Stream Water Quality Associated with a Livestock/Poultry Production Operation in Southeastern Manitoba, Canada

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Abstract: Water quality was examined in two parallel streams in southeastern Manitoba that enclosed a small hog and poultry operation with associated waste lagoons and manure spread fields. Nitrate-N (NN), molybdenum reactive phosphorus (MRP), dissolved organic matter index (DOMI), chloride, total alkalinity, total dissolved solids (TDS), total suspended solids (TSS), pH, temperature, and total (TC) and fecal (FC) coliform bacterial counts were measured at weekly intervals during the ice-free season at two upstream and two downstream sites relative to the operation. Significantly higher values downstream compared to upstream were observed for MRP, TSS, TDS, chloride, and to some extent NN, indicating the escape of these materials into the adjacent streams. TC were correlated with the rainfall, water temperature, TDS, and pH at all sites. However, TC were also correlated with TSS, MRP, and DOMI only at the downstream sites, while NN was correlated more strongly downstream than upstream. FC were correlated with water temperature and NN at all sites, as well as with TSS and MRP downstream only. Downstream FC/TC ratios increased with increasing rainfall, indicating proportionately greater escape of FC compared to TC under higher runoff conditions. The results suggested that environmental loading of livestock waste adversely altered natural stream water quality dynamics, underlining the need for improved management practices, including the timing of manure spreading during drier weather conditions to minimise the large-scale escape events.

Keywords: coliform bacteria; livestock; nitrogen; phosphorus; stream water quality

Intensive animal and poultry production is associated with numerous environmental and human health effects (e.g. Pip 2000; Burkholder *et al.* 2007), but nitrogen, phosphorus, and microbial escape are of particular concern (Mallin *et al.* 1997; Fisher *et al.* 2000). Significant threats to water quality may result from the proximity of surface water to lagoons and sprayfields (Mallin 2000), as well as over-application of manure to fields (Cook & Baker 2001), and may be further aggravated by spills and illegal dumping. Precipitation, erosion, and flooding may exacerbate contaminant escape (Thurston-Enriquez *et al.* 2005).

Intensive livestock facilities are frequently located beside streams, which are also the most vulnerable to contamination because of their limited dilution capacity (Pip 2005). In order to ascertain whether the downstream effects could be detected, the present study examined water quality during the ice-free season in two streams flanking a small hog/poultry operation in southeastern Manitoba.

MATERIAL AND METHODS

The study sites were located within the Brokenhead River watershed which sustains extensive cropland, and beef, dairy, hog, and poultry production (AAFC 2004). The livestock operation and its lagoons and spread fields were located in a region of high water table between the Brokenhead River (annual flow in 2008 of 138.06×10^6 m^3) and the smaller Hazel Creek; the latter is a tributary of the former (Figure 1).

This operation produced > 20 000 broiler chickens every 8 weeks, and also housed 8500 laying hens

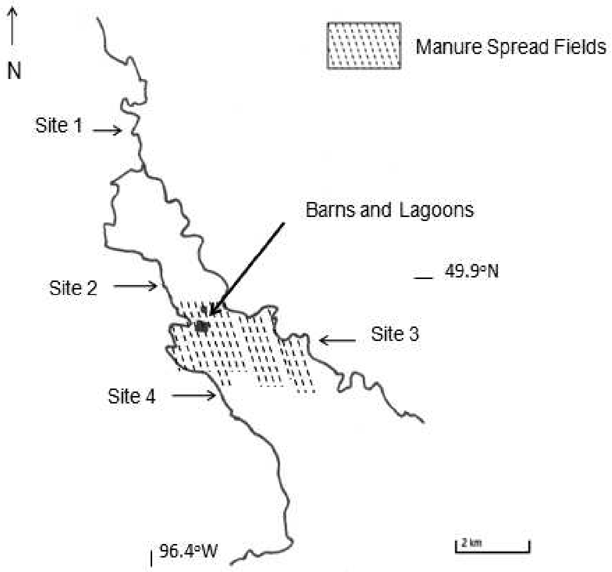

Figure 1. Location of sampling sites; direction of water flow is northwards

and 600 breeding sows. Waste was held in lagoons until spreading time to cropland (ca. 900 ha) in the fall, although inappropriate waste disposal on the stream banks has also occurred (CBC 2007). Human waste from the ~ 110 permanent residents of the operation colony was held in a separate lagoon which was also indirectly discharged into Hazel Creek.

