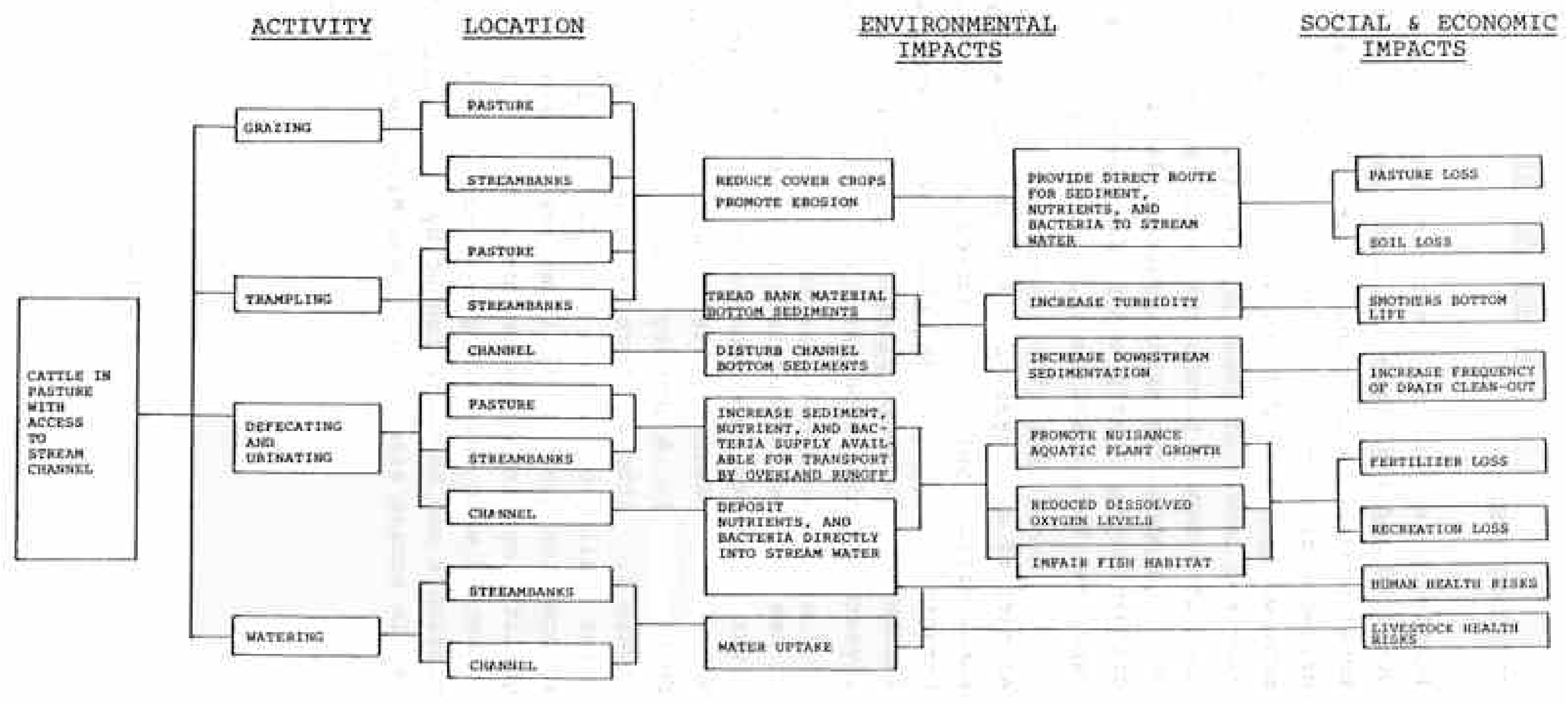

Figure 1: Potential Impacts of Livestock Activity at Cattle Access Sites

2.0 STUDY SITE LOCATIONS

Several potential study sites were selected from a basin inventory of all cattle access locations; these were investigated for site suitability. Five sites were chosen on the basis of the following criteria: intensity of in-stream livestock activity, variability in length and type of access, accessibility for field work, and good farmer cooperation. In order to help characterize water quality impacts of specific and localized cattle activity, most of the study sites were selected in the upper basin where channel width was less than 25 m. Four of the sites were located in the upper basin above Stratford. One site was situated in the lower basin downstream of the village of Avonton. (Figure 2)

3.0 METHODS

3.1 Dry Weather Survey

Each of the five sites were monitored for two dry weather days (5-7 hours/day) during the period from July to September. Cattle were in pasture on each of these days.

3.1.1 Field Observations

Quantitative measurements of physical characteristics included channel width and channel depth at the access site, the length of access from upstream to downstream limits, and water flow rates. Qualitative observations were made to determine the nature of stream-bed materials, the amount of vegetative cover on the channel bottom, the extent of bank trampling and erosion, and the bank slope.

Several observations were recorded to characterize livestock activity at the access site while the cattle were in the channel.

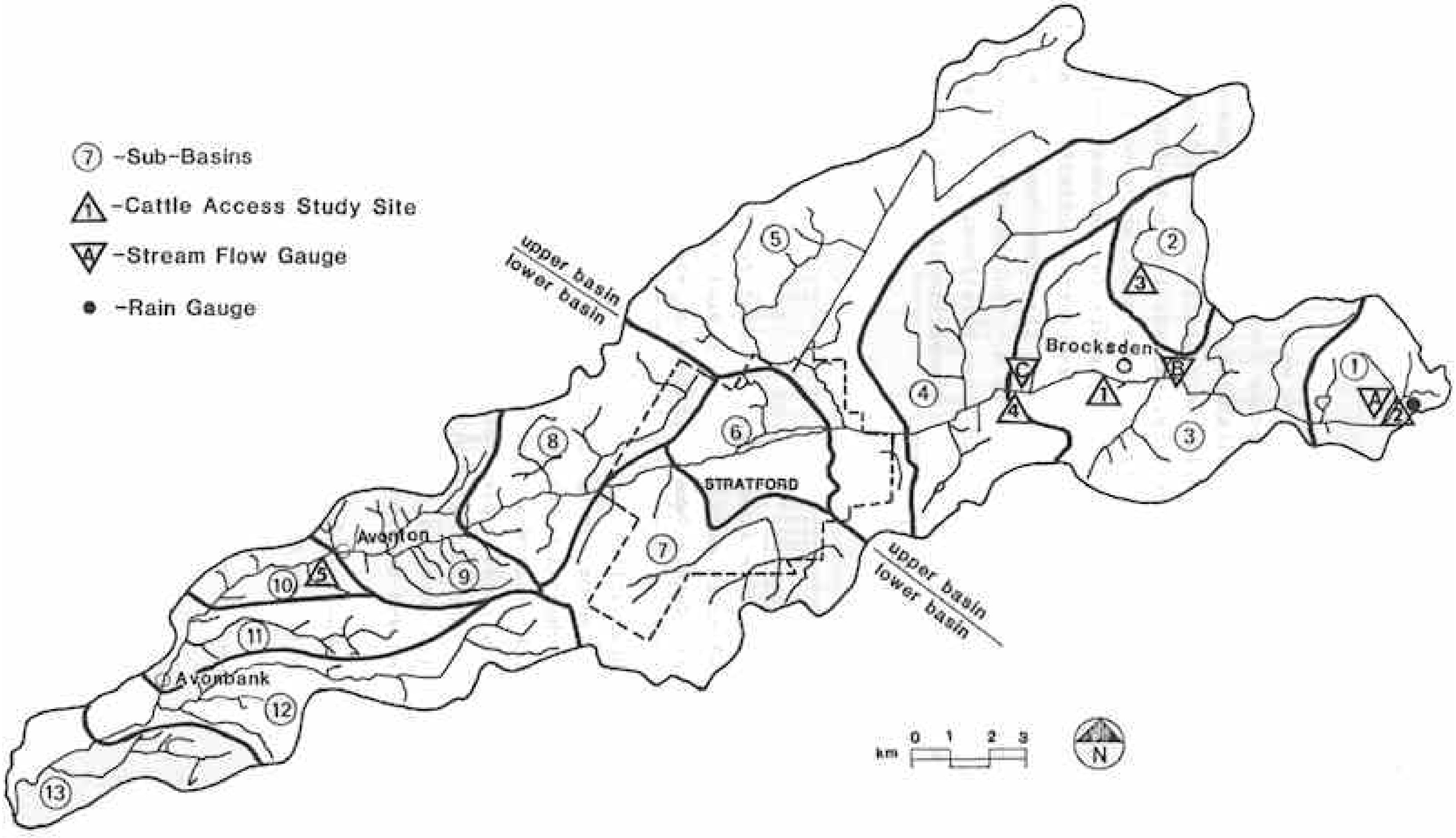

Figure 2: Location of Cattle Access Study Sites, Stream Flow Gauges and Rain Gauge, Avon River Basin, July - September, 1982

