Land application of milking centre wastewater

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Jamieson, R.C., Gordon, R.J., Cochrane, L.M., Madani, A. and Burney, J.R. 2002. **Land application of milking centre wastewater**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**:6.1-6.10. Wastewater generated from milkroom cleaning activities on dairy farms may pose a risk to water resources if improperly managed. Vegetated infiltration areas (VIA) have been recommended as a possible treatment/disposal option for milking centre wastewater. In this study, a VIA was constructed on a commercial dairy farm milking approximately 50 cows. A gently sloping vegetated infiltration area (8 m x 32 m, 4.5% grade) was built on a loam soil. The system was loaded during two consecutive growing seasons (May - November, 1999 and June - November, 2000). Groundwater chemistry and soil moisture content along the strip length were monitored. The wastewater contained high concentrations of total phosphorus (TP = 30 mg/L), chloride (Cl = 200 mg/L), and sulphate (SO_4 = 500 mg/L) and possessed a high five-day biochemical oxygen demand (BOD_5 = 500 mg/L). A significant increase ($p < 0.05$) in groundwater concentrations of calcium (Ca), electrical conductivity (EC), iron (Fe), chloride (Cl), manganese (Mn), and sodium (Na) over background conditions was observed, however, only Mn exceeded Canadian Drinking Water Quality Guidelines (CDWQG). No surface runoff leaving the infiltration area was observed during the study period. A valve, which was installed in the milkroom to divert the first rinse of the milk pipeline wash cycle to the manure storage, resulted in a 76% decrease in the suspended solids loading to the treatment system. Vegetated infiltration areas, with proper design and management, may have the potential to provide cost effective management of milking centre wastewater. However, the long term (> 10 yrs) effects of wastewater loading on groundwater quality requires further investigation**.**

Les eaux usées de laiterie, si on n'en dispose pas adéquatement, peuvent représenter une menace pour l'environnement. Des bandes d'infiltration végétalisées ont été envisagées pour disposer ou traiter des eaux usées de laiterie. Lors de ce projet, un bande végétalisée a été aménagée sur une ferme laitière commerciale. La bande d'infiltration fut construite avec une pente (8m X 32 m, pente 4.5%) sur un sol loameux. On y disposa des eaux de laiterie durant deux saisons de croissance consécutives (mai-novembre 1999 et juin-novembre 2000). Un suivi de la chimie de l'eau souterraine et de l'humidité du sol fut fait sur la longueur de la bande filtrante. Les eaux usées contenaient des concentrations élevées de phosphore total (PT = 30 mg/L), de chlorures (Cl = 200 mg/L) et de sulfates (SO_4 = 500 mg/L). La demande biochimique en oxygène de ces eaux était également élevée (BOD_5 = 500 mg/L). On a observé une augmentation significative des concentrations de calcium (Ca), de conductivité électrique (CE), fer (Fe), chlore (Cl), manganèse (Mn) et sodium (Na) dans les eaux souterraines. Cependant, seule la concentration de manganèse (Mn) dépassait les *Recommandations pour la qualité de l'eau potable au Canada*. Durant la période d'étude, il n'y a pas eu de ruissellement sortant des parcelles. La charge de solides en suspension traitée par la bande végétalisée a pu être réduite de 76% grâce à une valve installée dans la laiterie qui permettait de dévier l'eau du premier rinçage du lactoduc vers le système d'entreposage des fumiers. Des bandes végétalisées bien conçues et gérées adéquatement peuvent représenter une solution abordable au problème de disposition des eaux usées de laiterie. Cependant, les effets à long terme (> 10 ans) sur la qualité des eaux souterraines devront être examinés.

INTRODUCTION

Management of water resources is of great importance, especially within the agricultural industry. The dairy sector, in particular, is responsible for the management of wastewater generated from several sources (Willers et al. 1999). One challenge that the industry faces is the management of wastewater produced from the cleaning of milking equipment and facilities. Milk pipelines are typically cleaned twice daily, after milking, while bulk storage tanks are cleaned every second day. The wastewater produced contains milk residues and cleaning chemicals. Five-day biochemical oxygen demands can range from 300 to 7000 mg/L (Anderson 1992); however, the first rinse of the washing sequence, which consists only of hot water, typically contains over 90% of the total wastewater suspended solids (Hayman 1987). Phosphorus (P) based detergents and phosphoric acids are used to remove organic material and calcium (Ca) deposits from the milk pipelines and bulktanks. Phosphorus must be carefully managed as it is usually the limiting nutrient in fresh water ecosystems (Correl 1998). The United States Environmental Protection Agency (USEPA) has established guidelines of 100 µg/L P for streams and 50 µg/L P for lakes in order to prevent eutrophication (Sharpley 1995). Other chemicals that are used during the cleaning process contribute substantial concentrations of chloride (Cl), sulphate ($SO_{4)}$, and sodium (Na) to the wastewater.

Dairy farms that manage manure as a liquid and have adequate storage capacity can incorporate their milkhouse wastewater into their manure storage system (NRAES 1998). Farmers who handle manure as a solid waste or do not have storage capacity to accommodate the additional volumes are faced with a challenging problem. In these cases alternative wastewater management systems are required. The use of septic systems has been attempted, but with limited success (Miller et al. 1987; Anderson 1992; Cuthbertson et al. 1995). Milk fats, which may not be completely degraded in the septic tank, clog soil pores in the leachfield resulting in hydraulic failure of the system (NRAES 1998).