Sites 1 (49°58.4'N, 96°25.5'W) and 2 (49°56.6'N, 96°24.9'W) were located on the Brokenhead River downstream of the operation, while site 3 (49°55.2'N, 96°1.8'W) and site 4 (49°54.5'N, 96°23.0'W) were upstream, on the Hazel Creek and the Brokenhead River respectively (Figure1). The Agassiz Provincial Forest Reserve, where these streams originated, was located upstream of sites 3 and 4.

The sampling was conducted weekly at the same time of day from 1 May to 5 November 2008. Temperature and pH were measured *in situ* using a thermometer and pH meter (Radiometer, Copenhagen, Denmark). The water samples were collected midstream 10 cm below the surface. Midstream water depth at the sites did not exceed 2 m during the sampling season. One sample was filtered through a pre-weighed Whatman No. 1 filter and the filtrate was frozen for chemical analysis. Total suspended solids (TSS) were subsequently quantified by weighing the filter papers, air-dried to constant weight at room temperature. A second water sample was collected into a sterile bottle for microbial analysis. Immediately on return to the laboratory, this sample was inoculated in triplicate as serial dilutions using the Durham tube method and sterile lactose (incubated at 37°C) and Brilliant Bile Green (44.5°C) media (EMD Chemicals Inc., Gibbstown, USA) for total (TC) and fecal (FC) coliforms, respectively (Cappucino & Sherman 2005). TC and FC counts were calculated as Most Probable Number/dL (MPN).

Chemical analysis of the filtrate included nitrate-N (NN), molybdenum reactive phosphorus (MRP), dissolved organic matter index (DOMI), chloride, and total alkalinity using the methods recommended by APHA (1995). Total dissolved solids (TDS) were measured directly using a calibrated TDSTestr 1 (Oakton, Wards Natural Science, St. Catharines, USA).

Statistical tests were conducted using SPSS (Chicago, USA). The data were transformed as appropriate and distributions were pretested for parametric eligibility (Sokal & Rohlf 1981). The critical significance level for all statistical tests was $P = 0.050$.

RESULTS AND DISCUSSION

Paired t-tests showed no significant differences for water temperature among the four sites (Figure 2). Precipitation data summed for each week (Figure 3) indicated a series of rainfall events, with the greatest amounts concentrated in June and July. Weekly precipitation was significantly correlated with water temperature ($r = 0.36$, $P < 0.001$, $n = 112$).

The soils in the region are classified as categories 2 and 3 (fine and coarse loam and clay) in the Canada Land Inventory System (AAFC 2004). Although the slope was minimal (< 5%), elevated levels of TSS were observed after rainfall events ($r = 0.21$, $P = 0.012$, TSS ln transformed, $n = 112$). moderately higher values were recorded over the season downstream of the fields, compared to upstream ($t = 2.21$, $P = 0.036$) (Figure 4). While TSS fluctuations were significantly correlated between sites 1 and 2 ($r = 0.69$, $P < 0.001$), and between sites 3 and 4 ($r = 0.74$, $P < 0.001$)($n = 56$), upstream and downstream sites were not correlated, indicating different erosion patterns on the permanently vegetated vs. cultivated lands.

The TDS values (Figure 5) and chloride concentrations (range < 0.1–6 mg/l) were also generally higher at the downstream sites, supporting the