These included:

(i) total number of cattle crossing the channel;
(ii) total number of cattle watering in or at the channel's edge;
(iii) total number of in-stream defecations; and
(iv) total number of in-stream urinations.
(v) The total numbers and types of cattle in pasture and the total duration of the access event (min) were also noted.

3.1.2 Water Quality Sampling

During periods of intense in-stream livestock activity, water chemistry and bacteriological samples were taken upstream and downstream of the access site.

During each access event, four water chemistry samples were taken immediately upstream of the upper limit of the access site to characterize background water quality. A series of downstream water chemistry samples were taken to characterize the sediment and nutrient loadings in the plug of contaminated water which results from in-stream activity. The downstream sampling site was located at a point where complete mixing of inputs occurred across the entire width of the channel. The downstream samples were taken using the following scheme:

(i) No. 1 - immediately prior to the access event;
(ii) No. 2 - as the leading edge of the plug of contaminated water passed the downstream sampling site (based on visual observation and estimated flow rates);
(iii) No. 3 - composite of four samples obtained at intervals throughout the main body of the plug; and
(iv) No. 4 - as the trailing edge of the plug moved past the sampling site.

All water chemistry samples were refrigerated and submitted to MOE Laboratory, London within 24 hours of sampling. The following chemical tests were performed according to

"Outline of Analytical Methods" (MOE, 1981): suspended solids, total phosphorus, filtered reactive phosphorus, total Kjeldahl nitrogen, nitrates and nitrites, free ammonia, and 5-day biochemical oxygen demand. Over the two-day observation period at each site, a total of eight upstream and eight downstream water quality samples were submitted characterizing the two most intense access event of each day.

To identify the extent of fecal contamination during each access event, one bacteriological sample was taken both upstream and downstream of the site. The downstream sample was taken in the main body of the plug. These samples were stored on ice and submitted to MOE Laboratory, London within 24 hours. They were tested for two fecal-indicator groups, - fecal coliforms and fecal streptococci - and a disease-related species, *Pseudomonas aeruginosa*. On occasion *Salmonella* spp. was also assayed. Over the two-day period total of two upstream and two downstream samples were submitted for each site characterizing the most intense access event of each day.

3.2 Wet Weather Survey

To detect the potential impacts of streambank activities on the surrounding water quality, an 11-hour wet weather survey was conducted at all five access sites from 18:30 September 14 to 05:00 September 15. A water chemistry sample was obtained at both upstream and downstream sampling points approximately every four hours for 11 hours. In addition, one upstream and one downstream bacteriological sample was taken during each of the first two sampling runs. A total of eight water chemistry and four bacteriological samples were obtained at each access location. All samples were stored, submitted and analyzed in the same manner as the dry weather samples. Rainfall and stream flow measurements were recorded at locations in the upper basin during the storm event (Figure 2).

4.0 RESULTS AND DISCUSSION

4.1 Field Observations

The following discussion of field observations includes physical site characteristics and animal behaviour results.

Physical characteristics, and the type and intensity of the surrounding land uses are summarized in Table 1. All sites were grazed during the entire season, May to September inclusive, by beef, dairy or heifer herds of varying sizes (10-50 cattle/herd).

Several factors were considered at each site. The length of stream accessible to cattle ranges from 9 m to 420 m. Sites 1 and 2 are both "limited" or "controlled" access sites which means that fencing has been used to restrict cattle, allowing them to cross or access the stream channel at only one location. Sites 3, 4 and 5 are "unlimited" or "uncontrolled" access sites permitting cattle to reach the water course along the entire length of streambank within the pasture. Site 5, which is located downstream of Avonton in the lower basin, has the greatest length of unlimited access, approximately 420 m.

Of all the study areas, site 5 has the largest dry weather flow rate, 0.385 cm, compared to an average of 0.041 cm for the four sites in the upper basin. The higher flow rate at site 5 creates a large dilution factor which seems to have masked potential water quality impacts of any in-stream livestock activity.

The intensity of channel use is measured as the number of pastured animals per unit area of actively accessed channel. It reflects the potential cumulative fecal loading in a unit area of stream channel which may be available for resuspension from cattle trampling or stream flow scouring. Sites 1, 2 and 3 had the highest intensity with 0.06l-0.556 animal units/m^2. Sites 4 and 5 had much lower levels of 0.00l-0.009 animal units/m^2. (An animal unit, as defined in the Agricultural Code of Practice, is the number of livestock which excrete 68-77 kg nitrogen/year-one dairy or two beef cattle).

TABLE 1: Physical Site Characteristics And Surrounding Land Use - Cattle Access Study, Avon River Basin, July - September, 1982

	Land Use				Physical Characteristics				
Site No.	Access Description	Pasture Area (ha)	No. of Cattle and Use	Concentration of animals (animal units/m^2)	Bank Slope	Bank Erosion	Dimensions d = depth w = width l = length	Vegetative Cover(% area)	Streambed M=mud & silt S = sand G = gravel C = cobbles
1	improved limited access: -fenced crossing,-concrete slate on bottom	2.5 (80% open 20% wooded)	25-30cattle pastured all season	0.065	moderate	slight trampling	d = 30-40cm w = 14m l = 30m	10% algae	M = 85% S = 5% G = 10%
2	improved limited access:-fenced crossing -rock rip-rap in channel	1.8 (100% open)	approx. 10 heifers pastured all season	0.556	moderate	moderate trampling	d = 10 cm w = 1m l = 9m	5% algae	M = 10% S = 5% G = 55% C = 30%
3	unlimited access, unimproved. (4-5 crossing sites)	1.9 (100% open)	45-50 beef cattle pastured all season	0.061	slight to moderate	moderate to extreme trampling moderate bank slumping	d = 10-15cm w = 2m l = 195m	15% algae 25% submergents 20% emergents	M = 40% S = 10% G = 30% C = 20%
4	unlimited access, unimproved (2 crossing sites)	14.0 (50% open, 50% wooded)	15-20 heifers pastured all season	0.009	moderate to steep	moderate to extreme trampling slight bank slumping	d = 30-40cm w = 15m l = 60 m of active access (375 m total)	25% algae 25% submergents 20% emergents	M = 50% S = 30% G = 20%
5.	unlimited access, unimproved	6.5 (90% open, 10% wooded	45-50 beef cattle plus other grazing animals pastured all season	0.001	slight to moderate	moderate slumping	d = 50cm w = 50m l = 420m	25% algae	M = 70% C = 30%

Qualitative assessments of muck and silt covering the channel bottom provide an indication of the quantity of fine particles potentially available for resuspension. The sites ranged between 30% and 85% muck and silt.