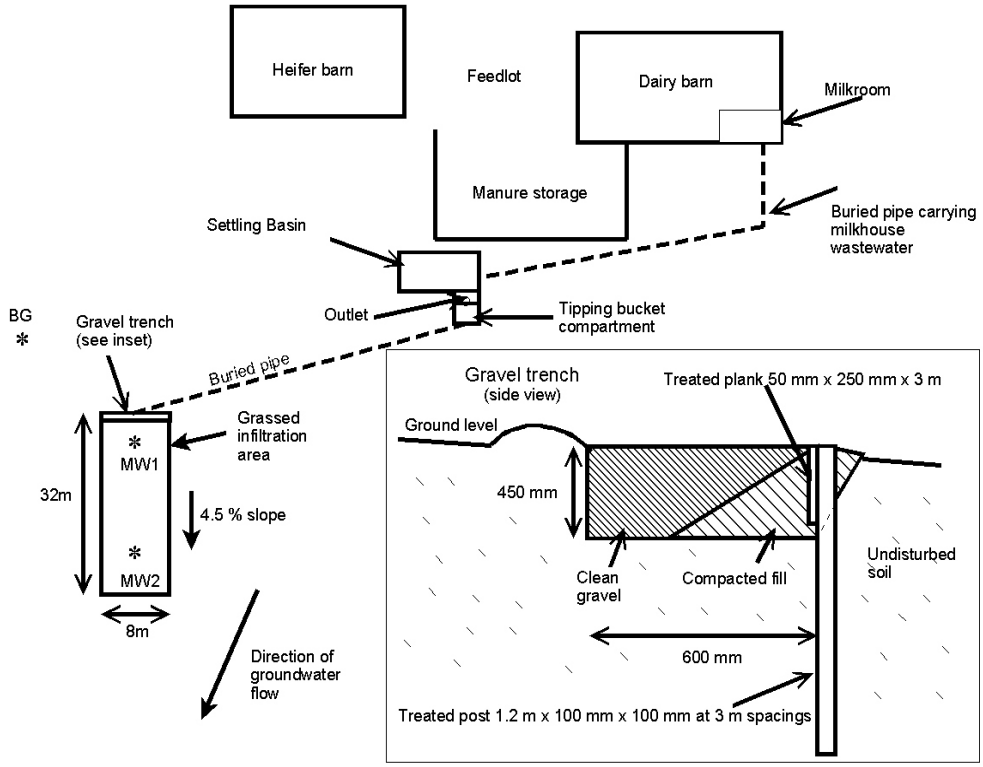

Fig. 1. Schematic illustrating the treatment system layout and the location of the groundwater monitoring wells.

Applying the wastewater to the surface of a vegetated area and allowing the wastewater to infiltrate has been recommended as an inexpensive and simple management option (White and Brugger 1981; NRAES 1998). Vegetated infiltration areas (VIA) rely on the soil environment for wastewater treatment, similar to septic systems. Suspended solids are deposited on the surface of the VIA and undergo rapid aerobic degradation. In general, P is relatively immobile in the soil environment due to precipitation with various cations and adsorption onto organic and mineral surfaces. The primary cations that will precipitate P include iron (Fe), aluminum (Al), and calcium (Ca) (Gale et al. 1994; Sharpley 1995).

The effects on groundwater quality with respect to the continuous loading of milking centre wastewater to a relatively small land area has not been rigorously addressed. The objective of this study was to evaluate the effectiveness of a VIA receiving milking centre wastewater during the growing season. Specifically, this study monitored soil moisture status and changes in groundwater chemistry within a VIA during the first two consecutive growing seasons after implementation.

METHODS

A VIA was designed and constructed on a commercial dairy farm located in Central Nova Scotia (45° 40' N, 62° 50' W). The farm has approximately 50 milking cows in a tie-stall set-up. Approximately 450 L of wastewater are produced daily from the cleaning of the milk pipeline. Every second day an additional 200 L of wastewater is produced from the cleaning of the milk storage tank. The wastewater treatment system consisted of a pre-treatment settling basin which discharged effluent to a gently sloping grassed infiltration area (Fig. 1). The infiltration area was established in the fall of 1998 and received miking centre wastewater only during the 1999 and 2000 growing seasons (May through October). The system initially began receiving wastewater on May 4, 1999.

The settling basin was constructed of pressure-treated lumber with a concrete floor and was designed wide enough to allow periodic sludge removal with a front-end loader. The settling basin was also sealed with 6 mm plastic. The basin outlet consisted of a 150 mm diameter PVC standpipe with 19 mm holes. An expanded metal screen with 19 mm openings was placed in front of the standpipe outlet to help prevent clogging of the standpipe perforations.

The design of the wastewater distribution system was based primarily on the system described by Wright et al. (1993). A 450 mm deep by 600 mm wide trench was dug across the top of the filter area. Three pressure treated 3 m x 50 mm x 250 mm planks were placed across the front of the trench anchored by 100 mm x 100 mm posts placed at 3 m spacings (Fig. 1). The planks were leveled and then backfilled on both sides with native soil. The trench was then filled with 19 mm washed stone. Once the applied wastewater fills the gravel trench, it will evenly spill over top of the level lip, creating an even distribution of wastewater over the entire width of the infiltration area. The infiltration area consisted of a 8 m wide x 32 m long grass strip. The infiltration area was on a slope of 4.5% and was relatively uniform across its width. Soil was transported to the site and used to construct 300 mm high berms around the filter area to prevent outside runoff surface water from entering the treatment area. The berms and infiltration area were reseeded after construction and 45 kg of 24-12-12 fertilizer were applied to the VIA. The grass was allowed to fully establish in the fall of 1998, prior to wastewater application. Vegetation was cut twice during each growing season and removed from the infiltration area.