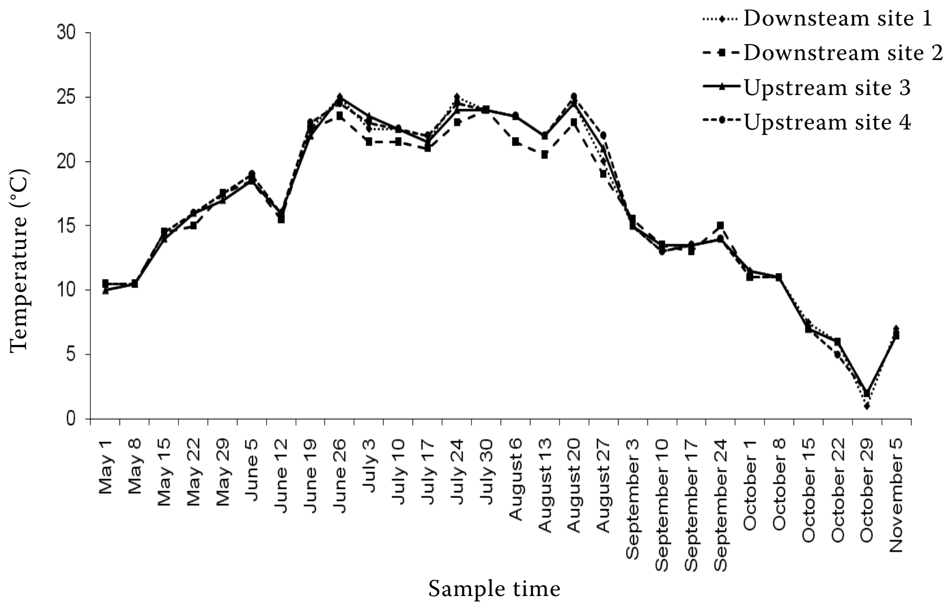

Figure 2. Water temperature at the study sites

findings of Sherwood (2005) for increased chloride loadings associated with livestock and poultry waste. DOMI was significantly higher at upstream site 3 than at all other sites ($t = 7.35–9.94$, $P < 0.001$, $n = 112$) (Figure 6), because site 3 waters originated in bogs in Agassiz Provincial Forest. Fluctuations in DOMI were correlated with weekly precipitation overall ($r = 0.26$, $P = 0.003$, $n = 112$), while pH ($r = -0.21$, $P = 0.012$) showed an inverse correlation with rainfall, likely associated with increased