Vegetative cover in the stream may reduce the impact of trampling on bottom sediments or aid in trapping suspended solids as they move downstream of an access area. Sites 3 and 4 had much higher vegetative cover in the stream (60%-70%) than sites 1, 2 and 5 (5%-25%).

In-stream cattle activities observed at each access site are described in Table 2. On average during each access event 76% of the herd entered the stream. Of those cattle in the stream approximately 83% actually watered at the stream and therefore spent more time in or near the channel than the remaining 17% which only crossed the stream. In addition, of those cattle which did enter the stream 12% urinated and 18% defecated directly into the water course. The total duration of the access event varied with the number of cattle accessing at any given time, the watering activities, and the degree of crowding at the access area.

4.2 Dry Weather Chemistry Impacts

Dry weather water chemistry concentrations and bacterial counts are outlined in Table 3. Stream flow rates are also included in this table. The levels of all chemical and bacterial parameters associated with sediment, animal feces or urine are expected to increase immediately as a result of in-stream livestock activity. This excludes nitrates and nitrites, which are by-products of the decay of ammonia and organic nitrogen, and also *Pseudomonas aeruginosa*, a disease-related bacteria which is associated with human wastes (MOE, 1981). The following discussion outlines the dry weather water chemistry and bacteriological results.

TABLE 2: In-stream Cattle Behaviour - Cattle Access Study, Avon River Basin July - September, 1982

Site No.	Sample Date	Total No. of Cattle in Pasture	Total No. of Cattle Entering Stream	Total No. of Cattle Watering	Total No. of In-stream Defecations	Total No. of In-stream Urinations	Duration of Access Event (minutes)
1	July 13/82	26	17	17	5	5	6
	July 14/82	30	30	30	7	10	31
2	July 20/82	10	10	9	2	0	6
	July 21/82	10	10	9	0	0	11
3	Aug. 4/82	45	16	5	1	0	10
	Aug.11/82	43	40	25	6	0	45
4	Aug.17/82	17	16	16	5	2	15
	Aug. 18/82	17	10	12	1	1	7
5	Sept. 7/82	45	3	3	0	0	5
	Sept. 8/82	45	0	0	0	0	0
	TOTAL	198	151	126	27	18	121

TABLE 3: Dry Weather Chemistry Concentrations (mg/L) and Bacterial Counts (Count/100 mL) Due To In-stream Livestock Activity July- September, 1982

Site No.	Sample Date	No of Samples	Mean Water Chemistry Concentrations (mg/L)							Bacterial Data (count/100 m)^2			Duration^3 of Contaminated plug of Water (min.)	Flow Rate (cm)	Distance Between Sampling Sites (m)
			Suspended Solids	Total Phosphorus	Filtered Reactive Phosphorus	Free Ammonia	Nitrite and Nitrate	Total Kjeldahl Nitrogen	5-day Biochemical Oxygen Demand	Fecal Coliforms	Fecal Strepto-cocci	*Pseudo-monas aeruginosa*			
1	July 13/82	U/S-4	13.4	.024	.002	.005	2.26	.70	6.2	1,100	370	8			
		D/S-4	19.3	.069	.008	.005	2.26	1.26	5.2	38,105	2,648	4	40	.047	60
	July 14/82	U/S-4	2.1	.039	.004	.019	2.41	.56	1.6	340	140	4			
		D/S-4	13.7	.049	.003	.153	2.34	.72	3.7	31,000	13,600	4	40	.047	60
2	July 20/82	U/S-4	10.5	.071	.048	.031	9.64	.88	1.6	4,500	2,900	4			
		D/S-4	331.1	.804	.134	.194	7.13	4.70	16.3	90,000	3,500	28	15	.020	10
	July 21/82	U/S-4	43.9	.077	.039	.046	8.52	.85	1.2	1,300	120	4			
		D/S-4	506.9	.791	.079	.389	8.42	4.42	8.9	100,000	80,000	4	18	.026	10
3	Aug. 4/82	U/S-4	10.5	.093	.048	.005	1.46	.68	2.7	6,400	2,500	4			
		D/S-3	6.6	.104	.050	.008	1.28	.70	1.8	7,400	800	4	15	.013	200
	Aug. 11/82	U/S-4	6.9	.060	--	--	--	--	--	1,700	1,100	4			
		D/S-4	45.3	.500	--	--	--	--	--	138,000	13,000	4	70	.003.	200
4	Aug. 17/82	U/S-4	1.9	.032	.012	.024	2.50	.47	0.6	1,700	320	4			
		D/S-4	5.3	.029	.008	.028	2.50	.49	0.7	800	300	4	17	.080	300
	Aug. 18/82	U/S-4	2.7	.033	.013	.018	2.24	.46	1.4	7,200	150	4			
		D/S-4	11.4	.084	.015	.005	2.24	2.09	20.0	3,100	100	4	10	.090	150
5	Sept. 8/82	U/S-4	5.9	.104	.064	.035	4.30	.80	2.1	50	20	4			
		D/S-4	1.6	.072	.040	.044	4.38	.75	1.3	100	30	4	0	.385	500

1 - U/S - upstream, D/S - downstream

2 - single observations, not means

3 - assessed visually based on turbidity

Upstream and downstream total phosphorus concentrations for all sites exceeded the provincial water quality (0.03 mg/L) objective on all but two days. This level of 0.03 mg/L has been set to reduce nuisance algae growth in rivers and streams (MOE, 1978). Mean upstream concentrations ranged from 0.024 to 0.104 mg/L. Downstream concentrations ranged from 0.029 to 0.804 mg/L. In the upper basin, total phosphorus levels increased on six of eight days as a result of in-stream livestock activity.

As evidenced by the low filtered reactive phosphorus levels, the majority of total phosphorus exists in particulate form. Total phosphorus levels are expected to increase as a result of phosphorus associated with resuspended stream bottom sediments or newly deposited feces. At site 5 in the lower basin, impacts of in-stream activity were negligible for all water chemistry parameters. This was probably due to the extremely limited activity level and the dilution effect of the large upstream flows.

Most sites revealed only slight or negligible increases in filtered reactive phosphorus. At site 2, however, downstream filtered reactive phosphorus increased 2 to 2½ times. The bottom substrate at site 2 is approximately 85% muck and silt with only 10% vegetative cover (Table 1). In-stream trampling may have resuspended the fine bottom sediments, thereby releasing interstitial soluble phosphorus.

Free ammonia levels showed large increases on only three of nine days. These are probably due to increases in direct urine inputs to the water course. Mean upstream concentrations for all sites ranged from 0.005 to 0.046 mg/L; mean downstream concentrations ranged from 0.005 to 0.389 mg/L.

Downstream total Kjeldahl nitrogen levels were 1.5 to 5 times higher than the upstream levels on four of nine days. Organic nitrogen is the difference between total Kjeldahl nitrogen and free ammonia (MOE, 1981); for these sites increased total Kjeldahl nitrogen levels are primarily due to increases in organic nitrogen. These elevated downstream concentrations are directly related to both freshly deposited and resuspended feces or other organic matter.

There was negligible change in nitrate and nitrite concentrations for all study sites. Nitrates and nitrites which are water soluble nitrogen oxides would not be expected to increase as an immediate result of in-stream livestock activity. There must be sufficient time for free ammonia in urine to be oxidized first to nitrite and then to nitrate.

Biochemical oxygen demand (BOD) was increased 7-14 fold as a result of in-stream activity on three of the nine days. An increase in the biochemical oxygen demand is expected with deposition of fecal material or resuspension of organic material.

In summary, site 2 on July 20 and 21, and site 4 on August 17 exhibited the greatest increases in those parameters associated with particulate material: suspended solids, total phosphorus, total Kjeldahl nitrogen and biochemical oxygen demand. Site 1 on July 14 and site 2 on July 20 and 21 showed the largest increases in free ammonia concentrations. Site 2 on July 20 also had the largest increase in filtered reactive phosphorus.