A calibrated tipping bucket was installed in a below ground insulated compartment built onto the settling basin. The tipping bucket was equipped with a magnet and reed switch that sent a voltage output to a Campbell Scientific CR10 datalogger (CSI, Logan, UT) each time the bucket tipped. Water samples were collected manually from the tipping bucket in 1 L polyethylene bottles to characterize the quality of the effluent being applied

Table 1. Average concentrations of primary wastewater parameters before (n = 8) and after (n = 10) the installation of the first rinse diverter valve (valve installed on June 15, 1999). Samples were collected at the outlet of the settling basin.

Parameter	Before diverter valve installed		After diverter valve installed	
	Mean	S.D.	Mean	S.D.
BOD_5 (mg/L)	1164.2	327.4	459.4	279.8
TSS (mg/L)	613.7	73.7	147.6	70.4
TP (mg/L)	31.1	10.6	25.6	12.7
SRP (mg/L)	26.8	10.1	19.1	9.9
Fats (mg/L)	164.7	185.0	33.5	20.2
pH	6.5	0.6	7.1	0.7

to the filter area biweekly. The samples were analyzed for: pH, total P (TP), soluble reactive P (SRP), total suspended solids (TSS), BOD_5 and fats (APHA 1998). A standard water analysis was also performed on one sampling occasion (July 15, 1999) which included the following parameters: Ca, magnesium (Mg), Na, Cl, SO_4, Fe, Mn, copper (Cu), zinc (Zn), nitrate-nitrogen (NO_3-N), alkalinity, pH, EC, and hardness. The tipping bucket was removed prior to the 2000 monitoring period and the wastewater was piped directly to the infiltration area. Rainfall at the site was measured using a tipping bucket rain gauge and was recorded continuously with a CR10 datalogger.

Split spoon (50 mm daimeter) soil samples were collected at two locations along the strip length (5 and 25 m from the distribution trench) on June 19, 1999 with the use of an auger drill rig. Soil textural analyses were performed on samples collected at both locations following the Bouyoucos Hydrometer Method (Bouyoucos 1962). Core samples were taken at depths of 0-100, 200-300, and 400-500 mm within the infiltration area on August 10, 1999. Moisture retention (at 0, 10, 33, 100, 300, and 1500 kPa), bulk density, and saturated hydraulic conductivity were determined for all cores using methods 84-036, 84-029, and 84-037, respectively, outlined in *Analytical Methods Manual* (Land Resource Research Institute 1984). Core samples used to determine hydraulic conductivity and bulk density were taken 2 m downslope of the distribution trench. Volumetric soil moisture content (θ) was monitored continuously over the two growing seasons at three locations along the strip length (3, 10, and 25 m) using a Campbell Scientific CS615 Water Content Reflectometer, which utilizes time domain reflectometry, wired into a CR10 datalogger (CSI, Logan, UT). A single 300 mm probe was placed vertically into the soil profile at each location.

Small diameter monitoring wells were installed at two locations within the treatment area (MW1 at 5 m and MW2 at 25 m from the distribution trench) on June 19, 1999. An additional well (BG) was installed at a location approximately 15 m upgradient of the disposal area to provide background water quality. Holes were bored (100 mm diameter) with solid stem earth augers to the desired well installation depth (5 m). The well, which consisted of a 1.50 m section of 50 mm diameter, 20 slot PVC well casing connected to 50 mm diameter solid PVC pipe, was lowered into the bore hole. A silica sand pack was placed around the well screen in the borehole annular space. Above the sand pack the bore-hole was grouted with a bentonite seal and backfilled with native soil. After installation, the well was developed by pumping out three well volumes of water to remove drill cuttings. Groundwater elevations at the three well locations were measured and used to determine the approximate direction of groundwater flow (Fig. 1).

Shallow groundwater samples were collected approximately bi-weekly during both growing seasons. The wells were purged prior to sampling by removing either three well volumes of water or by pumping the well dry twice. Water samples were then collected in 1 L polyethylene bottles and placed in an ice-packed cooler. Analysis included: Ca, Mg, Na, Cl, SO_4, Fe, Mn, Cu, Zn, alkalinity, pH, EC, hardness, SRP, and BOD_5.

To collect surface water, small holes were dug at several locations along the infiltration area. Three sampling devices were installed, equally spaced, across the width of the strip at distances of 2, 5 and 10 m from the distribution trench. A 125 mm section of 75 mm diameter PVC pipe, capped at both ends, was placed inside each hole. When surface water was observed on the infiltration area, the sampling ports were uncapped and a small cup was placed inside of the pipe section. A small metal flume was used to direct surface water into the cup and collect a sample. Water samples collected from the three sampling ports located across the strip were composited in 1 L polyethylene bottles to produce one sample from each of the sampling distances. Parameters analyzed included BOD_5, TSS, TP, SRP, fats, and pH.

RESULTS and DISCUSSION

Wastewater characteristics

The settling basin did not provide adequate removal of milk solids during the initial month (May, 1999) of loading. An accumulation of milk solids was observed in the gravel trench, which hindered the flow of wastewater through the gravel. The continual application of wastewater to the gravel trench produced waterlogged conditions. This did not provide optimum conditions for degradation of milk fats. Therefore, on June 15, 1999, a valve was installed in the milkroom to divert the first rinse of the pipeline wash sequence away from the treatment system and therefore lower the solids loading to the treatment system. The first rinse water was diverted to the solid manure storage, but this material could have been collected and fed to calves.

Samples of wastewater flowing to the filter area from the settling basin were collected on several occasions both before and after the installation of the first rinse diverter valve with results presented in Table 1. The diversion of the first rinse greatly decreased the solids content of the wastewater. Concentrations of BOD_5, TSS, and fats were lowered by 60, 76, and 80%, respectively.

Table 2. Standard water quality analysis of milking centre effluent after pretreatment within the settling basin (n=1).