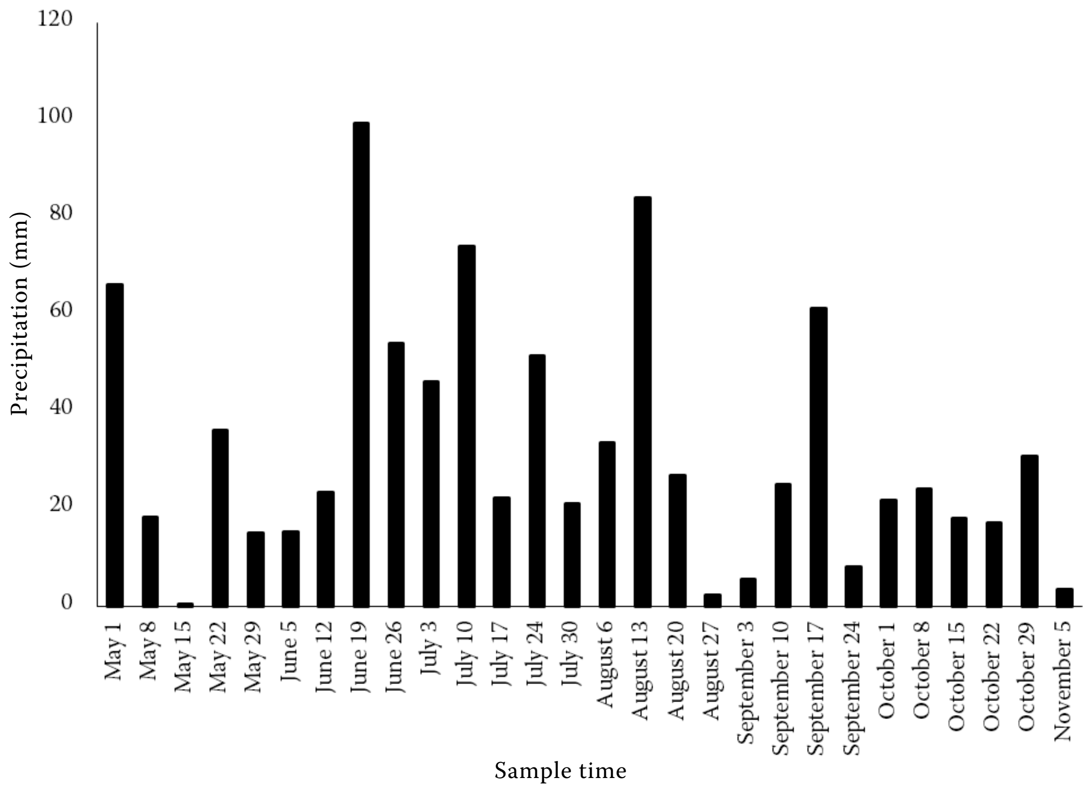

Figure 3. Regional precipitation summed weekly during the 2008 season

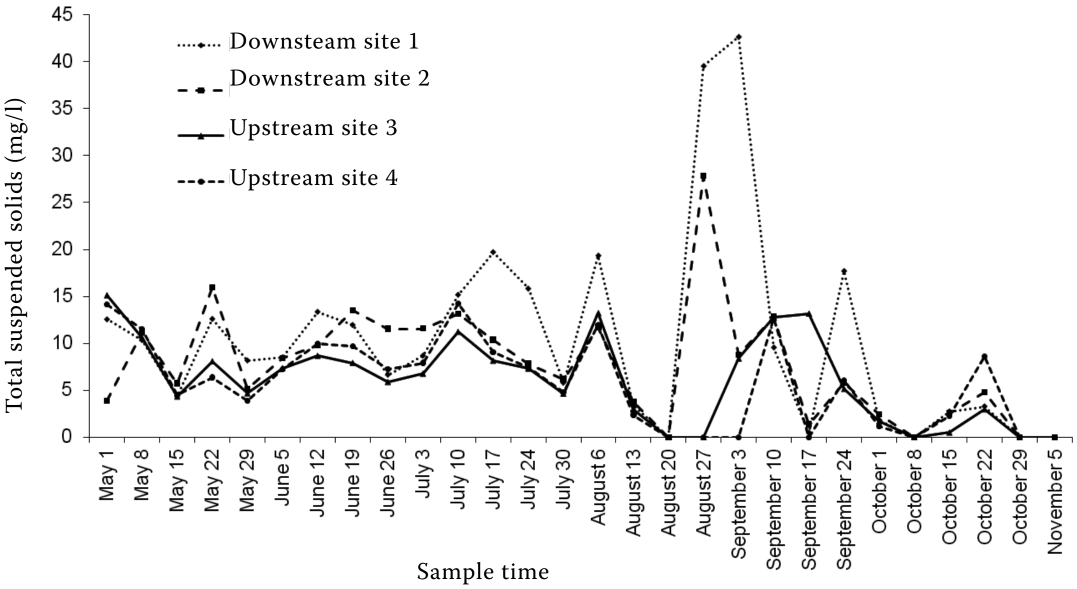

Figure 4. Total suspended solids at the study sites

organic leaching from upstream acidic bogs after rainfall events. The pH (range 6.9–8.1) and total alkalinity (range 90–240 mg/l $CaCO_3$) were not significantly different among the four sites.

Fluctuation patterns for NN were not significantly correlated among any of the sites (Figure 7), although a moderately significant ($P = 0.028$) increase was observed downstream compared to upstream. However MRP (Figure 8) showed pronounced elevation at the downstream sites ($t = 5.80$, $P < 0.001$). A large spike in MRP was observed in late September at both of the downstream, but not the upstream, sites (Figure 8), indicating substantial phosphorus escape associated with the manure application period. While NN and MRP were not correlated with each other upstream, they showed a strong intercorrelation downstream ($r = 0.51$, $P < 0.001$, $n = 56$), reflecting a mutual source.

Significant correlations between TC and environmental parameters are shown in Table 1: MRP, TSS and DOMI were correlated with TC only at the downstream sites. NN was correlated with TC at all sites (but more pronounced downstream), supporting the findings of Reddy *et al.*