Downstream concentration data along with sampling times were used to delineate pollutographs for each access event. Pollutant loadings were estimated as the area under each pollutograph times the stream flow. The background loading, estimated using mean upstream concentrations, was subtracted from this downstream loading to obtain a net loading figure. This figure represents the short-term or Immediate impact of livestock activity in the stream. Net loading figures are given in Table 4.

TABLE 4: Dry Weather Water Chemistry Loadings (Kg) Per Access Event, July- September, 1982

Site No.	Sample Date	WATER CHEMISTRY LOADINGS (kg)					
		Suspended Solids	Total Phosphorus	Filtered Reactive Phosphorus	Free Ammonia	Total Kjeldahl Nitrogen	5-day Biochemical Oxygen Demand
1	July 13/82	1.180	.0070	.0009	.0000	.0897	0
	July 14/82	2.416	.0024	0	.0314	.0295	.2967
2	July 20/82	4.934	.0046	.0013	.0026	.0588	.2261
	July 21/82	14.372	.0215	.0011	.0093	.1041	.2246
3	Aug. 4/82	----	----	----	----	----	----
	Aug.11/82	.697	.0075	----	----	----	
4	Aug.17/82	.531	0	0	.0009	.0067	.0206
	Aug.18/82	----	.0027	.0001	0	.1014	----
5	Sept. 8/82	0	0	0	.0030	0	0
AVERAGE		3.440	.0057	.0002	.0007	.5530	.1280
SAMPLE SIZE		7	8	7	7	7	6

1. "----" means insufficient data was available for loading estimation purposes

Sites 1 and 2 had consistently high levels of most loadings associated with particulates. This trend is likely due to a lack of in-stream vegetative cover, a high concentration of animals over the season (Table 2) and a high concentration of animals during each access event. Sites 3 and 4 on average had lower loadings, likely due to the higher percentage of vegetative cover in the channel which entraps particulate organic matter as it moves downstream. Site 5, the only lower basin site, had the lowest loadings along with low levels of channel use intensity throughout the summer (0.001 animal units/m^2 channel area) and during this event.

Both filtered reactive phosphorus and free ammonia loads were relatively small compared to the other chemical parameters. The mean loads/event were 0.2 gm and 0.7 gm, respectively. Organic nitrogen loads, 55.3 gm/event, were approximately 10 times greater than total phosphorus loads of 5.7 gm/event. Mean suspended solids loads were the largest with 3440 gm/event contributed to the water column.

Total phosphorus loads were significantly correlated with suspended solids (0.912), filtered reactive phosphorus (0.715), and total Kjeldahl nitrogen loads (0.911). The first two correlations are to be expected, the third may indicate a common organic source such as feces for both the nitrogen and phosphorus. The only activity significantly correlated with water chemistry was the frequency of in-stream urinations with free ammonia (0.756). Urine is the principle source of ammonia nitrogen. All reported correlations are significant at a 95% level.

4.3 Dry Weather Bacterial Impacts

Upstream and downstream levels of fecal coliforms, at all sites in the upper basin, were equal to or greater than the MOE guidelines of 100 organisms/100 mL (Table 3) (MOE, 1978). At site 5, dry weather counts were less than the guideline.

For those sites which showed increased bacterial levels as a result of in-stream livestock activity (sites 1, 2, 3, and 5), downstream fecal coliforms were up to 2 orders of magnitude greater than upstream levels. At the same sites, downstream fecal streptococci levels were up to 3 orders of magnitude greater than upstream levels. In the upper basin, sites 1 and 2 showed consistently higher inputs, while site 3 results were more dependent on the intensity of in-stream activity. Site 5 in the lower basin showed only minor increases in both types of fecal bacteria most likely because of the large dilution factor. Decreased levels of fecal bacterial were observed on three days at two sites: fecal streptococci at site 3 on Aug. 4, and both fecal streptococci and fecal coliforms at site 4 on Aug. 17 and Aug. 18. These decreases are probably due to entrapment of solids by in-stream vegetation. The percentage of channel vegetative cover is higher at these sites than all others (Table 2).

When fecal-indicator bacteria are present in high numbers, disease-related bacteria such as *Pseudomonas* spp. and *Salmonella* spp. are also likely to be present. *Pseudomonas aeruginosa*, normally found in human wastes, was detected at two of five sites; *Salmonella* sp. was found only at one of two sites (Table 2).

In summary, the level of background fecal indicator bacteria, as determined by the upstream samples, exceeded MOE public health guidelines at all sites in the upper basin during the dry weather survey. The lower basin site was characterized by a water flow rate about ten times greater than the upper basin flows and fecal bacterial levels less than the MOE guideline. Disease-related bacteria were detected on two days at two separate sites.

Access sites with low in-stream vegetative cover, low flow rates, and high channel use intensity are most likely to exhibit high levels of bacterial contamination during access events.

4.4 Wet Weather Survey

The storm event of September 14, 1982 moved from west to east across the river basin starting at approximately 17:30 in the lower basin and 20:30 in the headwater area. At site 2 intense rain lasted about one hour and measured 18.2 mm. Streamflow rates are outlined in Table 5 for three stage flow gauges in the upper basin. Since the rain followed an extended dry period, soil moisture was low and, as a result, runoff flows likely were contributed only by areas in close proximity to the stream.

Mean water chemistry concentrations and bacteriological counts are presented in Table 6 and Figures 3, 4 and 5. These mean levels are likely to be low since the first flush of runoff occurred between the first and second sampling runs (Table 5).

During the runoff period phosphorus concentrations generally exceeded the dry weather observations by an order of magnitude. Other water chemistry values tended to be elevated above dry weather values, but not to the same degree. Each access site is discussed separately because of the site specificity of runoff conditions.

(i) At site 1 the major wet weather impacts are the elevated upstream levels of nitrite and nitrate. They result from feedlot runoff entering the Avon-River from a drainage ditch immediately upstream of the access site.

(ii) Site 2 exhibited a relatively high level of ammonia at the upstream sampling location, suggesting direct liquid waste inputs. Changes in suspended solids loads are the most notable impact at this access site. There was a 33% increase in the mean concentration of this parameter.

TABLE 5: Hourly Stream Flow Rates (Cfs) At Three Locations In The Upper Basin, Avon River, September 14-15, 1982

Stream Flow Gauge		Hourly Stream Flow Rates (cfs)			Remarks
		A	B[1]	C	
Nearest Cattle Access Sites		#2	#3	#1,#4	
Date	Time				
Sept. 2	18:00	32.84			- most recent peak flow
3	17:00		.39	27.93	
Sept. 14	06:00	.04	.04	5.76	- base flow
Sept. 14	17:00	.03	.04	5.89	
	18:00	.03	.04	5.97	
	19:00	.04	.04	5.97	
	20:00	.07	.04	5.97	- 1st sample run,19:30
	21:00	1.38	.04	6.60	- 18.3mm rain, Site #2
	22:00	2.22	.05	6.60	
	23:00	2.58[2]	.05	6.64	
	24:00	2.44	.05	6.75	- 2nd sample run,23:00
Sept. 15	01:00	2.05	.05	7.06	- 3rd sample run, 01:30
	02:00	1.48	.05	8.02	
	03:00	1.31	.05	9.32	
	04:00	1.13	.05	10.84	- 4th sample run, 04:30
	05:00	.99	.05	12.64	
	06:00	.84	.05	14.94	
	07:00	.67	.05	17.41	
	08:00	.60	.05	18.82	
	09:00	.53	.05	20.06	
	10:00	.49	.05	20.09[2]	
	11:00	.42	.05	19.28	
	12:00	.35	.05	18.40	
	13:00	.32	.05	17.55	
	14:00	.32	.06	16.70	
	15:00	.28	.06	15.86	
	16:00	.28	.06	15.15	
	17:00	.25	.06	14.58	
	18:00	.25	.06	14.09	
	19:00	.25	.06	13.60	
	20:00	.21	.06	13.21	
	21:00	.21	.06	12.89	
	22:00	.21	.06	12.57	
	23:00	.21	.06	12.25	
	24:00	.18	.06	12.00	
Sept. 17	06:00	.11	.07[2]	8.69	

1. Note: although no direct rainfall occurred at this site, field observations reveal that intense rainfall began at about 20:00 on September 14, at Site #3.