Parameter	Concentration
Ca (mg/L)	20.2
Mg (mg/L)	4.5
Na (mg/L)	216.7
Cl (mg/L)	212.6
SO_4 (mg/L)	579.6
Fe (mg/L)	0.91
Mn (mg/L)	0.1
Cu (mg/L)	0.08
Zn (mg/L)	0.14
Nitrate-N (mg/L)	2.34
Alkalinity (mg/L)	325
Conductivity (μS/cm)	1670
Hardness (mg/L)	71.0

Adequate pretreatment is crucial to the success of the treatment system. Overloading of wastewater solids can cause clogging of the distribution trench and surface sealing of the infiltration area. The settling basin was found to be ineffective in removing solids from the wastewater. This was due to the inability of the settling basin to remove floating solid material. A two compartment septic tank with baffled inlets and outlets would probably provide more effective pretreatment. Diverting the first rinse reduced the suspended solids loading by 76%. The automated diverter valve which was installed cost $450 CDN, and would be a worthwhile investment for farmers not willing to divert the first rinse manually. The diversion of the first rinse will increase the life span of the system as well as decrease the frequency of removal of solids from the pretreatment system. The diversion of the first rinse resulted in only a small decrease in the wastewater P concentrations. For samples collected after the valve was installed, 75% of the P was in the soluble reactive form. The pH of the wastewater remained consistently neutral throughout the study period. The results of the standard water quality analysis, performed on one sample taken on July 15, 1999, are provided in Table 2. The wastewater contained high concentrations of Na, Cl, and SO_4.

In 1999 the flow of wastewater from the settling basin to the infiltration area was adjusted with a valve to an amount which the tipping bucket could handle. Therefore, the milking centre wastewater had a significant detention time in the settling basin where large evaporative water losses occurred. Approximately 84 m^3 of wastewater was applied to the infiltration area during the 1999 study period. The tipping bucket and valve were removed in 2000 to simulate a more accurate farm wastewater loading scenario thus resulting in a shorter wastewater detention time in the settling basin in 2000. It was therefore assumed that a negligible volume of water evaporated before reaching the infiltration area in 2000. Taking into account the amount of water used daily in the milkroom and the number of days the system was loaded, it was calculated that approximately 94 m^3 of wastewater were applied to the infiltration area during the 2000 growing season.

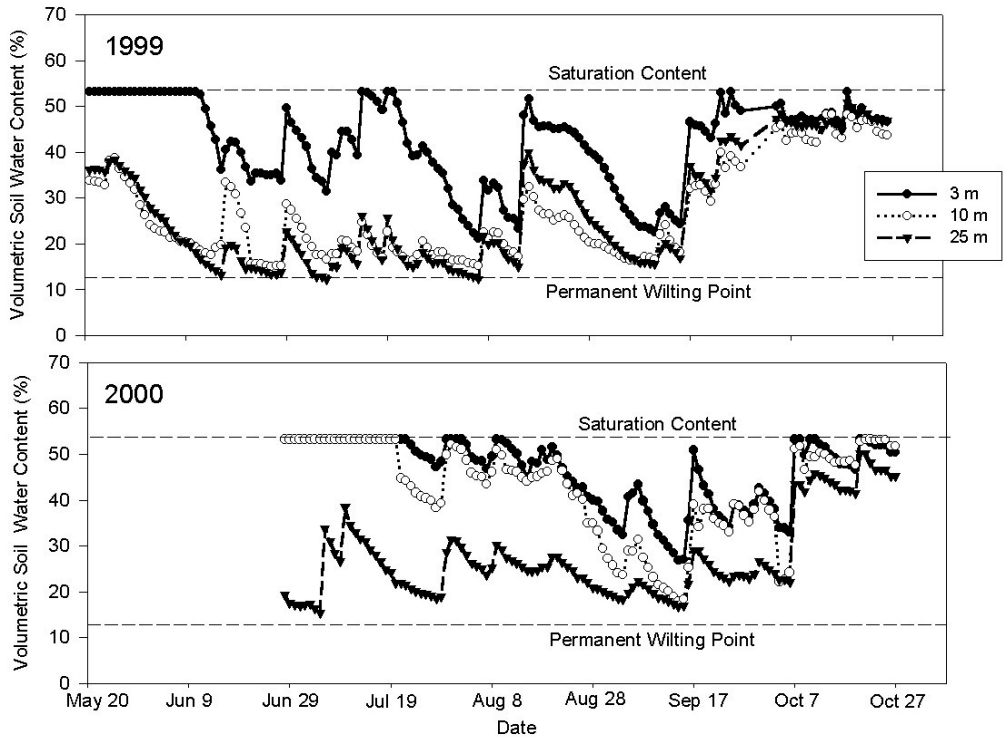

Fig. 2. Daily values of volumetric soil water content (0-300 mm) at 3, 10, and 25 m from the distribution trench during 1999 and 2000 wastewater application period.

Hydrologic status

Soil texture ranged from a loam to a silt loam (Table 3). Throughout the study period the VIA system performed as intended with no observed surface flow discharges. From visual observations the gravel trench distribution system was effective in producing an even distribution of wastewater over the infiltration area. The trench heaved slightly during the winter, but was easily readjusted with a sledgehammer.

Soil moisture levels during the 1999 and 2000 study periods are illustrated in Fig. 2. Monthly rainfall totals for 1999 and 2000 are provided in Table 4. The average θ_{sat} of the top 300 mm of the soil profile was calculated to be 53.5%. Soil water content values at a pressure of 0 kPa, obtained from laboratory measurements

Table 3. Physical properties of the treatment area soils.