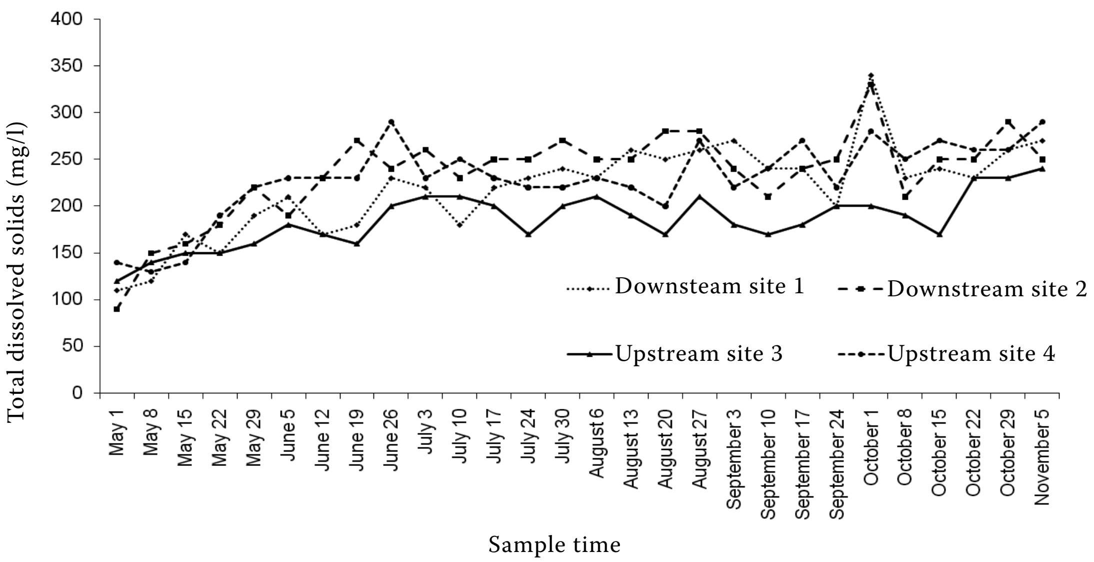

Figure 5. Total dissolved solids at the study sites

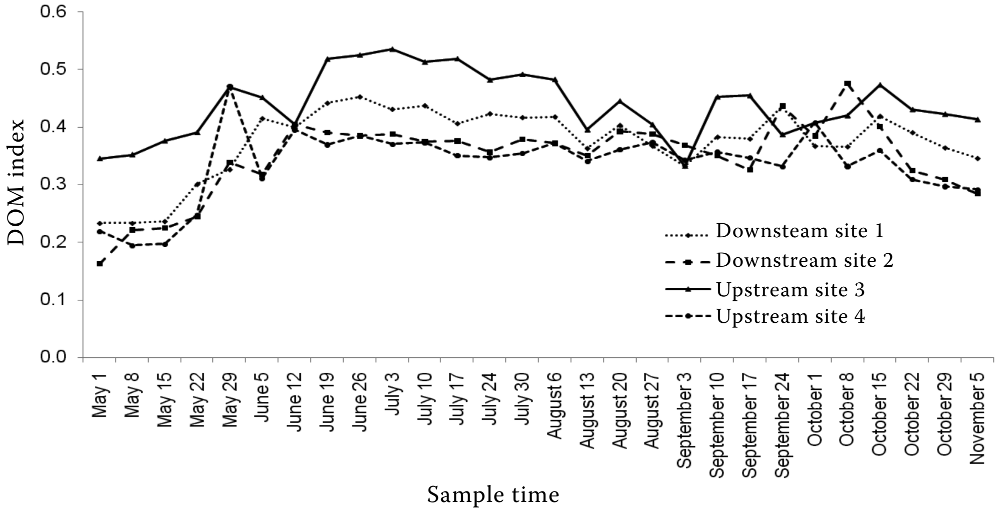

Figure 6. Dissolved organic matter index (absorbance at 275 nm) at the study sites

(1986) who also reported TC correlations with seasonal changes of both nitrate and phosphate in ponds receiving runoff. The NN/MRP ratio (NPR) was positively correlated with TC upstream, but strongly inversely downstream (Table 1); thus as downstream phosphate increased relative to nitrate, TC increased as well.

Rainfall is an important factor in the migration of coliforms to surface water downstream of livestock operations (Mallin 2000). In our study, TC was exponentially correlated with rainfall at all sites throughout the season (r = 0.13, P = 0.003, both ln transformed, n = 112). However, at the end of September large TC spikes (Figure 9), also preceded by precipitation (Figure 3), were observed at the two downstream sites, and coincided with the MRP maximum (Figure 8) at downstream site 1, and the NN peaks at downstream sites 1 and 2 (Figure 7), indicating large-scale escape events associated with the manure spread and lagoon discharge period. Thus timing the latter activities to drier weather conditions would reduce the magnitude of such escape occurrences.

While intense, the nutrient and bacterial spikes were of short duration, a phenomenon which has also been reported by Mallin (2000), illustrating why environmental compliance monitoring may easily miss spills if conducted on a too-infrequent basis. Although contamination from such events is rapidly flushed downstream in flowing water,