2. Peak flow rate (cfs) for the storm event.

TABLE 6: Wet Weather Water Chemistry Concentrations (mg/L) And Bacterial Counts (count/100 ml), September 14-15, 1982 (11-hour intensive survey)

		Mean Water Chemistry Concentrations (mg/L)[1]							Mean Bacterial Counts[2] (count/100 mL)		
Site No.	No. of[3] Samples	Suspended Solids	Total Phosphorus	Filtered Reactive Phosphorus	Free Ammonia	Nitrate and Nitrite	Total Kjeldahl Nitrogen	5-day Bio-Chemical Oxygen Demand	Fecal Coliform	Fecal Streptococci	*Pseudomonas aeruginosa*
1.	U/S-4	49.2	.544	.285	.190	5.21	1.66	2.3	21,600	7,700	20
	D/S-4	57.2	.593	.373	.239	2.88	1.84	3.4	171,200	68,000	6
2[4]	U/S-2	41.1	.269	.150	.487	3.17	1.70	3.0	46,700	56,500	160
	D/S-2	63.9	.376	.182	.338	3.32	1.81	4.6	71,800	83,400	110
3	U/S-4	22.9	.289	.032	.010	1.70	.58	0.4	1,400	900	4
	D/S-4	51.1	.201	.106	.060	1.56	.92	2.1	35,500	9,400	70
4	U/S-4	5.1	.059	.032	.028	2.32	.55	0.8	3,300	1,100	4
	D/S-4	5.7	.052	.030	.030	2.07	.52	0.8	5,600	1,500	4
5	U/S-2	29.2	.231	.127	.068	2.60	1.03	5.6	25,300	22,900	220
	D/S-2	30.1	.232	.125	.070	2.60	1.02	5.6	25,500	17,300	190

1. arithmetic means of 4 samples for water chemistry
2. geometry means of 2 samples for bacterial counts
3. U/S - upstream sample; D/S - downstream sample
4. arithmetic means of 2 samples for water chemistry

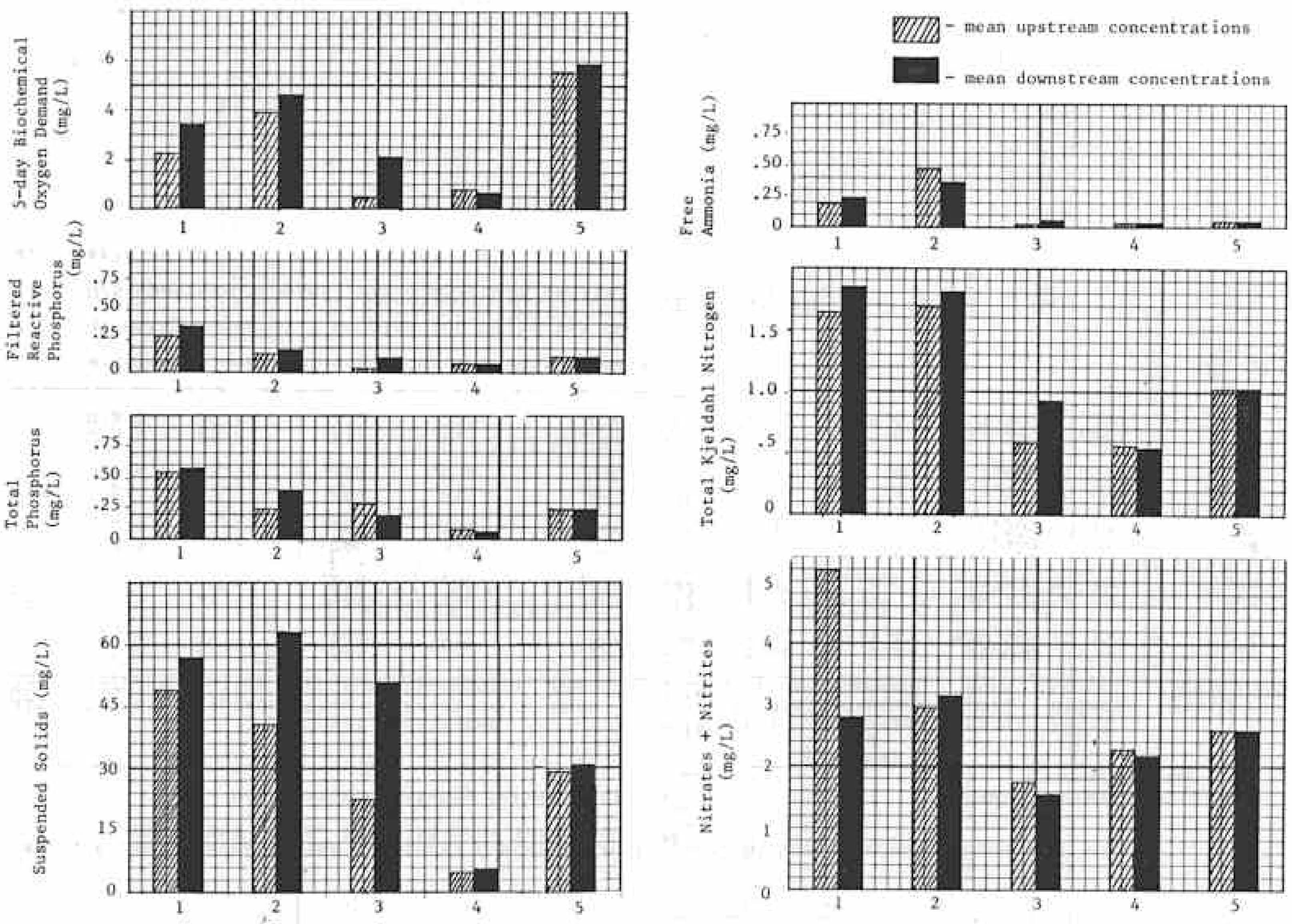

Figure 3: Mean wet weather concentrations (mg/L) for water chemistry parameters at cattle access study sites, Avon River basin, Sept. 14-15/82 (n=4 - Sites 1,3,4; n=2 - Sites 2,5)