Location	Depth (mm)	Sand (%)	Clay (%)	Textural classification
MW1	0-600	44	12	Loam
	600-1200	39	25	Loam
	1500-3000	17	24	Silt loam
MW2	0-600	51	18	Loam
	600-1200	39	22	Loam
	1500-3000	8	25	Silt loam

Depth† (mm)	Hydraulic conductivity (m/s)	Bulk density (Mg/m^3)
0-100	1×10^{-4}	1.11
200-300	4.8×10^{-5}	1.39
400-500	4×10^{-6}	1.64

† Samples analyzed for hydraulic conductivity and bulk density were collected 2 m downslope of the distribution trench.

of the soil water release curve, were used to estimate θ_{sat}. Field measurements of θ exceeding θ_{sat} were assumed to indicate ponding of water on the ground surface. In 1999, θ at 3 m from the distribution trench exceeded θ_{sat} through mid-June. Soil water contents throughout the growing season at 10 and 25 m from the distribution trench were similar, never approaching θ_{sat}. In 2000, θ measurements taken at 3 and 10 m from the distribution trench both remained close to θ_{sat} until mid-August, while θ at 25 m remained below field capacity through late October.

Wright et al. (1993) investigated several filter strips in New York State receiving milking center wastewater and observed surface flows on only the first 5 m of strip for the majority of the treatment systems. Yang et al. (1980) found that the highest loading rate for zero surface runoff under the most adverse soil conditions in the winter on a silt loam soil with a fragipan at 500 mm depth was 4.3 mm/d. The highest hydraulic loading rate in this study occurred during October, 2000 where the total hydraulic loading (wastewater + rainfall) was 7.7 mm/d which resulted in no apparent surface runoff. The soils located within the treatment site ranged from a loam to a silt loam at depth, with the limiting soil layer possessing a hydraulic conductivity of 14.3 mm/h (Table 3), which is classified as moderately slow (Reed et al. 1995).

Table 4. Summary of rainfall (mm) during the 1999 and 2000 wastewater application periods.

Month	Rainfall (mm)	
	1999	2000
June	35	58
July	74	88
August	141	57
September	112	81
October	124	173
Total	485	457

Groundwater

Temporal changes in groundwater concentrations of Mn, Ca, SRP, Cl, and SO_4 are presented in Fig. 3 while groundwater concentrations of EC, pH, Mg, Na, and Fe are presented in Fig. 4. Statistical summaries of the groundwater samples collected in 1999 and 2000 are provided in Tables 5 and 6, respectively. A paired t-test was used to test for differences in mean concentrations of chemical parameters between well locations (Minitab Inc. 1999)

In 1999, Ca, Na, Cl, and EC concentrations at both MW1 and MW2 were significantly different ($p < 0.05$) from concentrations observed at the background well location. Magnesium and pH levels at MW1 were significantly different than those observed at the background well location, whereas levels at MW2 were not. Manganese and SO_4 concentrations at MW1 were not significantly different from background conditions, whereas concentrations at MW2 were significantly different (Table 5). In 2000, Ca, Mg, SO_4,and Fe concentrations were the same at the MW1 and MW2 locations but significantly different from those found at the background well location. For Na, pH, and Mn, concentrations at MW1 were significantly different than those found at the background well, whereas concentrations at MW2 were not (Table 6). There was no increase in concentrations of either SRP or BOD_5 at MW1 and MW2 over background conditions in 1999 and 2000.

A t-test was used to test for differences between 1999 and 2000 with respect to mean concentrations of chemical parameters at each well location (Minitab Inc 1999). Manganese concentrations at MW1 increased significantly ($p < 0.05$) in 2000 as compared to 1999 (Fig. 3) and greatly exceeded the CDWQG Aesthetic Guideline of 0.05 mg/L (Health Canada 1999). Manganese concentrations at MW2 did not change from 1999 to 2000 while Mn concentrations at the background well (BG) decreased significantly. Although Mn was not present at high concentrations in the milking centre wastewater, it is more mobile in waterlogged soils (Bohn et al. 1985). Additionally, if organic matter is present, Mn can be used as an electron acceptor to oxidize organic matter (Bohn et al. 1985). Manganese will then be reduced from a tetravalent form to the more soluble divalent form, which is more susceptible to leaching (Levine et al. 1980). Soils adjacent to the distribution trench in this study were continuously waterlogged, increasing the potential for Mn reduction and movement.

Calcium and SRP concentrations generally exhibited greater variability in 2000 than 1999, whereas Cl and SO_4 appeared more stable, especially in MW1 (Fig. 3). Calcium concentrations at MW1 decreased significantly in 2000 as compared to 1999, but did not change at MW2 and BG. Soluble reactive phosphorus did not increase significantly at any well location from 1999 to 2000. Chloride concentrations are greater within the treatment area as opposed to background but are still below the CDWQG Aesthetic Guideline of 250 mg/L (Health Canada 1999) and exhibited no significant increase in 2000 at any well location. Sulphate concentrations at MW1 decreased significantly in 2000 as compared to 1999, while MW2 and BG showed no change.