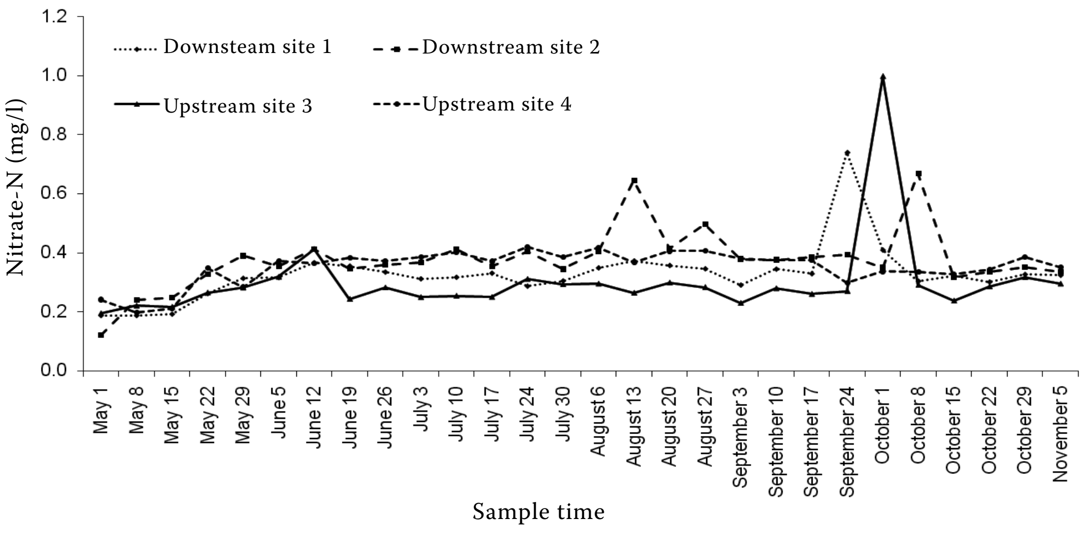

Figure 7. Nitrate-N at the study sites

Table 1. Significant correlations among total and fecal coliform counts and water quality parameters upstream and downstream of the livestock/poultry operation; transformed (abbreviated) parameters in parentheses

	Total coliforms		Fecal coliforms	
	upstream	downstream	upstream	downstream
Temperature (temp.)	$r = 0.21$ $P = 0.05$ (ln TC, temp.)	$r = 0.27$ $P = 0.023$ (ln TC, temp.)	$r = 0.27$ $P = 0.039$ (ln FC)	$r = 0.30$ $P = 0.018$ (ln FC, temp.)
pH	$r = 0.41$ $P = 001$ (ln TC)	$r = 0.41$ $P = 0.001$ (ln TC)	NS	NS
Total suspended solids (TSS)	NS	$r = 0.24$ $P = 0.037$ (ln TC)	NS	$r = 0.32$ $P = 0.012$ (ln FC, TSS)
Total dissolved solids (TDS)	$r = 0.44$ $P < 0.001$ (ln TC, TDS)	$r = 0.41$ $P = 0.001$ (ln TC, TDS)	NS	NS
Nitrate-N (NN)	$r = 0.40$ $P = 0.001$ (ln TC, NN)	$r = 0.60$ $P < 0.001$ (ln TC, NN)	$r = 0.25$ $P = 0.045$ (ln FC, NN)	$r = 0.22$ $P = 0.05$ (ln FC, NN)
Molybdenum reactive phosphorus (MRP)	NS	$r = 0.80$ $P < 0.001$	NS	$r = 0.45$ $P < 0.001$ (ln MRP)
Nitrate-N: reactive phosphorus ratio (NPR)	$r = 0.33$ $P = 0.007$ (ln TC, NPR)	$r = -0.54$ $P < 0.001$ (ln NPR)	NS	NS
Dissolved organic matter index (DOMI)	NS	$r = 0.56$ $P < 0.001$ (ln TC)	NS	NS

NS – not significant; TC – total coliforms; FC – fecal coliforms

coliform bacteria may continue to reside in the bottom sediments for extended times where they may present resuspension risks (Burkholder *et al.* 1997) and pose a continuing danger to human health (Mallin & Cahoon 2003).

The FC counts showed midseason peaks (maximum 4600 MPN = 460/ml) in July, with the highest values at downstream site 2 (Figure 10). Paired *t*-tests indicated that fluctuations of TC and FC were correlated ($r = 0.31$, $P < 0.001$), although relative peak magnitudes differed. FC showed fewer significant correlations with environmental variables and therefore were less predictable than TC (Table 1). Correlations between FC and each of temperature and NN were similar upstream and downstream, but FC was correlated with MRP and TSS only downstream, again suggesting mutual sources.

Downstream FC/TC ratios were strongly linearly correlated with rainfall ($r = 0.36$, $P = 0.004$, $n = 56$), while no significant relationship with rain was apparent upstream. Thus downstream of the spread fields the proportion of fecal coliforms in the microbial load increased with increasing precipitation. Downstream FC/TC ratios were also moderately inversely correlated with both pH ($r = -0.29$, $P = 0.023$, ln FC/TC) and MRP ($r = -0.26$, $P = 0.040$, both ln transformed).