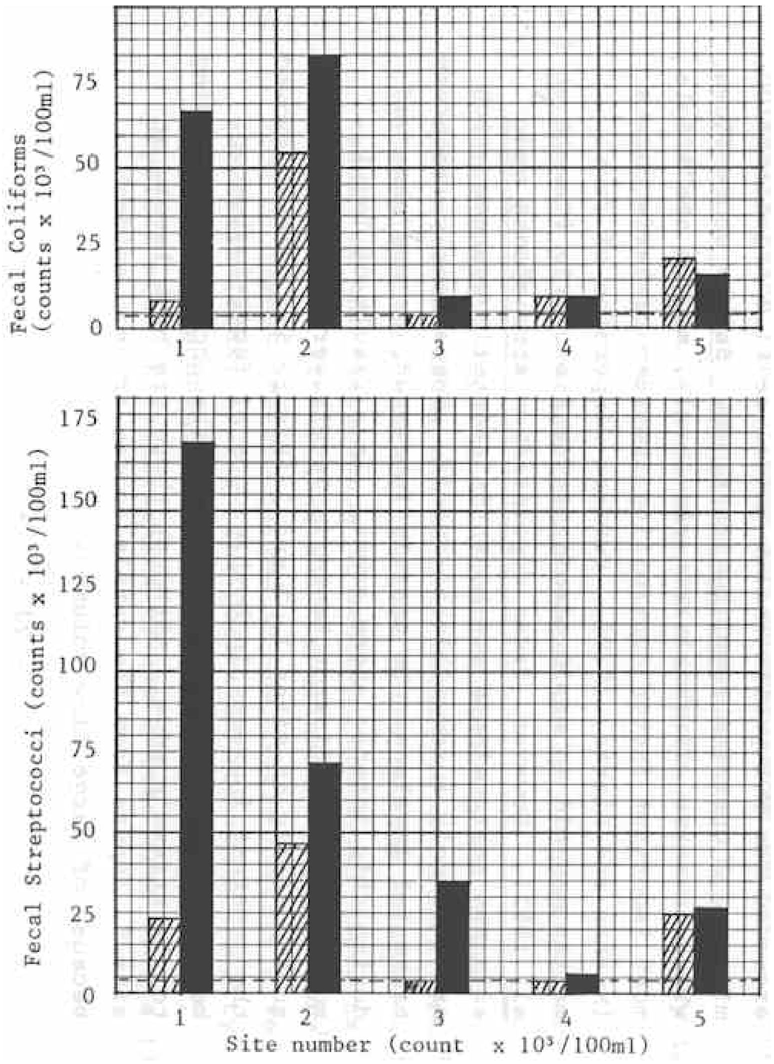

Figure 4: Mean wet weather counts (count x 10^3/100mL) for fecal - indicator bacteria at cattle access study sites, Avon River basin, Sept. 14-15/82 (n=2)

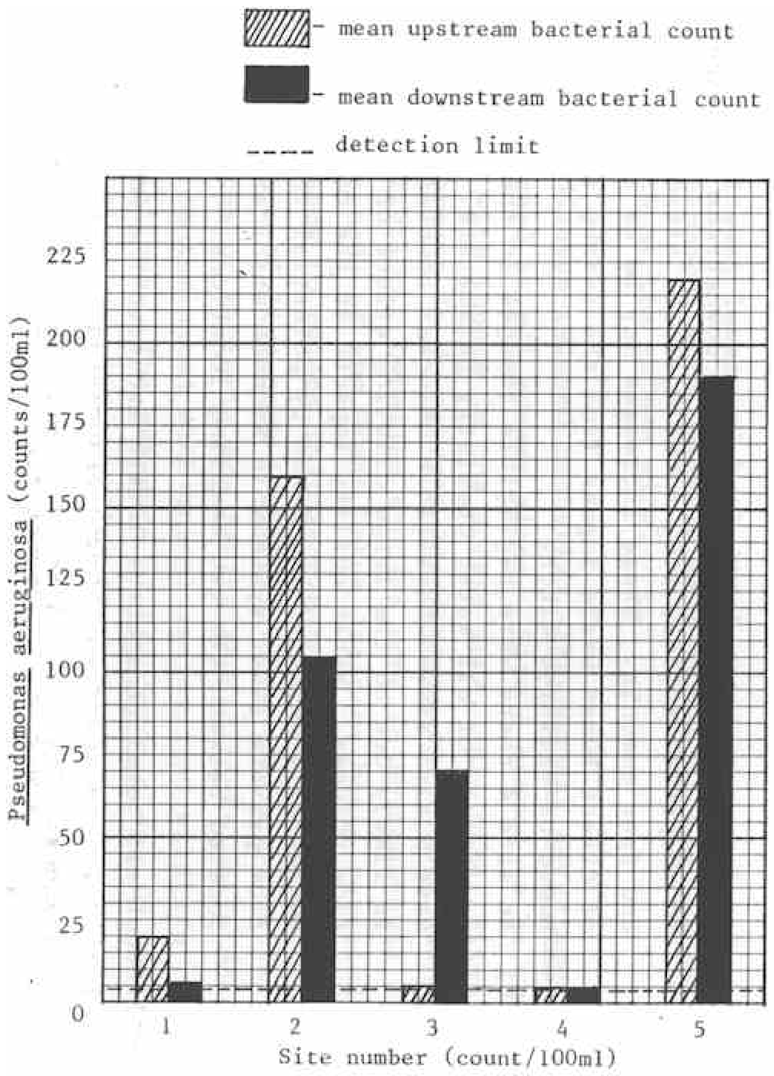

Figure 5: Mean wet weather counts (count/100mL) for *Pseudomonas aeruginosa* at cattle access study sites, Avon River basin, Sept. 14-15/82 (n=2)

(iii) Site 3 has the largest upstream to downstream increase in suspended solids, BOD5 total Kjeldahl nitrogen and free ammonia. These increases may be as a result of direct human waste inputs from the nearby farm house or drainage ditch.

(iv) At site 4 there were negligible changes in the already low levels of all water chemistry parameters.

(v) Site 5 also showed negligible changes; however, this is likely due to the large dilution effect of upstream flow volumes. Water quality impacts at, the cattle access site may also be masked by potential inputs from private sewer systems in Avonton which are located between the two sampling locations.

Although all total phosphorus levels exceeded the MOE guideline, local nutrient inputs associated with runoff from cattle access sites seemed to be minor. Suspended solids concentrations were most susceptible to increase, especially in the headwater areas (sites 1, 2 and 3).

Wet weather levels of fecal coliforms and fecal streptococci exceeded the MOE public health guideline (100 organisms/100 mL) at all upstream sampling locations. Summer storm flows, which increase all fecal bacteria levels, may be the single most important factor controlling in-stream bacteria counts (Meehan and Platts, 1979). Surface dispersion of fecal matter may aid in rapid dieoff of fecal bacteria (Temple *et al*, 1982). However, feces deposited on streambanks and adjacent pasturelands are potential bacteria sources which are extremely susceptible to runoff. Consequently, in-stream bacterial levels may be greatly increased, as was observed during this intense storm event. As a result of local runoff, fecal-indicator bacteria levels were increased substantially at sites 1, 2 and 3 (Figure 5). Site 1 showed the greatest increase in both groups of fecal-indicator bacteria, likely due to runoff from the access ramps leading to the stream's edge. Although there are high levels at site 5, inputs from the cattle access are not evident because of large flow volumes.

The lowest levels of both fecal coliform and fecal streptococci were observed at site 4 with negligible direct inputs at the access site.

The disease-related bacterium, *Pseudomonas aeruginosa*, was detected at all access sites. Site 3 seemed to be the only site with inputs in the access zone. All other sites showed a, decrease in downstream *Pseudomonas* sp. counts due possibly to dilution. Detailed studies done in agricultural watersheds of the Great Lakes drainage basin revealed little evidence to relate indicator-bacteria to the presence or absence of livestock (PLUARG, 1978). Other potential sources of bacteria are faulty septic tanks, tile drains, soil contaminated with animal wastes, and wildlife populations. The presence of *Pseudomonas* sp. in upstream Avon River samples verifies the existence of recent inputs of human wastes during storm conditions. In addition, a portion of the fecal-indicator bacteria may also result from human wastes. *Salmonella* spp. were not tested.

In summary, fecal-indicator bacteria exceeded the MOE public health guideline upstream and downstream of all sites. The presence of *Pseudomonas aeruginosa* suggests that rural diffuse inputs of bacteria and nutrients are not solely from agricultural sources.

4.5 Summary of Factors Affecting Water Quality Impacts at or near Cattle Access Sites

Water quality impacts of livestock activity at or near cattle access sites can be both immediate and short-term as a result of dry weather in-stream activity, and delayed as a result of the disturbance of sediment and fecal deposits from adjacent streambanks and the streambed during storms. Similar impacts were observed in the Little Ausable River sub-basin (Beak, 1977). The potential for water quality impacts is dependent upon many factors. In this study, physical site characteristics of the access area (Table 1) and the type and extent of livestock behaviour (Table 2) were compared to water quality loadings and concentrations (Tables 3, 4 and 5). Because of the subjective and qualitative nature of many of the observations only trends in the severity of water quality impacts were noted.