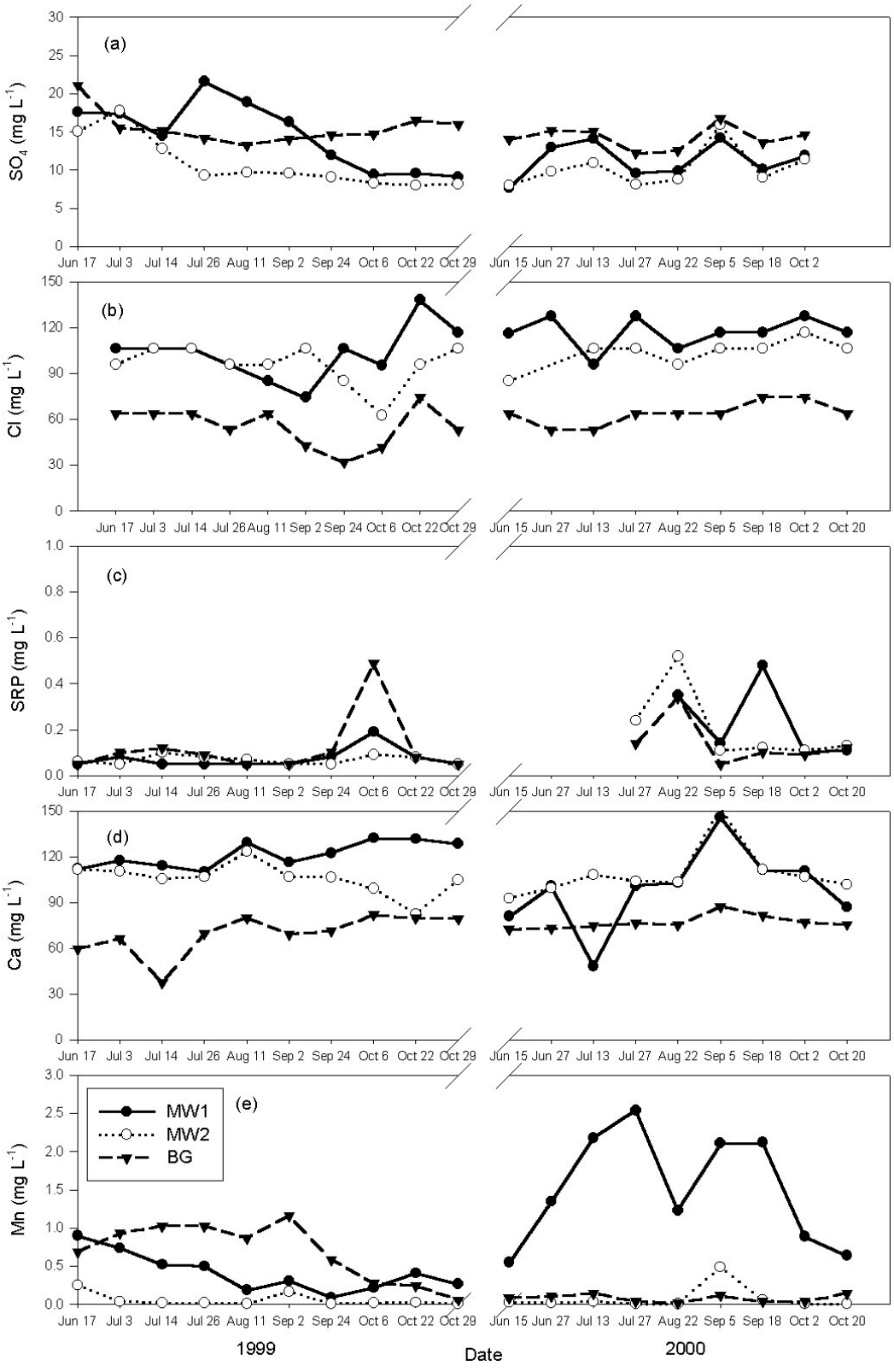

Fig. 3. Changes in groundwater concentrations of (a) sulphate (SO_4), (b) chloride (Cl), (e) soluble reactive phosphorous (SRP), (d) calcium (Ca) and (e) manganese (Mn) during the 1999 and 2000 study periods at the background well (BG) and the treatment area wells (MW1, MW2).

Sodium concentrations at MW1 increased significantly during 2000 as compared to 1999 (Fig. 4), but are still well below the CDWQG Aesthetic Guideline of 500 mg/L (Health Canada 1999), while MW2 and BG exhibited no change. Electrical conductivity measurements at all three well locations were consistent from 1999 to 2000 with MW1 and MW2 exhibiting greater concentrations than the background well (Fig. 4). Magnesium concentrations decreased significantly at MW1 and BG but showed no change at MW2 (Fig. 4).

The system appeared effective in removing P from the percolating wastewater. Groundwater SRP concentrations within the treatment area did not increase as compared to background levels (Tables 5 and 6, Fig. 3). Yang et al. (1980) and Beek et al. (1977) both reported greater than 90% removal of phosphates in soil infiltration systems. Toombs (1997) investigated several vegetative-soil filter systems in Ontario treating dairy yard runoff, finding no increase in the value of any of the groundwater parameters tested for, including P. From the data collected during this study, it appears that the two water quality parameters that would pose the greatest risk of impairing groundwater, with respect to potable water quality, are Cl and Mn. To reduce the potential of contaminating groundwater supplies with Cl, non-chlorinated cleaners and disinfectants, such as hydrogen peroxide,