In conclusion, downstream impacts on adjacent stream water quality were evident even though the present operation was small by industry standards. While the escape of nutrients and bacteria oc-

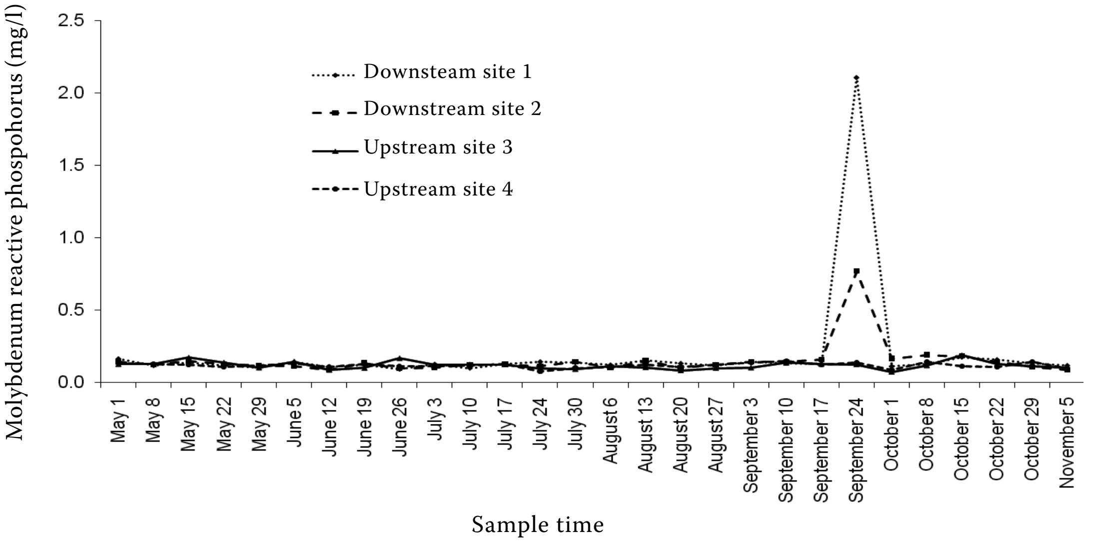

Figure 8. Molybdenum reactive phosphorus at the study sites

curred throughout the ice-free season, the timing of manure spreading and lagoon discharge relative to weather conditions was a particularly important factor related to large-scale escape events. Even at recommended manure application rates, the transport of nutrients and bacteria may occur through aerosols and runoff (see Burkholder *et al.* 2007), but the losses increase with greater applications (Hooda *et al.* 2000) and proximity to receiving waters (Mallin 2000). Mitigation strategies must take into account the particular local conditions of soil, distance to surface water, hydrology, precipitation and rate and timing of application in order to reduce the impacts on receiving waters.