During dry weather, immediate water quality impacts were more evident at sites with the following characteristics:

(i) limited in-stream vegetative cover to trap newly deposited and resuspended matter;

(ii) high percentage of muck, silt and organic debris on the streambed that can be resuspended;

(iii) high seasonal concentration of animals in pasture (as represented by the number of pastured animal units/m^2 of channel area) resulting in high cumulative fecal loadings/unit area of stream over the grazing season;

(iv) high concentration of animals during any given event leading to trampling of the streambed and a high probability of in-stream nutrient inputs from defecation or urination;

(v) longer duration of the access event, which increases the probability of in-stream nutrient inputs from defecation and urination, and increases the amount of trampling of the bottom sediments; and lower flow volumes and therefore limited dilution potential.

Potential wet weather water quality impacts are dependent upon the following factors:

(i) the length and slope of stream bank used by livestock in accessing the channel, reflecting the total land area susceptible to erosion from trampling;

(ii) the percent vegetative cover on the streambanks at the access site, reflecting the susceptibility of the banks to erosion from trampling;

(iii) the total number and concentration of cattle on the streambank, reflecting the amount and intensity of bank trampling incurred at the access;

(iv) the total time spent near the access site, reflecting the probability of defecation on the streambanks; and

(v) the volumes of stream flow.

It is only by considering site characteristics and cattle activities in or near the stream under both wet and dry weather conditions that the potential for water quality impairment can be determined.

4.6 Estimation of Seasonal Nutrient Loads Delivered to the Stream

Estimates of phosphorus loadings were calculated for various rural diffuses sources in the Avon River basin as part of an investigation of all nutrient inputs to the river (Fortin, et al, 1983). Seasonal nutrient loads which are delivered directly to the Avon River as a result of in-stream livestock activity are calculated in this section. Figure 6 outlines the cattle access sites for the entire basin. The following discussion includes an outline of the assumptions used in the estimation, and the subsequent results.

4.6.1 Assumptions

Several assumptions regarding basin cattle populations, cattle behaviour and fecal nutrient composition were necessary to determine the total basin load. These assumptions, based on the literature and field observations made during this study, are outlined below.

(i) The basin population of pastured cattle with access to the Avon River are as follows: dairy - 1039 cattle, heifer - 47 cattle, and beef - 840 cattle. Approximately 30% of the cattle have access to alternate pastures without stream access (Hayman, 1983). It was assumed that the alternate pastures

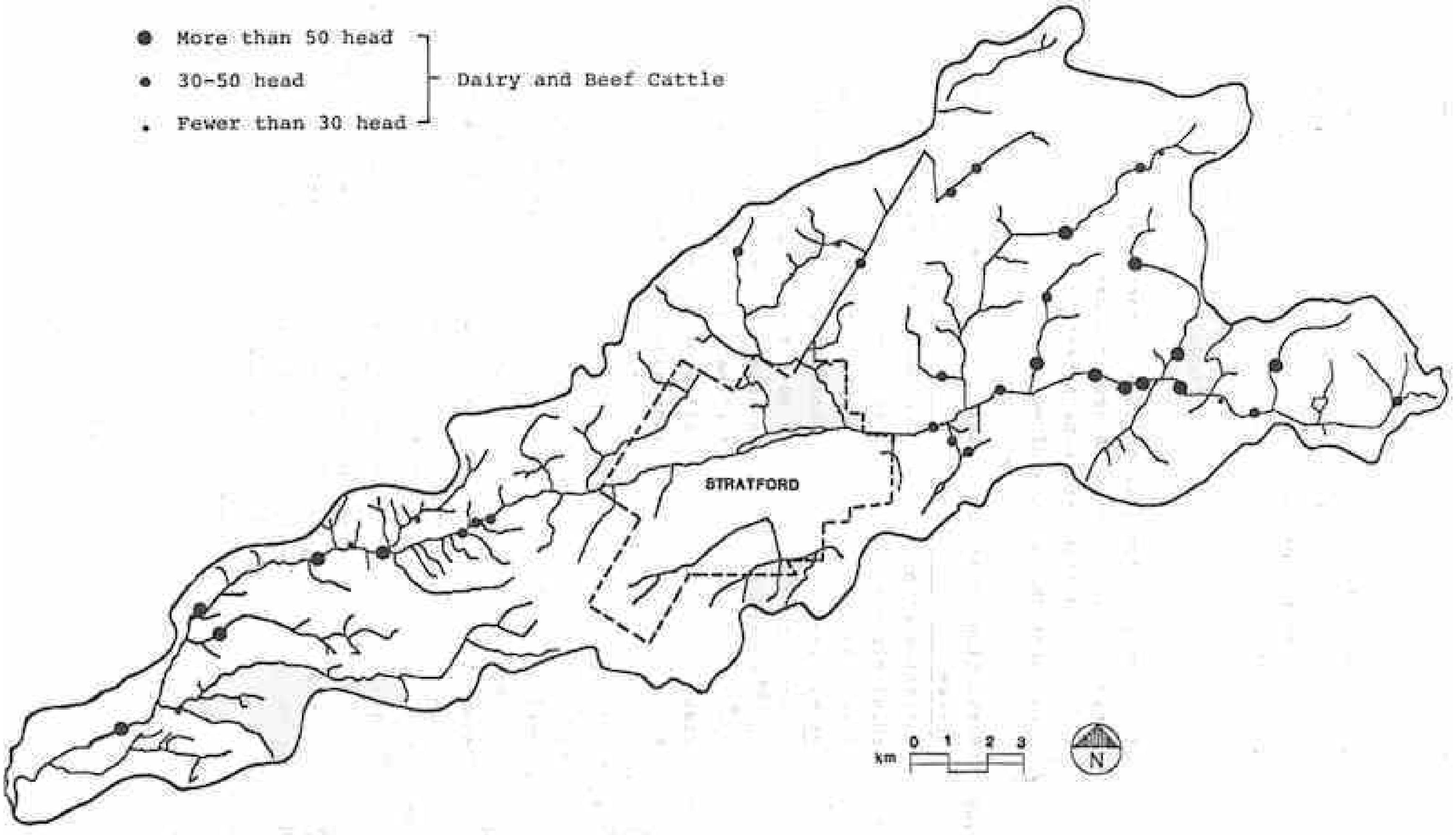

Figure 6: Location of Cattle Access Sites, Avon River Basin, 1980. (from Hayman, 1983)

were used 50% of the time which consequently decreases the total number of cow-days spent in pastures adjacent to stream waters.

(ii) The season modelled here lasts 153 days, May to September inclusive.

(iii) The average daily frequencies of defecation and urination are considered constant for all breeds of cattle. Volumes for each eliminative event vary according to breed, and food and water requirements. On average cattle defecate 15 times/day and urinate 9 times/day (Hafez and Bouissou, 1975).

(iv) On average pastured cattle water at the rate of 1-4 times per day. The frequency of watering is dependent upon several factors including water content of the grass, temperature and relative humidity. Although different breeds or types of cattle have different water requirements, the volume and not the frequency of water consumption is variable (Hafez and Bouissou, 1975). Limited field observations (5-7 hours/day for nine days) of watering frequency confirmed these literature values.

(v) During any given access event, the probabilities that a single cow entering the stream will defecate and urinate in the stream are 17.9% and 11.9%, respectively (Table 2). These probabilities were estimated from field observations as the total number of defecations (or urinations) divided by the total number of cattle in the stream.