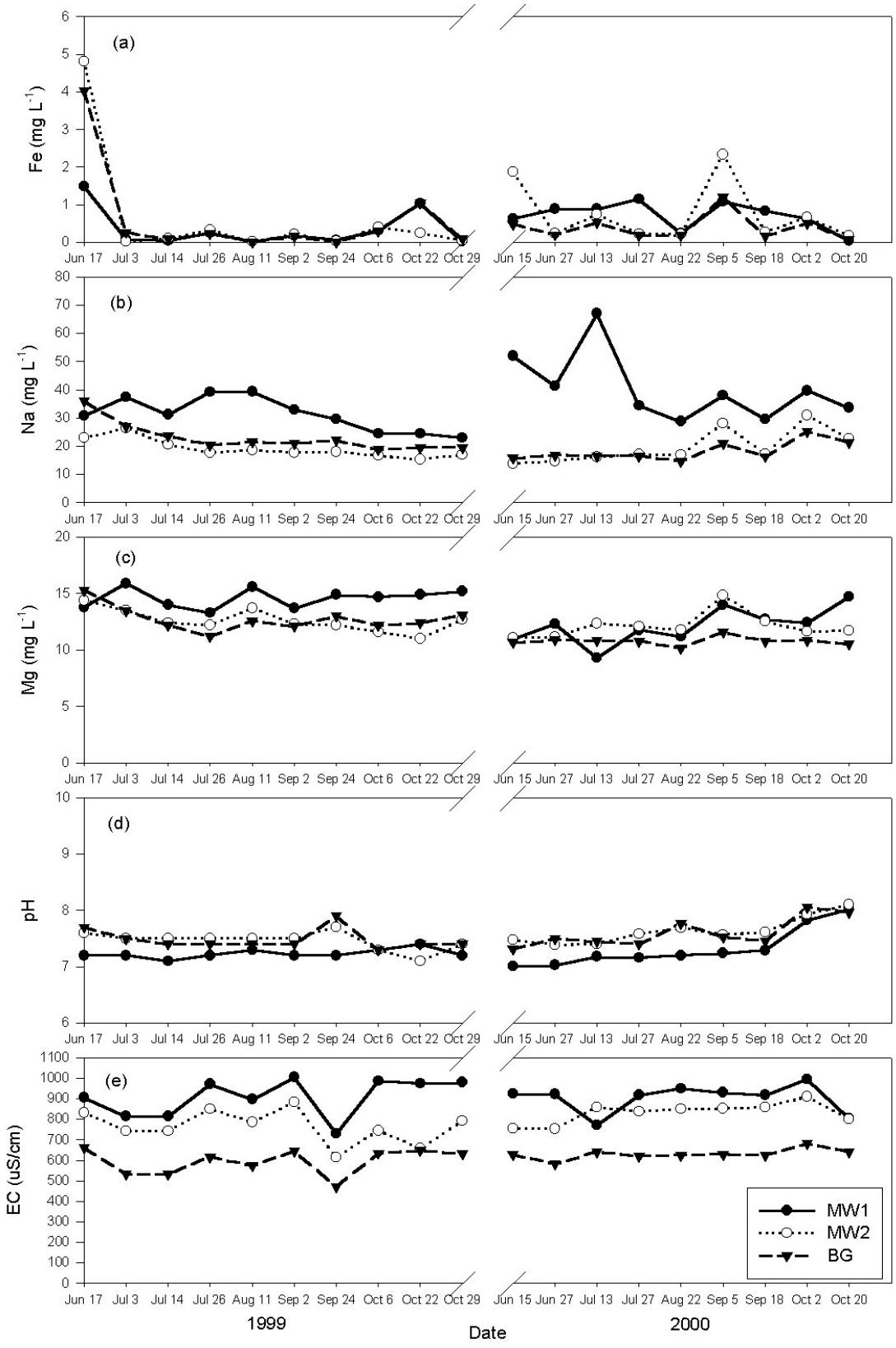

Fig. 4. Changes in groundwater concentrations of (a) iron (Fe), (b) sodium (Na), (c) magnesium (Mg), (d) pH, and (e) EC during the 1999 and 2000 study periods at the background well (BG) and the treatment area wells (MW1, MW2).

could be used in milkroom cleaning activities. The migration of Mn to groundwater could be minimized through infiltration area management strategies that prevent the treatment area from being continuously saturated, such as alternating wastewater application periods.

Surface water

During May and early June of both years there were several occasions where wastewater was ponded on the surface of the infiltration area at distances of 5 m or greater from the distribution trench. A summary of the quality of the samples that were collected during these events is provided in Table 7. Wastewater fats were most effectively removed by the grass filter with an 83% reduction in the first 5 m, followed by BOD_5 with a 44% reduction. Total P and SRP exhibited the least reductions of 38.2% and 15.6%, respectively. Broten and Brubenzer (1978) found grass filters to be effective in removing total solids and COD, but ineffective in removing NO_3-N and dissolved inorganic P. Schwer and Clausen (1989) also found that surface effluents leaving a land application system, that treated milking center wastewater, exceeded values expected for

Table 5. Statistical summary of 1999 groundwater samples collected at monitor wells 1 (MW1) and 2 (MW2) and the background well (BG). Samples were collected bi-weekly from mid-June through October 1999 (n = 10).

Parameter	Well†	Mean†	S. D.	Minimum	Maximum
Ca (mg/L)	MW1	121.3[a]	8.4	110.2	132.0
	MW2	105.7[b]	10.3	82.5	123.3
	BG	69.6[c]	13.3	37.8	81.9
Mg (mg/L)	MW1	14.6[a]	0.9	13.3	15.9
	MW2	12.6[b]	1.0	11.0	14.4
	BG	12.7[b]	1.1	11.2	15.3
SRP (mg/L)	MW1	0.07[a]	0.04	<0.05	0.19
	MW2	0.07[a]	0.02	<0.05	0.10
	BG	0.12[a]	0.13	<0.05	0.49
Na (mg/L)	MW1	31.2[a]	6.1	22.9	39.4
	MW2	19.1[b]	3.3	15.3	26.4
	BG	22.9[c]	5.2	18.8	35.9
pH	MW1	7.2[a]	0.08	7.1	7.4
	MW2	7.5[b]	0.17	7.1	7.7
	BG	7.5[b]	0.18	7.3	7.9
SO_4 (mg/L)	MW1	14.6[a]	4.4	9.2	21.6
	MW2	10.8[b]	3.3	8.0	17.8
	BG	15.5[a]	2.2	13.3	21.1
Cl (mg/L)	MW1	103.1[a]	17.4	74.4	138.2
	MW2	95.5[a]	13.6	62.4	106.3
	BG	55.2[b]	13.2	31.9	74.4
EC (µS/cm)	MW1	908[a]	93	730	1005
	MW2	764[b]	83	615	883
	BG	595[c]	63	473	660
BOD_5	MW1	11.1[a]	9.5	2.3	21.7
	MW2	10.4[a]	10.9	<2	24.9
	BG	12.2[a]	11.1	2.5	22.4
Mn (mg/L)	MW1	0.42[a]	0.26	0.09	0.90
	MW2	0.06[b]	0.08	0.01	0.25
	BG	0.69[a]	0.38	0.06	1.20
Fe (mg/L)‡	MW1	0.13[a]	0.5	<0.02	1.5
	MW2	0.15[a]	1.5	<0.02	4.8
	BG	0.20[a]	1.2	<0.02	4.0

†For each parameter, monitor well mean concentrations followed by a different letter indicate a significant difference from other well locations at the $P \leq 0.05$ level.