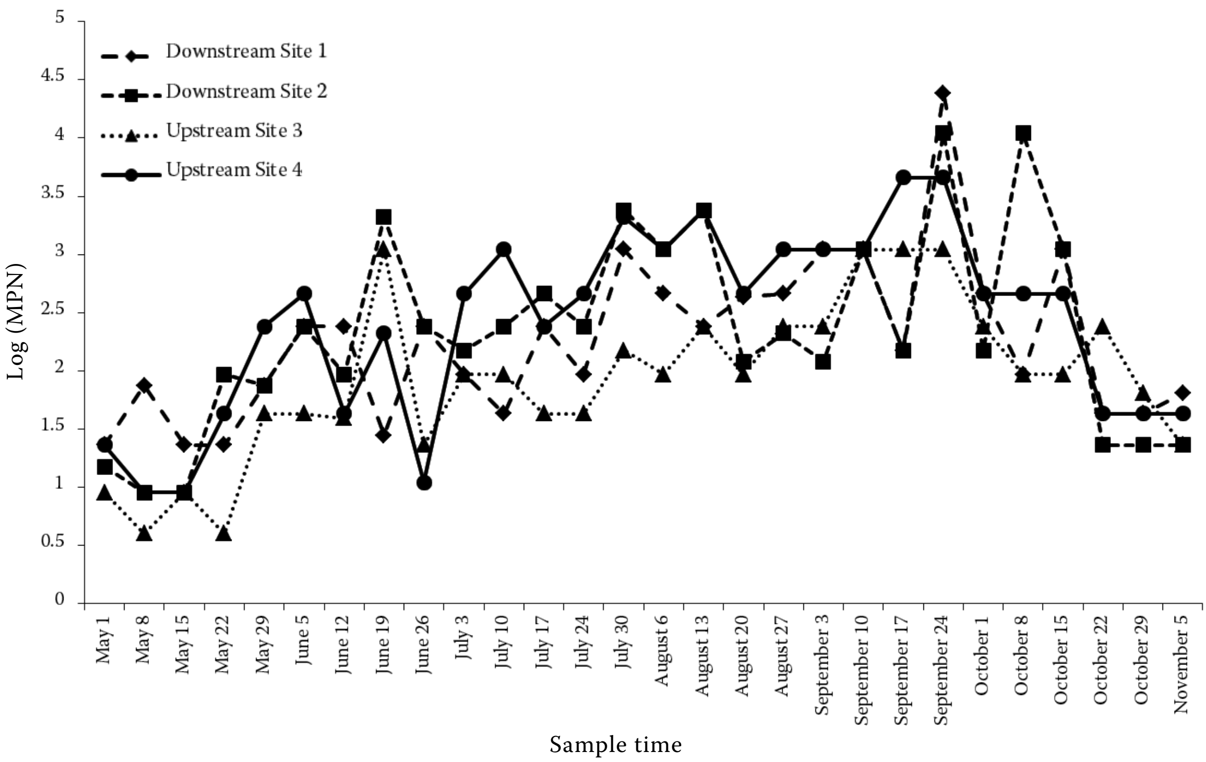

Figure 9. Total coliform counts at the study sites. (+ indicates above maximum detection limit of 25 000 MPN); vertical axis is exponential

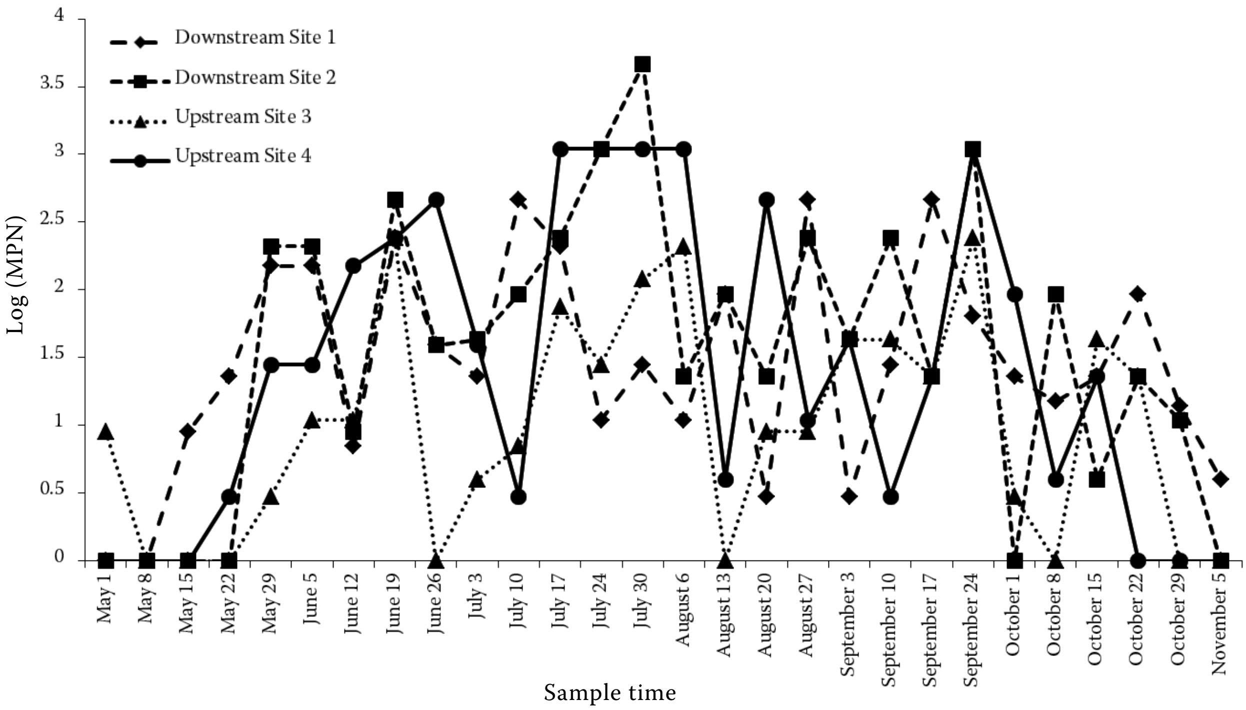

Figure 10. Fecal coliform counts at the study sites; vertical axis is exponential

Furthermore the combined effects of multiple livestock operations (Mallin & Cahoon 2003) and other anthropogenic contributions within the same watershed (Pip 2005) must be considered in land and water management planning.

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