(vi) The source of nutrient loadings in fresh manure, without bedding, are as follows: nitrogen - 48% feces, 52% urine; phosphorus - 100% feces, 0% urine; and potassium - 14% feces, 86% urine (calculated from Maclean and Hare, 1979).

(vii) The amount of phosphorus excreted per defecation- ranges from 1.1 to 2.4 gm; urine contains negligible amounts of phosphorus. Nitrogen loadings range from 2.6 to 5.6 gm/defecation and 4.7 to 10.1 gm/urination (Table 7).

TABLE 7: Nutrient Loadings (gm) Excreted By Cattle

	Parameter[3]	TYPE OF CATTLE		
		Dairy (545 kg)	Heifer (15-24 mo)	Beef (185-500 kg)
Nutrients excreted	N	175.3	82.2	87.7
in feces & urine	P	36.2	16.7	18.1
combined (gm/day)[1]	K	181.9	85.2	91.0
Nutrients Excreted/	N	5.6	2.6	2.8
Defecation (gm)[2]	P	2.4	1.1	1.2
	K	1.7	0.8	0.8
Nutrients Excreted/	N	10.1	4.7	5.1
Urination (gm)[2]	P	0	0	0
	K	17.4	8.1	8.7

1. Calculated from Agric. Canada. Publ. #1534, 1980
2. Assumptions (iii) and (vi)
3. N-nitrogen; P-phosphorus; K-potassium

4.6.2 Nutrient Loadings

To estimate the seasonal nutrient loadings to the watercourse due to in-stream cattle activity, daily cow-unit loadings were calculated. These results are outlined in Table 7.

Field behaviour observations, were applied to the loading estimates (defecation or urination) to determine direct nutrient inputs to the stream. The total nutrient loading delivered directly to the Avon River from cattle excretion was calculated in the following manner: the nutrient loadings per urination (or defecation) X the probability of a single cow urinating (or defecating) in the stream X the number of watering events per day X the number of days per grazing season X the total number of cows with stream access in the basin.

The nutrient loadings per urination (or defecation) and the number of cows were adjusted according to the type of cow. Table 8 outlines these seasonal nutrient loadings. Based on an average watering frequency of 2.5 times/day, the total seasonal nutrient loads for the basin are: nitrogen - 1048 kg; phosphorus - 203 kg; and potassium - 1125 kg. Although both potassium and nitrogen far exceed the phosphorus contribution, phosphorus is the nutrient of greatest concern. It is most frequently the limiting factor for plant growth in aquatic ecosystems as well as the most readily controlled. The full range of seasonal phosphorus loadings to the basin is 81-325 kg, for a watering frequency range of 1-4 times/day.

Using a number of behavioural assumptions, Robinson and Draper (1978) estimated that a maximum phosphorus load of 130 gm/dairy cow/year reached the stream at cattle access sites. Based on the field observations and assumptions made in this study, it is estimated that 164 gm/dairy cow/year (an average watering frequency of 2.5 times/day) are deposited directly into the watercourse as a result of in-stream cattle activity. These two estimates are surprising similar given the degree of error inherent in such estimates. Robinson and Draper calculated the total loadings to watercourse in the southern Ontario

TABLE 8: Estimates Of Seasonal (May-September) Nutrient Loadings (kg) Delivered To The Avon River Due To In-stream Cattle Activity

Sub-Basin [1]	Cowdays/Grazing Season			Percent of Basin Herd With Stream Access	Pasture Area With Stream Access (hectares)	Seasonal (May-Sept)[2] Nutrient Loadings Delivered to Water Course (kg)		
	Dairy	Heifer	Beef			Nitrogen As N	Phosphorus As P	Potassium As K
1	--	3672	--	1.48	3.2	9.48	1.83	10.11
2-3	46512	--	54774	40.59	9.3	407.83	78.76	447.17
4-7	48348	--	23562	28.82	91.9	331.29	64.35	355.99
8-10	22185	--	28764	20.41	93.5	201.85	38.95	216.30
11-13	13770	--	7956	8.70	29.9	97.82	18.97	105.99
TOTAL	130815	3672	115056	100.00	311.6	1048.26	202.86	1124.60

1. See Figure 2 for sub-basin locations.
2. An assumed average watering frequency of 2.5 times per day.

Great Lakes basin to be 160 tonnes. When these total loadings were distributed over all animal units (2,120,000) in the same area, the maximum loading was estimated as 80 gm/animal unit/year. Robinson and Draper add that this estimate may be an order of magnitude too high. In the Avon River basin, there is an average of 68.9 animal units on each of 183 livestock operations (Carroll, 1981) and therefore 12611 animal units in-total. Distributing the total phosphorus loadings of 203 kg/year (an average watering frequency of 2.5 times/day) across all animal units in the basin results in 16 gm/animal unit/year to be delivered to the stream. This estimate is within the same order of magnitude as the Robinson and Draper estimate.

Nutrient loadings/cow based on in-stream water chemistry, results (Table 2, Table 4) were compared with loadings/cow based on amount excreted/event (Table 7). Average in-stream water chemistry loadings were 1.6 gm total phosphorus/defecation (range: 0.3-2.7 gm), 1.6 gm free ammonia nitrogen/urination (range: 0-3.1 gm), and 355.2 gm suspended solids/in-stream cow (range: 17.4-1437.2 gm). Nutrient loadings delivered directly to the stream through excretion were calculated as 1.8 gm total phosphorus/defecation (range: 1.1-2.4 gm), and 7.6 gm free ammonia nitrogen/urination (range: 4.7-10.1 gm).

In-stream phosphorus loads are about equal to the delivered loads. When comparing the range of values, however, the in-stream loads vary greatly from the expected delivered loads. This is likely a function of the duration of disturbance and the amount of organic and fecal material on the channel bottom available for resuspension from in-stream trampling. This is supported by the strong correlation between total phosphorus and the higher suspended solids loads. Free ammonia nitrogen loads calculated from in-stream chemistry results appear to greatly under-estimate delivered loads. This is likely due to immediate dilution of the soluble ammonia which would move downstream more quickly than the visible sediments which were sampled. Consequently, the soluble loadings may not have been sampled accurately.

In summary, total phosphorus in-stream loads are more closely correlated with suspended solid loads than in-stream defecations. Free ammonia nitrogen loads are less than would be expected from urination. Estimates of seasonal phosphorus loadings from cattle access sites range from 81 to 325 kg for the Avon River basin depending upon the daily watering frequency.

5.0 CONCLUSIONS

Intensive water quality and animal behaviour monitoring of several cattle access sites in the Avon River revealed a detrimental impact of livestock activities on water quality during the summer grazing season. The levels of suspended solids, total phosphorus, free ammonia, total Kjedahl nitrogen and biochemical oxygen demand all increased as a direct result of in-stream livestock activity during dry weather. From a single storm runoff survey only minor water chemistry impacts were apparent. Fecal bacterial contamination was a definite problem under both wet and dry weather conditions. However, during storm events cattle access sites were not the sole contributors of bacteria.

The degree and persistence of water quality impairment is influenced by several animal behaviour and access site characteristics. Increases in most chemical and bacterial loads appear to be more closely related during dry weather conditions to the fecal and organic matter which has accumulated on the channel bottom over time. This material acts as a source of matter for resuspension and dispersion from in-stream trampling.

Free ammonia inputs were most closely related to the number of in-stream urinations. Deposition of feces on the streambanks and erosion from bank trampling are two factors which lead to impairment of stream water quality during wet weather conditions. Bacterial contamination evident during the wet weather survey was greater than that which occurred during dry weather access episodes.

The full extent of water quality impairment is not accurately *known.* It is estimated, however, that approximately 200 kg total phosphorus are delivered to the *Avon* River from cattle access sites during the summer season as a direct result from defecation and urination in the stream.

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