‡The median is reported here as the measure of central tendency because the data distribution was not normal.

agricultural watersheds. From these results it is clear that a vegetative-soil system treating milking center wastewater should be designed to provide complete infiltration of all applied wastewater.

CONCLUSIONS

A vegetated-soil infiltration system (8 x 32 m) provided treatment of milking center wastewater with minimal adverse impacts on surface and groundwater quality. The gravel trench distribution system proved to be an effective method of spreading the wastewater over the infiltration area. No surface discharges were observed leaving the treatment area over the study period. From visual observations, in conjunction with soil moisture measurements, it appeared that all the applied wastewater infiltrated within 10 m of the distribution trench during the growing season. The settling basin was ineffective in removing solids from the wastewater, primarily because of the floating solids contained in the wastewater. Installation of an automatic first rinse diverter valve resulted in a 76% decrease in TSS concentrations. Adequate solids removal is crucial to the success of the treatment system. The application of milking center wastewater for two consecutive growing seasons increased groundwater concentrations of Ca, EC, Fe, Cl, Mn, and Na to levels exceeding background concentrations, however, the only parameter which consistently exceeded CDWQG Aesthetic Guidelines was Mn. The wastewater application did not cause an increase in SRP concentrations as compared to background conditions. It should be noted, however, that these results are for a relatively short loading period (2 yrs). Further research is needed to investigate the effects of long-term (> 10 yrs) wastewater loading on groundwater quality. Although no surface water was observed leaving the treatment area, surface water samples were collected at distances of 2 and 5 m from the distribution trench during the spring of 1999. Removal of BOD_5 by overland flow was fair (44%), but only a 15.6% reduction of SRP concentrations in surface flows was observed, therefore milking centre wastewater vegetated filter strips should be designed to provide complete infiltration of all applied wastewater.

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Table 6. Statistical summary of 2000 groundwater samples collected at monitor wells 1 (MW1) and 2 (MW2) and the background well (BG). Samples were collected bi-weekly from mid-June through mid-October 2000 (n = 9).

Parameter	Well†	Mean†	S.D.	Minimum	Maximum
Ca (mg/L)	MW1	98.7[a]	26.7	48.4	145.7
	MW2	108.8[a]	16.9	92.6	151.6
	BG	77.1[b]	4.7	72.6	87.6
Mg(mg/L)	MW1	12.2[a]	1.6	9.3	14.7
	MW2	12.1[a]	1.1	11.1	14.8
	BG	10.8[b]	0.4	10.2	11.6
SRP (mg/L)	MW1	0.18[a]	0.16	<0.05	0.48
	MW2	0.17[a]	0.15	<0.05	0.52
	BG	0.12[a]	0.09	<0.05	0.34
Na (mg/L)	MW1	40.5[a]	12.2	28.8	67.0
	MW2	19.7[b]	6.1	13.8	30.9
	BG	18.3[b]	3.4	14.8	25.3
pH	MW1	7.3[a]	0.35	7.0	8.0
	MW2	7.6[b]	0.24	7.4	8.1
	BG	7.0[b]	0.26	7.3	8.1
SO_4 (mg/L)	MW1	11.3[a]	2.4	7.6	14.2
	MW2	10.3[a]	2.6	8.0	15.9
	BG	14.3[b]	1.5	12.2	16.5
Cl (mg/L)	MW1	116.9[a]	10.6	95.7	127.6
	MW2	103.6[b]	9.4	85.0	116.9
	BG	63.8[c]	7.5	53.2	74.4
EC (μS/cm)	MW1	903[a]	70	772	994
	MW2	830[b]	52	753	910
	BG	631[c]	26	583	682
BOD_5	MW1	5.2[a]	4.6	<2	13.0
	MW2	3.1[a]	1.5	<2	5.0
	BG	5.1[a]	6.1	<2	21.0
Mn (mg/L)	MW1	1.5[a]	0.74	0.55	2.54
	MW2	0.07[b]	0.16	<0.01	0.49
	BG	0.08[b]	0.05	0.02	0.15
Fe (mg/L)	MW1	0.7[a]	0.4	0.04	1.2
	MW2	0.7[a]	0.8	0.18	2.3
	BG	0.4[b]	0.4	0.08	1.2

†For each parameter, monitor well mean concentrations followed by a different letter indicate a significant difference from other well locations at the $p \leq 0.05$ level.

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Table 7. Samples were collected at distances of 2 and 5 m downslope of the gravel filled distribution trench before the installation of the diverter valve.

Parameter	Influent	Distance from distribution trench		Reduction at 5 m (%)
		2 m	5 m	
BOD_5 (mg/L)	1119	711	624	44.2
TP (mg/L)	31.7	27.6	19.6	38.2
SRP (mg/L)	27.4	19.6	23.1	15.6
Fats (mg/L)	178.8	40.6	29.2	83.7
pH	6.7	6.3	6.6	

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